A Novel Low-Loss Slow-Wave Microstrip Structure

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***Abstract*—A low-loss slow-wave microstrip line using a periodic structure in the ground plane is presented. The periodic structure is realized with metal pads etched in the ground plane connected by thin lines to form a distributed LC network. The slow-wave factor is demonstrated to be 1.2–2.4 times larger than that of conventional microstrip lines over a wide frequency range. Due to the unique design of the structure, low insertion loss comparable to conventional microstrips has been achieved. The proposed structure is easier to fabricate than other slow-wave devices which require multilayer substrates or very fine features.**

***Index Terms*—Slow-wave factor, slow-wave structure.**

I. Introduction

Slow-wave mode propagation is of great interest for its use both in matching the field velocity to the electron velocity in traveling-wave tube (TWT) systems and reducing the dimension of distributed components in integrated circuits. In the latter application, it is very critical to minimize the disparity of area between passive and active devices in both hybrid and monolithic circuits. Slow-wave structures such as metal–insulator–semiconductor (MIS) transmission lines have been extensively investigated [1]–[3]. Several disadvantages, however, make MIS slow-wave structures inappropriate for applications at high frequencies. First of all, ohmic loss is high owing to the large current density on the surface of conductor [4]. Second, imaginary part of the permittivity of the material is inversely proportional to frequency, which makes the slow-wave factor decreases with an increase of frequency [5]. Furthermore, the characteristic impedance of a MIS structure is usually so low that accurate photolithography is required for very fine features [6]. Modifications of MIS structures such as cross-tie slow-wave structures were proposed to solve those problems [7]–[9]. The insertion loss of that type of structure, however, is still much higher than that of a conventional microstrip line and complicated fabrication process has to be employed. An ideal slow-wave structure with moderate impedance and low loss properties as well as easy fabrication features is still the objective of many researchers. In this letter we present a new type of slow-wave microstrip line with periodic structure patterned in the ground plane. The periodic structure in the ground plane together with the uniform dielectric layer can be regarded as a slow-wave substrate that can be integrated with other microstrip components. Experiments have been made to compare both slow-wave factor and insertion loss of the proposed structure with those of a conventional microstrip line. The results show that this novel slow-wave microstrip line is very promising for use in MIC and MMIC because of its low loss and compact size.

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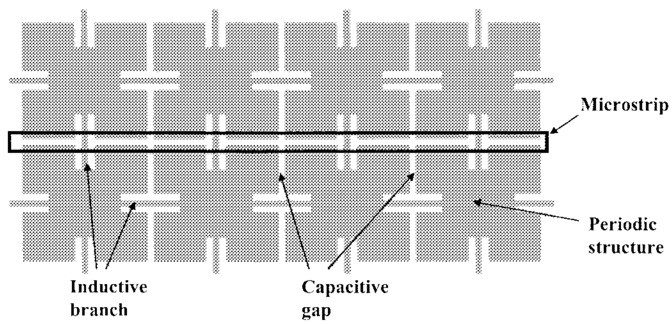

(a)

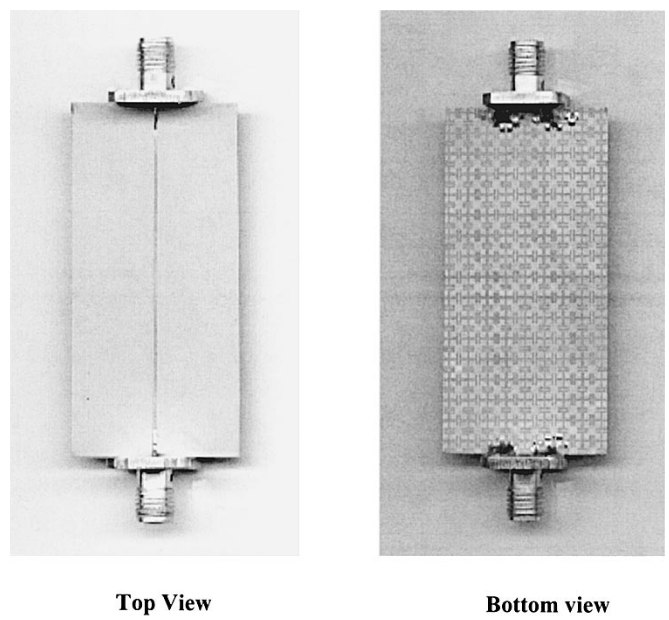

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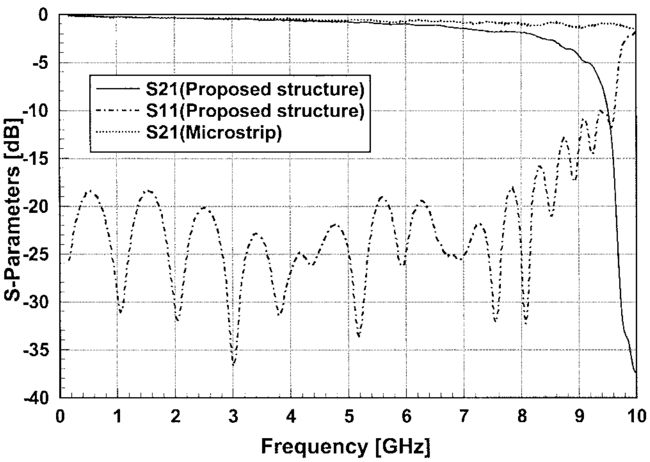
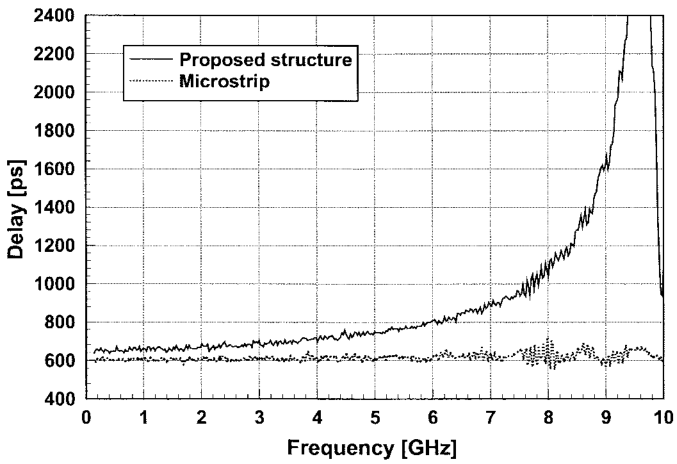
Fig. 1. (a) Schematic of the proposed slow-wave structure with the substrate removed for clarity. Microstrip is on the top side of the substrate while the connected-pads is on the other side. (b) Photographs of the top and bottom sides of the fabricated test structure.

II. Design Guidelines

A square pad with four connecting branches is used as a single element in the periodic structure. Fig. 1 shows the



(a)



(b)

Fig. 2. (a) Measured S-parameters and (b) group delay of the proposed slow-wave structure in comparison with a conventional microstrip line.

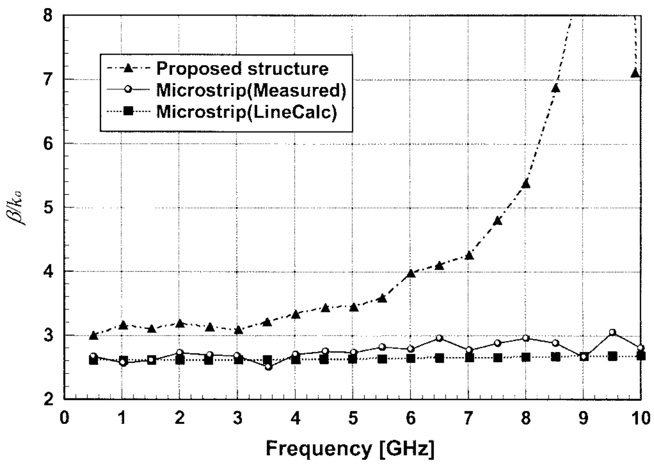


Fig. 3. Slow-wave factor of the proposed structure in comparison with a conventional microstrip line.

periodic structure patterned in the ground plane associated with a 50-Ω microstrip. Because the current density is small in the ground plane, the discontinuities in it will not introduce large loss. The narrow branch is used to create the inductive effect that can be enhanced further with an inset for each connection. Gaps between adjacent pads provide capacitive coupling, as well as increase the shunt capacitance seen by the microstrip. The series reactive elements combined with the shunt capacitances determine the propagation constant and the characteristic impedance of the slow-wave structure. The width of each gap and inductive branch are chosen to be 10 mil. The length of the inset is 27.5 mil and the period of the structure is 120 mil. The substrate is RT/Duroid 6010 with a dielectric constant of 10.2 and thickness of 25 mil. The width of the microstrip is 25 mil, corresponding to 50-Ω microstrip line on a conventional ground plane.

III. Measured Results

Fig. 2(a) shows the measured S-parameters of two 2-in-long microstrip lines with the proposed and a conventional ground plane, respectively. The insertion loss in the operating frequency of the proposed structure is at the same level as that of a conventional 50-Ω line. The cutoff frequency of S21 is observed around 9 GHz, which can be controlled by adjusting the dimensions of the periodic structure. Fig. 2(b) shows the measured group delays of the proposed slow-wave structure and a conventional microstrip line. The difference between those two can be easily distinguished even at very low frequency. The delay increases as the frequency approaches the cutoff. It should also be pointed out that the insertion losses in Fig. 2(a) are for two lines with identical physical length (2 in). Although the proposed structure appears to have larger loss at higher frequencies, the wavelength is also reduced significantly at the same time and the insertion loss per wavelength is comparable to that of the reference microstrip.

Fig. 3 displays the slow-wave factor of this new structure in conjunction with that of a conventional microstrip line. At frequencies lower than the cutoff, the slow-wave factor $\beta/(k_o)$ is 1.2–2.4 times higher than that of conventional microstrip line. The slow wave is generated because both inductance and capacitance of the transmission line are increased. We believe that the slow-wave factor can be enlarged further by controlling each element in the periodic structure.

Additionally, the fact that the slow-wave structure is well matched over a wide range of frequency indicates that the ratio of the inductance and the capacitance per unit length is relatively constant. Unlike the case of MIS microstrip lines, the problem of low characteristic impedance does not exist. The proposed structure exhibits the same slow-wave effect as for a conventional microstrip line with a higher dielectric constant, but without major consequential increase in conductor loss. For example, the conductor loss of 50-Ω line in the proposed structure is 0.17 dB/in at 6 GHz. On the other hand, the conductor loss for a conventional microstrip line with the same impedance and propagation constant would be 0.46 dB/in, since the microstrip width has to be reduced substantially to keep the line impedance at 50 Ω due to an increase of the dielectric constant of the substrate. It was also found that the slow-wave factor of this proposed transmission line is insensitive to the alignment of microstrip with the periodic structure. Different orientations of microstrip with respect to the periodic structure have been tested and the variations of slow-wave factors are less than ±5%, which is a favorable characteristic in practical applications. We are currently developing a numerical model for rigorous analysis of the slow-wave factor as well as the cross-talk between closely located microstrip lines based on this new structure.

IV. Conclusion

A new type of slow-wave microstrip line using a periodic structure in the ground plane has been proposed. A slow-wave factor of 1.2–2.4 times larger than that of conventional microstrip line has been demonstrated experimentally. The insertion loss of this new structure is very small and comparable to conventional microstrip lines. This novel periodic structure can be easily integrated with other microstrip components to miniaturize the circuit configuration. Existing fabrication techniques of both hybrid and monolithic circuits can be applied without any modification. It is believed that this novel structure will find enormous applications such as phase shifters, delay lines, high-performance filters, and compact microstrip antennas.

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