Uniplanar microstrip periodic structure for microwave circuits

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A novel microstrip slow-wave structure is presented. The slow-wave factor is mainly controlled by the signal strip and the inserted ground metal pattern in a coplanar manner. A third-order Chebyshev filter was designed and fabricated to demonstrate the proposed structure. Good agreement between the simulated and measured responses is observed.

Introduction: The microstrip line is one of the most popular transmission lines since it is easily integrated with passive and active microwave devices and can be fabricated by photolithographic processes. The length of the conventional microstrip line is dominated by the dielectric constant ε_r [1] so that the circuit constructed by the conventional microstrip line cannot reduce the phase velocity by less than $1/\sqrt{\varepsilon_r}$ of the free-space light velocity. Hence, the circuit may occupy a large area, which causes a serious problem for miniaturisation. As a result, the high-dielectric-constant substrate is required to reduce the circuit size. Another method to reduce the circuit size is to utilise slow-wave structures [2–5]. The mechanism behind the slow-wave propagation is to separately store the electric and magnetic energies as much as possible in the guided-wave media. The electromagnetic energy in the conventional microstrip line is stored inefficiently since the current flow and charge distribution are mostly concentrated along the outer edges [6]. Therefore, we can modify the internal part of the conventional microstrip line without altering the propagation property.

In this Letter, we propose a one-dimensional (1D) periodic structure with a ground metal pattern inserted in the signal strip of a conventional microstrip line. The slow-wave factor is easily controlled by the signal strip and the ground metal pattern on the same plane. The proposed structure has the same outline contour and a lower phase velocity compared to the conventional microstrip line. On the other hand, compared to the published slow-wave structures, the proposed one has either a larger slow-wave factor or a lower fabrication cost. Finally, one application example is demonstrated.

Structure design and simulation: Fig. 1 shows the schematic of the proposed microstrip slow-wave structure, where the physical parameters are indicated. Each unit cell has a specific ground metal pattern inside the central part of the microstrip line so that the inserted ground metal is surrounded by the signal strips on the top layer. Note that there is one via-hole on the middle of the inserted ground metal. To maximise the overlap length between the signal strip and the ground metal on the top layer, the ground metal pattern has a cross shape. Since the current and charge distributions are mainly concentrated along the edges, the proposed structure increases the capacitive load for each unit cell to reduce the phase velocity.

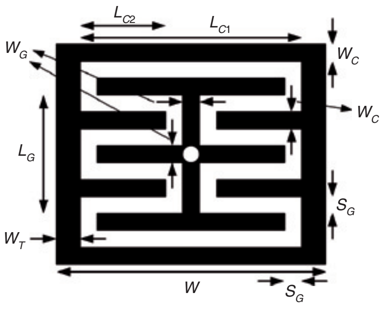

Fig. 1 *Schematic of proposed periodic structure (unit cell)*

The half-wavelength resonator using the proposed structure is shown in Fig. 2. The proposed resonator has the same outline contour as the conventional one. In the simulation, the resonators are realised on the substrates with a dielectric constant of 10.2 and two thicknesses h = 0.635 and 1.27 mm. The width of the outmost signal strip is W_T = 0.5 mm. The widths of the signal and ground strips (i.e. W_C, W_G) in the unit cell are all 0.3 mm, and the spacing S_G is 0.15 mm. Fig. 3 compares the slow-wave factor defined by λ_0/λ_g with total transverse width W for the conventional and proposed microstrip structures, where λ_0 is the free-space wavelength and λ_g is the guided wavelength of the microstrip line. Apparently, the proposed structure has a larger slow-wave factor than the conventional microstrip line. The slow-wave factor is especially large for the thick substrate. Moreover, the wider the line is, the larger the slow-wave factor is. This is because the loaded capacitance is particularly large for wide lines.

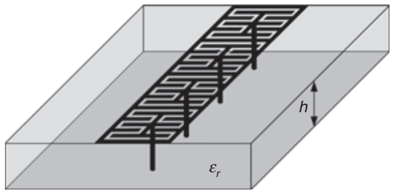

Fig. 2 *Three-dimensional view of proposed microwave resonator*

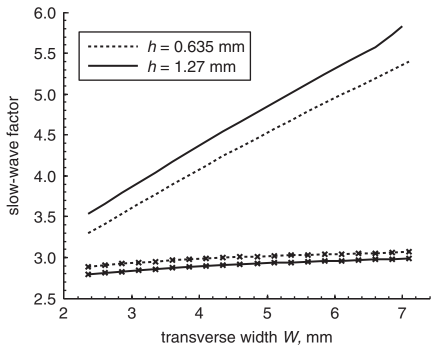

Fig. 3 *Slow-wave factor against total transverse width for proposed and conventional (×) microstrip lines*

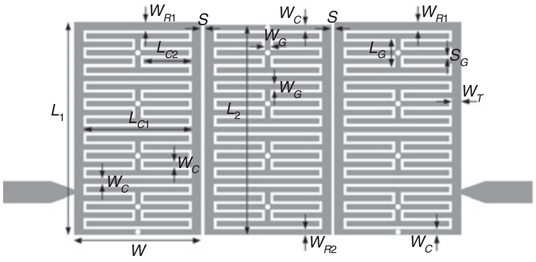

Fig. 4 *Configuration of proposed filter*

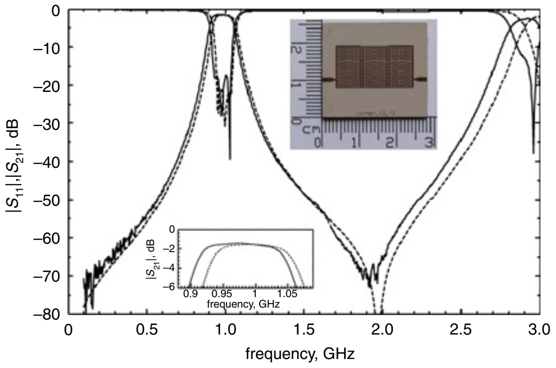

Fig. 5 *Simulated (dashed line) and measured (solid line) responses of filter*

Filter application and measurement: To demonstrate the proposed structure, a third-order Chebyshev interdigital bandpass filter with a passband ripple of 0.05 dB, a centre frequency of 1 GHz, and a fractional bandwidth of 10% was realised using the $\lambda/4$ resonator. The filter was fabricated on RT/Duroid substrate with a dielectric constant of 10.2 and a thickness of 0.635 mm. Each via-hole has a diameter of 0.3 mm. Fig. 4 shows the configuration of the proposed filter. The dimensions of the filter are: $L_1 = 11.25$ mm, $L_2 = 11.1$ mm, $L_{C1} = 5.7$ mm, $L_{C2} = 2.55$ mm, $L_G = 1.5$ mm, $W = 6.7$ mm, $W_C = W_G = 0.3$ mm, $W_{R1} = 0.45$ mm, $W_{R2} = 0.3$ mm, $W_T = 0.5$ mm, and $S = S_G = 0.15$ mm. The simulated and measured results are presented in Fig. 5, together with a photograph of the fabricated filter. The circuit size is 11.25 × 20.4 mm. The measured results show that the filter has a centre frequency of 0.981 GHz. Within the passband, the minimum insertion loss is 1.454 dB, and the return loss is better than 17.5 dB. The first spurious response is at 2.906 GHz, and the rejection level is better than −20 dB from 1.132 to 2.667 GHz.

Conclusions: A novel microstrip periodic structure is presented. The proposed structure has a pure planar configuration and is easily incorporated into the printed circuit board (PCB). Moreover, the designed filter has not only a similar response but also a smaller size compared to the conventional one. Therefore, the proposed structure is very appropriate for compact microwave circuits.

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References

1 Hong, J.S., and Lancaster, M.J.: 'Microstrip filters for RF/microwave applications' (Wiley, New York, 2001)
2 Hong, J.S., and Lancaster, M.J.: 'Capacitively loaded microstrip loop resonator', *Electron. Lett.*, 1994, **30**, (18), pp. 1494–1495
3 Yang, F.R., Qian, Y., Coccioli, R., and Itoh, T.: 'A novel low-loss slow-wave microstrip structure', *IEEE Microw. Guid. Wave Lett.*, 1998, **8**, (11), pp. 372–374
4 Lee, G.A., Lee, H.Y., and De Flaviis, F.: 'Perforated microstrip structure for miniaturising microwave devices', *Electron. Lett.*, 2002, **38**, (15), pp. 800–801
5 Yun, Y.: 'A novel microstrip-line structure employing a periodically perforated ground metal and its application to highly miniaturized and low-impedance passive components fabricated on GaAs MMIC', *IEEE Trans. Microw. Theory Tech.*, 2005, **53**, (6), pp. 1951–1959
6 Faraji-Dana, R., and Chow, Y.L.: 'The current distribution and AC resistance of a microstrip structure', *IEEE Trans. Microw. Theory Tech.*, 1990, **38**, (9), pp. 1268–1277