EXPERIMENTAL CONFIRMATION OF SLOW-WAVES IN A CROSSTIE OVERLAY COPLANAR WAVEGUIDE AND ITS APPLICATION TO BAND-REJECT GRATINGS*

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Absract

The slow-wave propagation along a new crosstie overlay slow-wave coplanar waveguide has been investigated both theoretically and experimentally. A slow-wave factor observed agrees reasonably well with the theoretical prediction. Based on this structure, a doubly-periodic band-reject grating was created. The band rejection phenomenon was observed as predicted.

I. INTRODUCTION

One of the most important things in the monolithic microwave integrated circuits (MMICs) design is to minimize the monolithic circuit size. The conventional printed line circuits cannot reduce the guide wavelength λ_g by more than $\sqrt{\varepsilon_r}$ (ε_r is the relative dielectric constant of the transmission medium) from free space wavelength λ_0. A slow-wave transmission line provides a possible remedy. Conventional MIS and Schottky slow-wave structures are inherently lossy [1], although the latter can provide the possibility of electronic tuning of the slow-wave factor by the dc bias applied to the wave-propagating electrode. Recently, Hasegawa proposed a new crosstie coplanar waveguide (CTCPW) slow-wave structure in which the wave attenuation is due predominantly to the conductor loss [1]. More recently, Wang and Itoh [2] have suggested a modification of Hasegawa's CTCPW and proposed a different crosstie overlay slow-wave structure which is more adaptable for monolithic circuit integration. Instead of buried crossties, overlay crossties were used (see Fig.1). As shown in Fig.1, both CPW and microstrip line versions of the new slow-wave structure can be realized by the overlay technique.

The objective of the present work is to create a physically short grating by means of this slow-wave structure. Grating structures are found useful in millimeter-wave integrated circuit applications such as band-reject filters [3],[4] and distributed Bragg reflector (DBR) oscillators [5]. In such applications, the gratings would be operated in stopbands, corresponding to Bragg reflection, in order to produce strong reflections. Because the band-reject filters or DBR structures made of the conventional dielectric waveguide and printed line tend to be electrically and physically long, they are not very suitable for monolithic integrated circuits. However, if such periodic structures can be made of the proposed crosstie slow-wave structures, the physical size of the grating can be made smaller while the electrical length is still long enough to observe grating effects. In this study, first, the dispersive characteristics of the new crosstie slow-wave CPWs were confirmed experimentally. Second, the distributed Bragg reflector were made of the new overlay crosstie mechanism to realize a slow-wave band-reject grating (see Fig.2) with a physical short dimension. From the transmission and reflection characteristics measurements, a band-reject phenomenon was confirmed. According to this study, the new crosstie overlay slow-wave structures appear to be potentially useful for miniturization of distributed circuits in GaAs MMICs.

* This work was supported by the U. S. Army Research Office under contract DA-AG-84-K-0076.

II. DISPERSIVE CHARACTERISTICS OF NEW CROSSTIE OVERLAY SLOW-WAVE CPW

The theoretical treatment of the new crosstie overlay slow-wave CPW (Fig.1) has been described in [2]. In the present experiment, a CPW pattern was photo-etched on a pre-thinned 15μm Cu-clad Epsilam-10 substrate surface with ε_r=10.2 and h=0.635mm (h is the thickness of substrate). The center conductor width of CPW is 2a=0.15mm and the distance between two ground planes is 2w=1.64mm. Twenty periods of metal crossties were photo-etched on another pre-thinned 15μm Cu-clad microwave substrate surface with ε_r=2.5 and h=0.762mm. The lengths of the constituent sections in each period are l_A=0.30mm (with crosstie) and l_B=0.30mm (without crosstie). By using the spun-on technique, a 3.0μm thick DuPont PI-2556 polyimide (ε_r=3.5) layer was coated on the surface of periodic crossties as the dielectric overlayer. After the polyimide was properly cured, construction of a crosstie slow-wave CPW was accomplished by attaching the substrate with CPW and another with crossties face-to-face. Mechanical pressure was applied to make sure that the two pieces had good contact.

The experimental verification of the slow-wave factor in the crosstie overlay slow-wave CPW was performed by measuring the phase shift using a Hewlett-Packard Network Analyzer. Figure 3 is the photograph of the disassembled crosstie slow-wave CPW. A section of 50 Ω conventional CPW was connected at each of the input and output ends. In measurement, these 50 Ω CPWs were connected directly to form a calibration reference. The measured values of slow-wave factor are plotted against frequency in Fig.4. The measured slow-wave factor of a simple CPW without a crosstie pattern is also shown for comparison. These results indicate slow-wave propagation with a linear dispersion. Measured values of the slow-wave factor are close to the theoretical values shown by the solid line. The cause of the discrepancy includes the existence of an airgap due to the thickness of the crossties. The measured values of the attenuation constant are plotted against frequency in Fig.5. The measured attenuation constant of a simple CPW without a crosstie pattern is also shown for comparison. As shown in this figure, the crosstie overlay slow-wave CPW exhibits higher attenuation per unit physical length than the simple CPW due to the existence of the crosstie conductors. However, the difference is much smaller if the values are compared with respect to the guide wavelength. Measured values of the attenuation constant agree reasonbly with the theoretical values shown by the solid line.

III. FREQUENCY-DEPENDENT REFLECTION AND TRANSMISSION CHARACTERISTICS OF THE BAND-REJECT GRATING

As shown in Fig.2, we have created a band-reject grating with its period comparable to the guide wavelength from the "uniform" crosstie overlay slow-wave CPWs. This "uniform" line itself is a periodic structure with its period much shorter than the wavelength and is designed as described in the previous section. Hence, the band-reject grating is physically a doubly periodic structure [6]. As shown in this figure, one period of the grating consists of two sections of crosstie overlay slow-wave CPWs with different slow-wave factors and characteristic impedances. The slow-wave CPWs in the section d_A consists of sections A and B (defined in Fig.1) of 0.10mm and 0.12mm long, respectively, while the one in section d_B is made of 0.12mm and 0.10mm long sections. Hence, in reference to Fig.2, l_A=0.10mm and l_B=0.12mm while l_A=0.12mm and l_B=0.10mm. The section d_A contains 17 periods of l_A+l_B whereas d_B contains 17 periods of l_A+l_B. Hence, the length of the period d of the band-reject grating is 7.48mm. The section d_A has a higher characteristic impedance than the section d_B. It should be noted that before the design of the grating, the slow wave factor is recalculated to include the airgap effect so that discrepancy of the calculated and measured slow wave factor is much smaller than the one observed in Fig.4.

Following fabrication procedures similar to those for the crosstie overlay slow-wave CPW, a 9.5 period long grating with total length 7.106 cm (9.5xd) was finally obtained. A section of 50 Ω conventional CPW was used at the input and output ends respectively as the test fixture. The same setup as that in the slow-wave factor measurement was exploited for the characterization of grating reflection and transmission properties. Fig.6 shows the calculated and the measured values of insertion loss and Fig.7 shows the return loss plotted against frequency of the fabricated grating. From these two figures, a band rejection phenomenon can be clearly recognized. The center frequency of the stopband is 4.95 GHz in experiment and 5.03 GHz in theory. The difference is about 1.6 %. The 3-dB bandwidth of the stopband is 0.56 GHz in experiment and 0.50 GHz in theory. The difference is caused not only by the errors in fabrication but also by the fact that the junction susceptance between two transmission lines was not taken into account in the theoretical calculation. The Q value inside the stopband is around 8.8 in experiment and 10 in theory. The peak insertion loss and the return loss in the stopband are 31 dB and 6 dB in experiment, 30 dB and 5 dB in theory, respectively. The slow-wave factor of this band-reject grating is about 4. From the above-mentioned quantities, our theoretical and experimental results are in good agreement. However, the somewhat higher insertion loss in the passband due to the attenuation of whole crosstie slow-wave CPW sections and the discontinuity effects, including radiation loss in the test device, requires further reduction in the practical applications.

IV. CONCLUSION

The slow-wave propagation along a new crosstie overlay slow-wave structure has been experimentally confirmed. Based on this new slow-wave structure, the distributed Bragg reflection mechanism was introduced to realize a band-reject grating. From the reflection and transmission characteristics measurements, we have demonstrated that the new slow-wave grating structures can be used as filters for GaAs MMICs. It is believed that many other applications, such as resonators, DBR oscillators, etc., are also possible.

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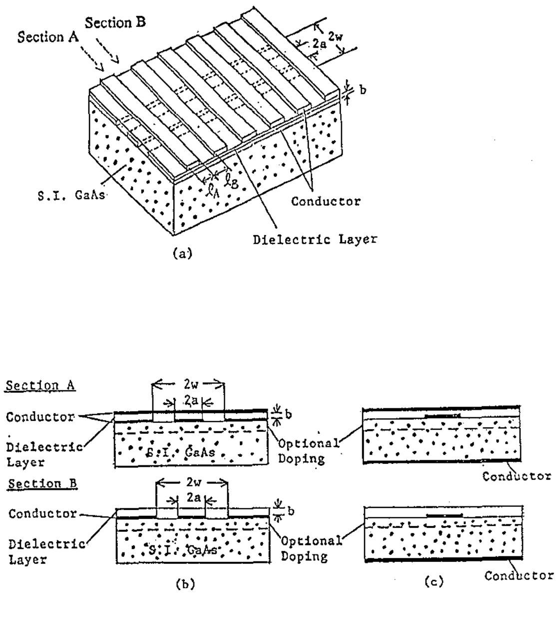
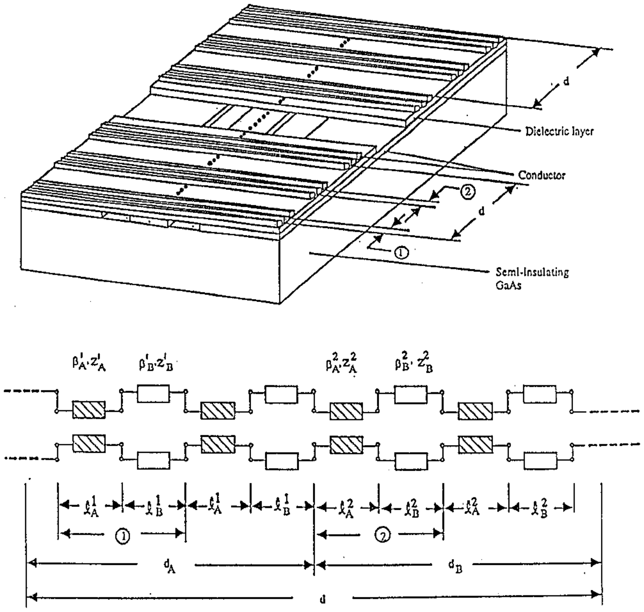


Fig.1 Crosstie overlay CPW and microstrip slow-wave structures. (a) CPW (b) Cross sections of CPW (c) Cross sections of microstrip.



$① = \ell_A^1 + \ell_B^1 \quad ② = \ell_A^2 + \ell_B^2 \quad d = m \times ① + n \times ②$

Fig.2 Schematic feature and equivalent circuit of the crosstie overlay slow-wave grating.

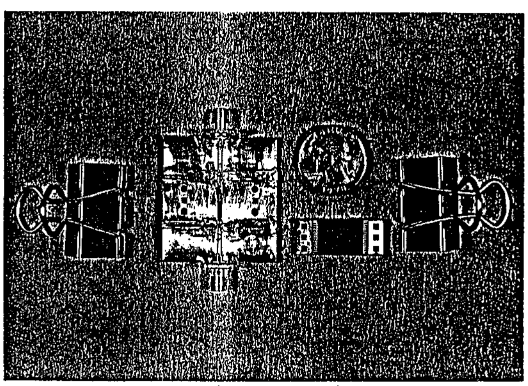


Fig.3 Photogrhph of the disassembled crosstie overlay slow-wave CPW.

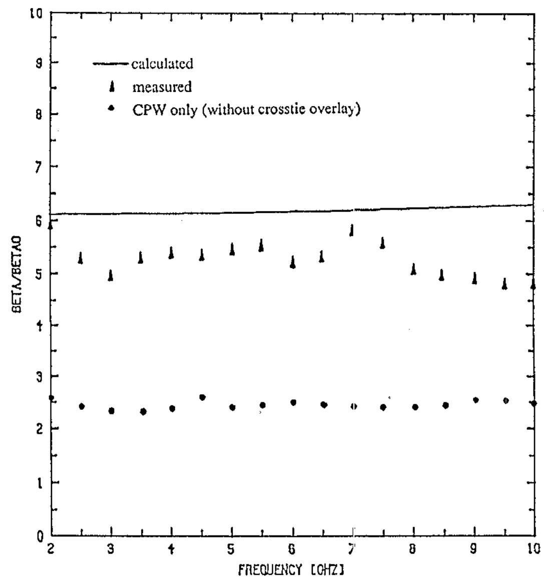


Fig.4 Slow-wave factor (β/β_0) of the crosstie overlay slow-wave CPW.

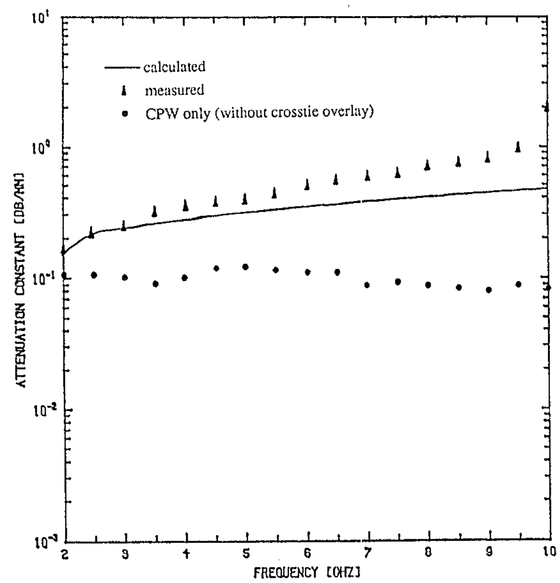


Fig.5 Attenuation constant of the crosstie overlay slow-wave CPW.

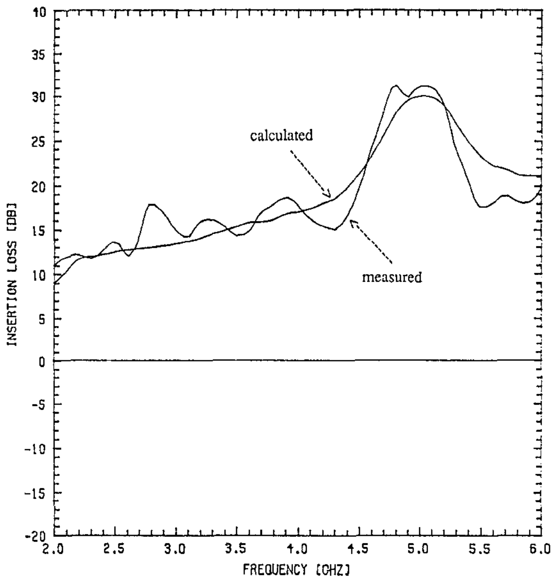


Fig.6 Insertion loss of the crosstie overlay band-reject grating.

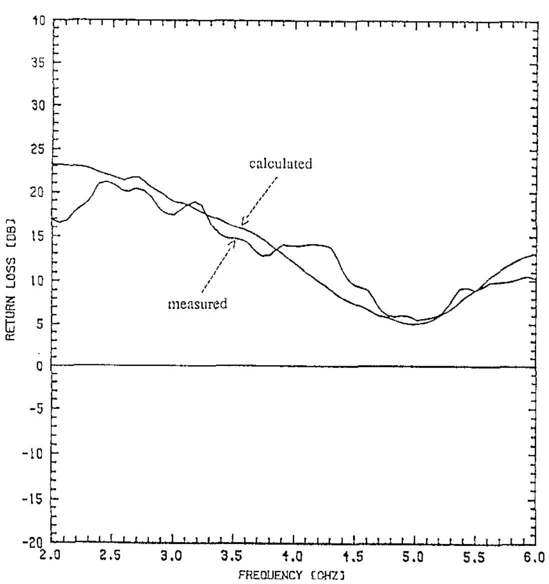


Fig.7 Return loss of the crosstie overlay band-reject grating.