Characteristics of Periodically Loaded CPW Structures

Adnan Görür, Ceyhun Karpuz, and Mustafa Alkan

***Abstract*— A capacitively loaded coplanar waveguide (CPW) resonator has been studied. It has been shown that the proposed resonator can be used to achieve a slow-wave effect without occupying extra surface area and it has a good performance as compared with the conventional half-wavelength CPW resonator. Furthermore, dispersive effects have been increased with the number of slots in periodically loaded structures.**

***Index Terms*—CPW resonators, slow-wave structures.**

I. Introduction

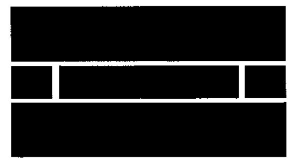
TO DATE, many studies into reducing the size of microwave components have been made by using slow-wave structures made of ferromagnetic substrate, ferromagnetic semiconductor substrate, and metal–insulator–semiconductor (MIS) [1]–[3]. Also, there have been some reports of miniaturization based on curving conventional transmission lines into microstrip and coplanar meander lines [4]. In addition to these structures, a capacitively loaded microstrip loop resonator has been investigated by Hong and Lancaster [5]. They have shown that the capacitively loaded resonator has not only a smaller size, but also a higher Q factor as compared with the conventional microstrip half-wavelength resonator.

As is well known, coplanar structures have several advantages over conventional microstrips for use in monolithic or hybrid integrated circuit applications at microwave frequencies, including easy parallel and series insertion of both active and passive components and high circuit density. Therefore, the purpose of this study is to characterize the interdigitated capacitor and slot-loaded coplanar waveguide (CPW) resonator.

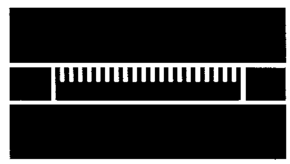
II. Theory

A conventional half-wavelength CPW resonator is shown in Fig. 1(a). Keeping the same occupied surface area, a conventional CPW can be loaded by cutting slots at periodic intervals into the signal strip, as shown in Fig. 1(b) and (c). As can be seen from the figure, this loading can be made by unilateral or bilateral cutting slots into the signal strip. Apart from these types of periodic loading, conventional CPW's can be loaded with interdigitated capacitors in two forms. The first is the unilateral loading with interdigitated capacitors within signal strip as shown in Fig. 1(d), and the second is the bilateral loading as shown in Fig. 1(e). It then can be expected that, for both the slot loading and the interdigitated capacitor loading, the frequency difference between resonance frequencies of bilateral loaded CPW and conventional CPW will be almost twice the difference between those of unilateral-loaded CPW and conventional CPW. Again, it can be expected that the resonance frequency of the bilateral slot-loaded CPW will be lower than that of CPW loaded with unilateral interdigitated capacitor, because the number of fingers in bilateral slot-loaded CPW in Fig. 1(c) is more than that of CPW loaded with unilateral interdigitated fingers in Fig. 1(d). These results have been observed in our experiments.

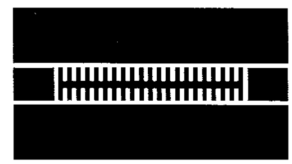
The fundamental resonance frequency of the CPW resonator might be estimated by assuming that its length equals a guided half-wavelength. The resonance frequency of a CPW resonator loaded with slots significantly changes from that of the associated half-wavelength CPW resonator. If the conventional CPW resonator is loaded with interdigitated fingers as shown in Fig. 1(d) and (e), the inductance per unit length increases, because the slots cut into the signal strip is decreased the width of signal strip. Therefore, it can be expected that the



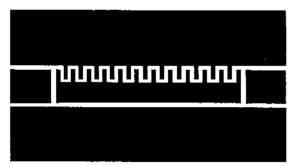
(a)



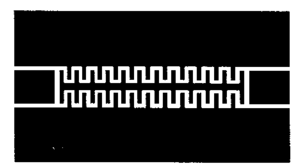
(b)



(c)



(d)



(e)

Fig. 1. CPW resonators: (a) conventional half-wavelength CPW resonator, (b) unilateral slot-loaded CPW resonator, (c) bilateral slot-loaded CPW resonator, (d) unilateral interdigitated capacitor-loaded CPW resonator, and (e) bilateral interdigitated capacitor-loaded CPW resonator.

Manuscript received March 19, 1998. This work was supported by the Research Fund of the University of Nigde, Turkey, Project FEB.96.001.

The authors are with the Faculty of Engineering and Architecture, Department of Electrical and Electronics Engineering, Nigde University, 51100 Nigde, Turkey.

Publisher Item Identifier S 1051-8207(98)05601-3.

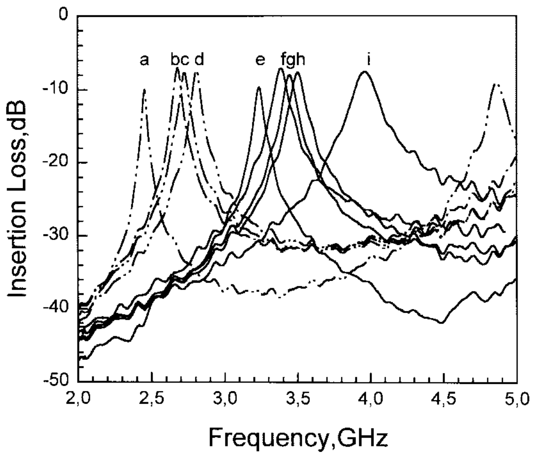


Fig. 2. Fundamental resonance frequency responses of resonators: (a) bilateral interdigitated capacitor-loaded CPW resonator with 41 fingers; (b) bilateral 40 slot-loaded CPW resonator; (c) bilateral 30 slot-loaded CPW resonator; (d) bilateral 20 slot-loaded CPW resonator; (e) unilateral interdigitated capacitor-loaded CPW resonator with 41 fingers; (f) unilateral 40 slot-loaded CPW resonator; (g) unilateral 30 slot-loaded CPW resonator; (h) unilateral 20 slot-loaded CPW resonator; and (i) conventional CPW resonator.

resonance frequency will be shifted down by more than that of the associated slot-loaded CPW. So, the velocity slowing on this type of resonator and probably its performance, mainly the Q factor, can be controlled by the number of slots or interdigitated capacitive fingers.

III. Experimental Results

To measure the fundamental resonance frequency and performance of the present structures, they were constructed on RO3003^{TM} with dielectric thickness 0.750 mm and relative dielectric constant $\varepsilon_r = 3$. The lengths of resonators were about 24.3 mm and the effective lengths of fingers and slots were, respectively, 1.4 and 1.6 mm for periodically loaded resonators. All coplanar resonators were fed with 0.5-mm gaps. The measured frequency responses of nine coplanar resonators are as follows: one conventional half-wavelength CPW resonator; three unilateral slot-loaded CPW resonators with 20, 30, and 40 slots; three bilateral slot-loaded CPW resonators with 20, 30, and 40 slots; one unilateral interdigitated capacitor-loaded CPW resonator with 41 fingers; and one bilateral interdigitated capacitor-loaded CPW resonator with 41 fingers. The frequency response of all nine resonators is shown in Fig. 2. Although all resonators occupy the same surface area, the resonance frequency is shifted down from ~4.2 GHz of the conventional half-wavelength resonator to ~2.4 GHz of CPW resonator loaded with interdigitated capacitor. In this case, the interdigitated capacitor loaded resonator has a lower resonance frequency with the same occupied surface area as that of the half-wavelength resonator indicates a reduction in size and a highly efficient manner of utilizing surface area.

The Q factors for the interdigitated capacitor-loaded CPW resonator and the conventional half-wavelength CPW resonator with longer length at about the same resonance frequency are also compared as shown in Fig. 3 and, as can be seen the Q factor for the interdigitated structure, is increased by a factor of two than that of the conventional resonator.

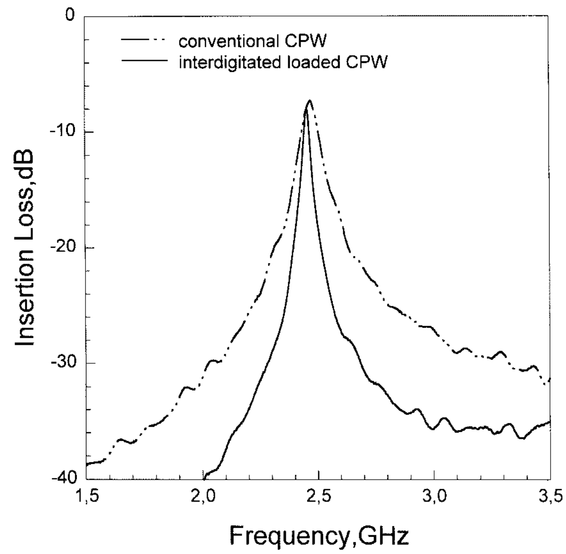


Fig. 3. The comparison of the Q factors for the interdigitated capacitor-loaded CPW resonator and the conventional half-wavelength CPW resonator.

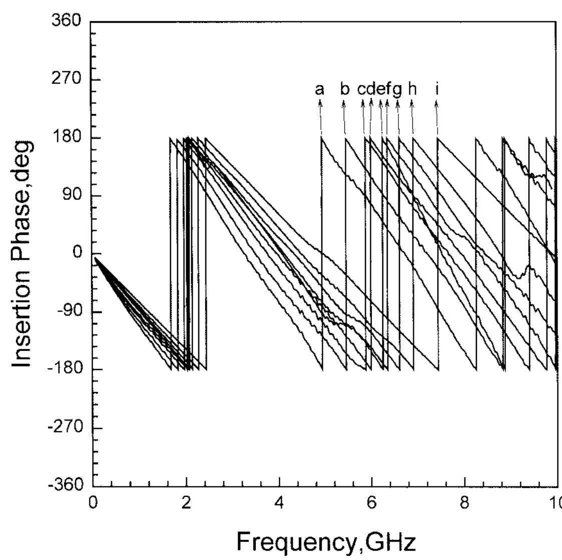


Fig. 4. Phase responses of resonators: (a) bilateral interdigitated capacitor-loaded CPW resonator with 41 fingers, (b) bilateral 40 slot-loaded CPW resonator, (c) bilateral 30 slot-loaded CPW resonator, (d) bilateral 20 slot-loaded CPW resonator, (e) unilateral interdigitated capacitor-loaded CPW resonator with 41 fingers, (f) unilateral 40 slot-loaded CPW resonator, (g) unilateral 30 slot-loaded CPW resonator, (h) unilateral 20 slot-loaded CPW resonator, and (i) conventional CPW resonator.

The phase responses of all coplanar resonators have also been measured, as shown in Fig. 4. It is seen that the rate of change in phase with respect to frequency for the slot-loaded resonators is increased as the number of slots increases, whereas all resonators have similar magnitude responses. Moreover, in the case of bilateral-loaded CPW the interdigitated structure has the highest rate of change in phase, as can be see in the figure. Therefore, it is obtained a reduction in phase velocity without occupying extra surface area because of slot or interdigitated loading. The normalized velocities of the unilateral-loaded CPW's with respect to the conventional CPW are found to be 0.84, 0.82, 0.80, and 0.76 for 20 slot-loaded CPW's, 30 slot-loaded CPW's, 40 slot-loaded CPW's, and interdigitated-loaded CPW's, respectively. Similarly, the normalized velocities of the bilateral loaded CPW's are found to be 0.66, 0.64, 0.62, and 0.57 for 20 slot-loaded CPW's, 30 slot-loaded CPW's, 40 slot-loaded CPW's, and interdigitated-loaded CPW's, respectively.

It is seen from Fig. 2 that, in the cases of both slot-loaded structure and interdigitated structure, the difference between resonance frequencies of bilateral-loaded CPW's and conventional CPW's is almost twice the difference between those of unilateral-loaded CPW's and conventional CPW's. In addition, the bilateral slot-loaded CPW has a lower resonance frequency than that of unilateral interdigitated-loaded CPW, because the number of fingers in bilateral slot-loaded CPW is more than that of unilateral interdigitated CPW. Moreover, although the number of fingers in interdigitated capacitor-loaded CPW equals to that of the slot-loaded CPW with 41 fingers (or 40 slots), the resonance frequency of interdigitated capacitor-loaded CPW is smaller than that of slot-loaded CPW.

On the other hand, the magnitude responses of the present structures have also been measured for frequency range from 0.05 to 20 GHz. It has been clearly seen from these measurements that, as the frequency increases, the separation between peaks in magnitude response decreases. This is probably due to dispersive effects. In addition to this case, it has been observed that dispersion increases as the number of slots in slot-loaded structures increases. Interdigitated-loaded CPW has been shown to exhibit higher dispersion than the other structures in this letter, because of the open-end effects within interdigitated structures.

IV. Conclusions

It has been shown that the periodically loaded CPW resonator has not only a smaller size which utilizes the circuit surface in a highly efficient manner, but also a higher performance as compared with the conventional half-wavelength CPW resonator. Furthermore the present structures and their frequency response are compatible with those of the conventional half-wavelength CPW resonator. In the cases of both slot-loaded structure and interdigitated structures, the difference between resonance frequencies of bilateral-loaded CPW and conventional CPW has been almost twice the difference between those of unilateral loaded CPW and conventional CPW. However, the separation between peaks in frequency response has decreased as the frequency increases, because of dispersive effects. These effects have also been increased with the number of slots in periodically loaded structures. Especially, interdigitated-loaded CPW has a higher dispersion than the other structures.

References

[1] H. Ogawa and T. Itoh, "Slow-wave characteristics of ferromagnetic semiconductor microstrip line" *IEEE Trans. Microwave Theory Tech.*, vol. MTT-34, pp. 1478–1482, 1986.

[2] H. Hasegawa and H. Okizaki, "MIS and Schottky slow wave coplanar stripline on GaAs substrate," *Electron. Lett.*, vol. 13, pp. 663–664, 1977.

[3] Y. Fukuoka and T. Itoh, "Analysis of slow-wave phenomena in coplanar waveguide on a semiconductor substrate," *Electron. Lett.*, vol. 18, pp. 589–590, 1982.

[4] J. A. Weiss, "Dispersion and field analysis of a microstrip meander line slow wave structure," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-22, pp. 1194–1201, 1974.

[5] J. S. Hong and M. J. Lancaster, "Capacitively loaded microstrip loop resonator," *Electron. Lett.*, vol. 30, pp. 1494–1495, 1994.