Characteristics of Multiconductor, Asymmetric, Slow-Wave Microstrip Transmission Lines*

T.C. Mu, H. Ogawa and T. Itoh

Department of Electrical and Computer Engineering
The University of Texas at Austin

ABSTRACT

Spectral Domain Technique has been applied to analyze multiconductor, asymmetric slow-wave microstrip lines. It is observed that slow-wave factor of odd mode of coupled microstrip lines may be equal to or larger than that of even mode under appropriate conditions. This presents the flexibility to realize a large variety of passive cmponents, such as directional coupler, phase shifter, power combiner/divider.

INTRODUCTION

The purpose of this research is to present detailed analysis of multiconductor, asymmetric slow-wave microstrip lines based on Spectral Domain Technique[1]. These structures are expected to realize a wide variety of passive components such as directional coupler, power divider/combiner, phase shifter and have large impact on monolithic microwave integrated circuits. We have discovered some interesting characteristics about three-layer substrate. The slow-wave factor of odd mode for two-strip coupled microstrip lines can be equal to or larger than that of even mode.

A number of analytical studies have been reported on several kinds of planar slow-wave structures[2]-[7]. Simplified parallel plate structure were first examined [2],[3], and other studies based on hybrid-mode approach have shown the applicability of several techniques to the analysis of MIS microstrip line, MIS coplanar waveguides[5],[6]. However, no theoretical results based on full-wave analysis have been reported on multiconductor, asymmetric slow-wave transmission lines except the coupled microstrip lines on two-layer substrate[7]. With a growing interest in very high speed digital integrated circuits, the thorough knowledge of the properties of various planar transmission lines on semiconductor substrate is essential in order to take full advantage of the inherent speed capability of the devices[8], besides the slow-wave phenomena have shown a potential to reduce the dimension of distributed components substantially so that the realization of novel integrated circuits for microwave frequency can be expected.

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NUMERICAL RESULTS AND DISCUSSION

The structure in Fig. 1 can model the slow-wave structure of MIS configuration as well as of the Schottky contact type. In the present case, the doped region of semiconductor substrate is treated as a dielectric layer with finite resistivity, which is included in the analysis by the complex permittivity for the layer. The reason why we can apply the present model is that most of the field lines concentrate under and between strip conductors and field far away from the strip conductors has very little effect on propagation characteristics.

Since the three-layer substrate is the most important and common structure used to fabricate GaAs MESFET, it is necessary to study the characteristics of this structure. We have found a very interesting phenomenon about the slow-wave factor in this structure. Under some conditions, the slow-wave factor of odd mode is larger than that of even mode. In the conventional coupled microstrip lines as well as in the coupled slow-wave microstrip lines on two-layer substrate[7], the propagation constant of even mode is always larger than that of even mode because of the field distribution[12]. This new phenomenon can be explained in Fig.2 and Fig.3. Fig.2 shows the slow-wave factor versus resistivity. Fig. 3 shows the slow-wave factor for different values of thickness of semi-insulating layer. When the resistivity is high, corresponding to lossless coupled microstrip lines, the propagation constant of even mode is larger than that of odd mode. However, when the resistivity becomes smaller, the slow-wave factor of odd mode increases more than that of even mode in the three-layer structure. The origin of this particular characteristics comes from the energy transfer across the interface between lossy layer and insulating layer. In the even mode, electric field tends to penetrate into the whole substrate. However, the thickness of lossy layer in three-layer structure is usually very thin. The major portion of electric energy will be stored in both thin insulating and semi-insulating layers. On the contrary, most of the electric energy is stored in thin insulating layer in two-layer structure. In Fig.3 we can see two intersection points. When the thickness of semi-insulating layer become very thin, corresponding to two-layer structure, the slow-wave factor of even mode becomes larger than that of odd mode. On the other hand, when the thickness of semi-insulating layer becomes thick enough, the propagation constant of odd mode will be smaller than that of even mode, as in the conventional coupled microstrip lines. Fig.2 and Fig.3 show another feature of coupled slow-wave microstrip lines. The directional coupler with the same propagation constants of even and odd modes can be realized with parameters corresponding to these intersection points.

At the fixed resistivity of 0.01 Ω-cm, the three-layer structure is studied by varying frequency. The resulted are shown in Figs.4-6. It is observed that the slow-wave factor of odd mode is larger than that of even mode for most part of frequency range.

The present program can handle asymmetric situation also. Fig.7 shows the propagation characteristics of two-strip asymmetric slow-wave microstrip lines. Although the propagation constant only changes 10%, the real part of characteristic impedance changes more than 50%. We can use this characteristic to adjust the impedance level of the circuit.

Finally the behavior of propagation characteristics for three-conductor and four-conductor on three-layer substrate are also investigated. The calculated results for three-conductor are shown in Fig.8. We use + and - to indicate the direction of J_z. The meaning of ++ is that the amplitude of the conductor is substantially larger than that of +. The relationship between -- and - are the same. As in the coupled slow-wave microstrip lines structure, all-positive potential situation has the lowest propagation constant among all the fundamental modes.

CONCLUSION

The characteristics of multiconductor, asymmetric slow-wave microstrips have been investigated thoroughly with Spectral Domain Technique. Characteristics of these structures have been studied for different values of structure parameters such as thickness and resistivity of the doped semiconductor layer. For instance, it has been found that slow-wave factors of odd mode for two-strip coupled microstrip lines can be equal to or larger than that of even mode. Since the slow-wave microstrip lines described here have structure similar to that of GaAs MESFET, they may be advantageously used in realizing physically small passive components such as directional coupler, and phase shifter for MMIC.

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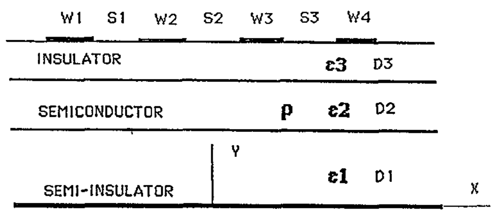

Fig. 1 Cross-section view of slow-wave multiconductor microstrip lines.

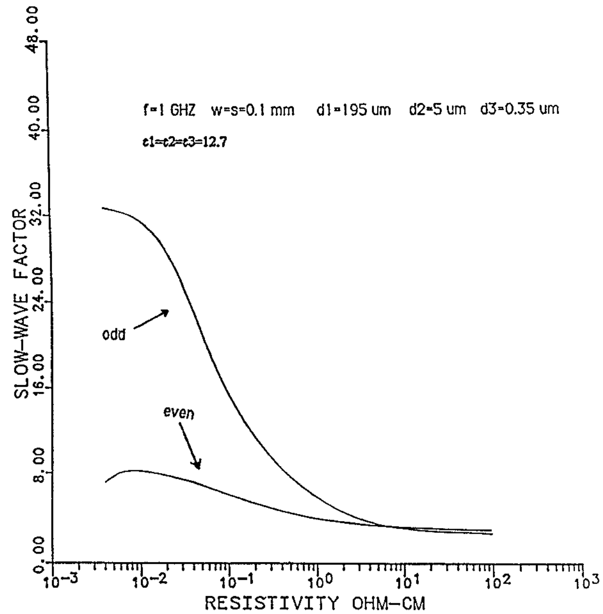

Fig. 2 Slow-wave factor of coupled slow-wave microstrip lines for three-layer substrate vs. resistivity.

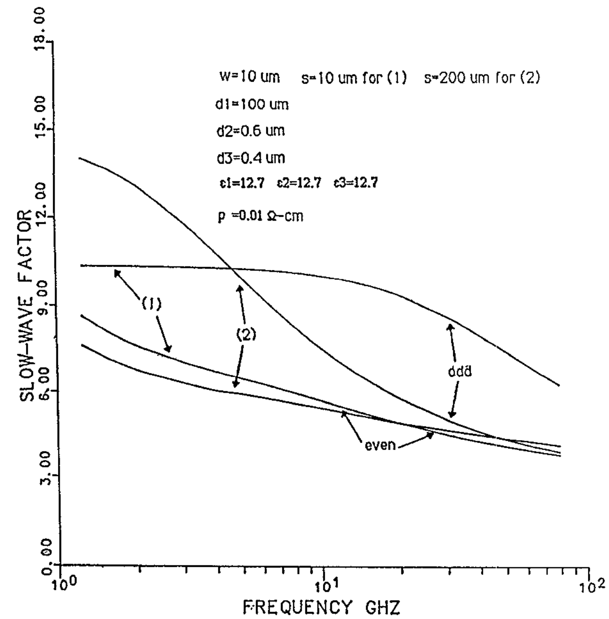

Fig. 4 Slow-wave factor of coupled slow-wave microstrip lines for three-layer substrate.

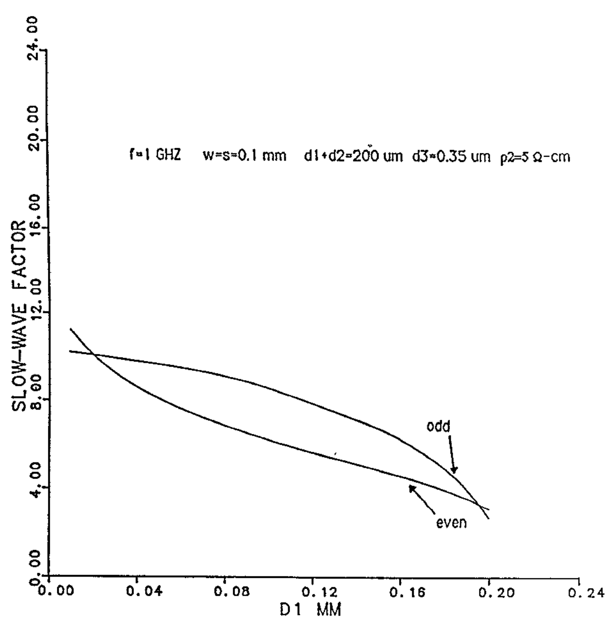

Fig. 3 Slow-wave factor of coupled slow-wave microstrip lines for three-layer substrate vs. d1.

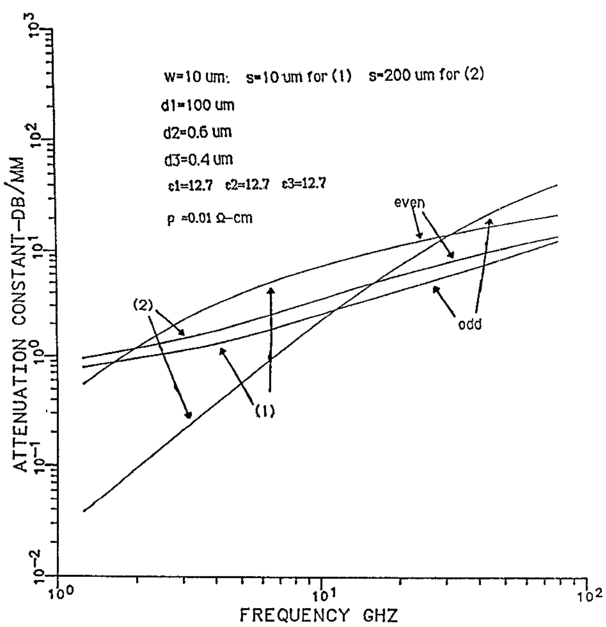

Fig. 5 Attenuation constant of coupled slow-wave microstrip lines for three-layer substrate.

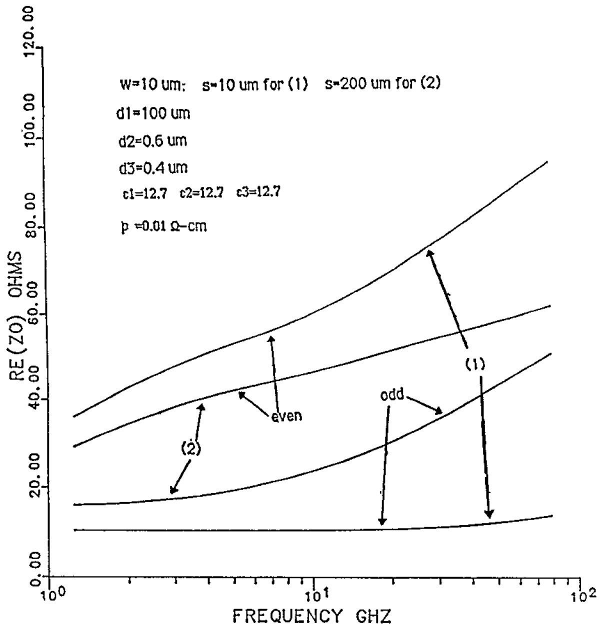

Fig. 6 Real part of characteristic impedance of coupled slow-wave microstrip lines for three-layer substrate.

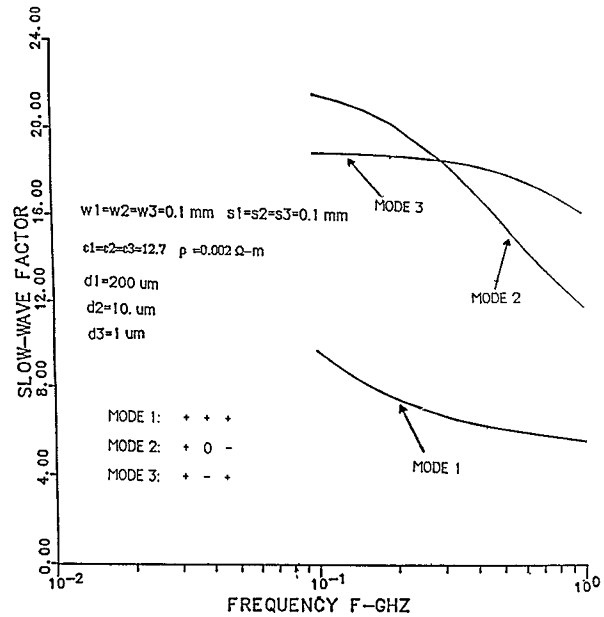

Fig. 8 Slow-wave factor of three-conductor slow-wave microstrip lines for three-layer substrate

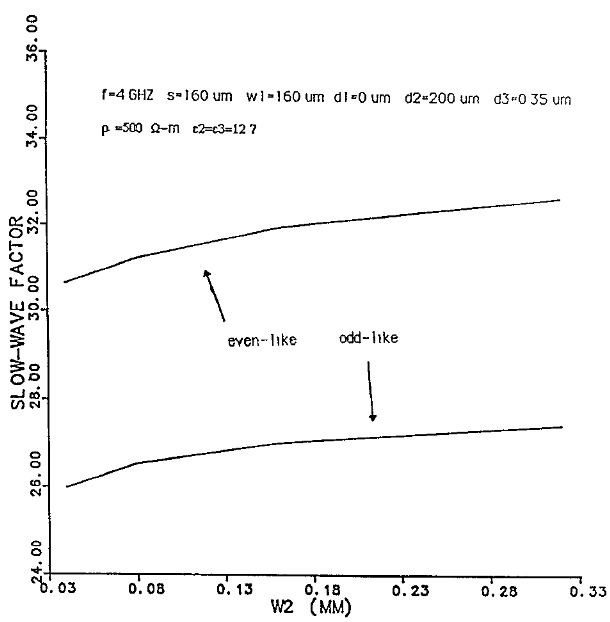

Fig. 7 Slow-wave factor of coupled asymmetric slow-wave microstrip lines for two-layer substrate.