A Novel Low-Loss Slow-Wave CPW Periodic Structure for Filter Applications

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***Abstract* — A novel periodic slow-wave structure for CPW is presented. This proposed structure exhibits low insertion loss in the passband, simple fabrication, and is intrinsically matched. The structure is applied to realize a miniature lowpass filter one-tenth the size of conventional filters, with spurious-free response and deep attenuation levels using only three cells.**

I. INTRODUCTION

Periodic structures of various types have always been a favorite topic of researchers and are currently enjoying renewed interest in the microwave field for their applications in the microwave and millimeter-wave regime [1]. For example, periodic structures have been used to achieve high-performance filters, to perform harmonic tuning in power amplifiers, and to suppress leakage in CB-CPW and stripline circuits [2]-[5]. These applications are possible because periodic structures exhibit distinctive bandstop characteristics when patterned on the microstrip ground plane. Additionally, the slow-wave characteristics exhibited by periodic structures can be exploited to reduce microstrip circuit component size. With chips sizes currently being limited by the size of passive components rather than of the active devices, it becomes increasingly attractive to develop a complementary CPW slow-wave structure for the miniaturization of MIC and MMIC circuits. Many exotic schemes have been proposed to this end. Metal-insulator-semiconductor (MIS) CPW lines can achieve very high slow-wave factors, but suffer from low impedance values and high insertion loss, making MIS CPW lines impractical at higher frequencies. MIS loss may be improved by introducing cross-tie periodic structures or by inhomogeneously doping the semiconductor, but these methods necessitate additional fabrication processes [6]-[7]. An ideal slow-wave structure with low loss properties, moderate impedance, and easy fabrication still remains the objective of many researchers. This paper entails our efforts to develop such a structure for CPW transmission lines.

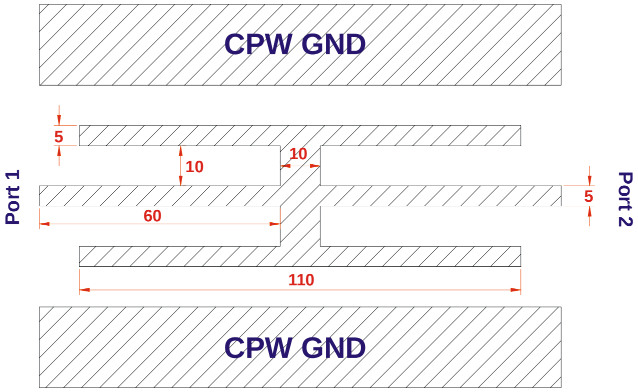

Fig. 1. Unit cell of proposed periodic structure (units in mils).

II. DESIGN GUIDELINES

From transmission line theory, the propagation constant and phase velocity of a lossless transmission line are given respectively as $\beta = \omega\sqrt{LC}$ and $v_p = 1/\sqrt{LC}$, where L and C are the inductance and capacitance per unit length along the transmission line. Thus, slow-wave propagation can be accomplished by effectively increasing the L and C values. One way to do this is by introducing periodic variations along the direction of propagation, such as by drilling holes in the substrate or by etching patterns in the microstrip ground plane [8]. Because the fields in a microstrip line are concentrated in the dielectric substrate region, these periodic variations strongly perturb the nature of the microstrip field distributions. In contrast, the fields in CPW are localized in the two slots, so that perforation of the two ground planes will have little effect on CPW wave propagation. Therefore, in order to increase the effective capacitance and inductance along the CPW line, we propose a periodic structure of the form depicted in Fig. 1. In this scheme, each unit cell consists of a narrow signal line that enhances the inductance per unit length while two branched arms located in the slots of

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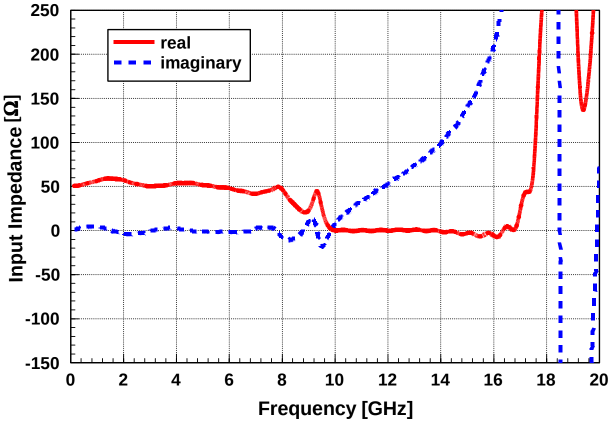

Fig. 2. Simulated input impedance of unit cell.

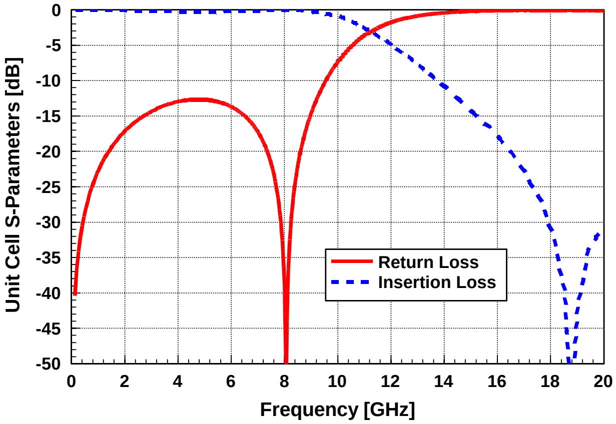

Fig. 3. Simulated S-parameters of unit cell using MoM.

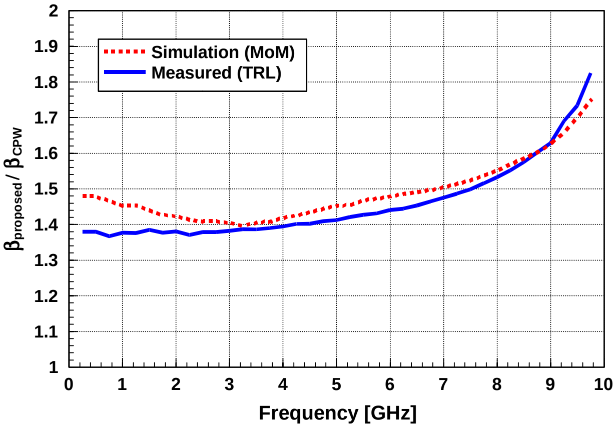

Fig. 4. Slow-wave enhancement of proposed structure over a conventional 50Ω CPW line on the same substrate.

the CPW enlarge the capacitance to ground. The proposed unit cell offers several advantages over existing structures. First, the ground planes of the CPW transmission line remain unperturbed. Although introducing discontinuities along the edges of the two ground planes can potentially enhance the capacitive and inductive effects, doing so reduces the transmission line's compatibility with active devices and increases the overall footprint of the periodic structure [9]-[11]. Second, the proposed structure is intrinsically matched over a wide range of frequencies from DC to about 9 GHz. This is shown in Fig. 2, which shows the simulated input impedance for a single unit cell. The relatively flat input impedance indicates that the ratio of the inductance and capacitance remain relatively constant, such that the unit cell may be cascaded in series or connected directly to a 50Ω CPW line without any additional matching. This differs from MIS-type transmission lines, which typically have very low impedance. Finally, the proposed periodic structure offers very simple fabrication that can be implemented on one side of a dielectric substrate using standard etching techniques. No additional procedures in the form of ion-implanting or cross-tie overlays are required. Moreover, the completely uniplanar geometry of the structure eliminates any uncertainty in positioning the signal line in reference to the ground plane. This differs from some microstrip periodic structures, where the insertion loss and return loss vary depending upon where the top conductor is placed in reference to the periodically etched ground plane [12].

A complete full-wave analysis is required for accurate analysis of the unit cell, since the inductive and capacitive values of any periodic structure are not entirely independent owing to coupling effects [13]. The scattering parameters for a single unit cell of the periodic structure are simulated using Agilent's Momentum software and shown in Fig. 3. For reference, the unit cell is connected to a 50Ω CPW line with center conductor width of 25 mils and gap spacing of 15 mils. The unit cell exhibits minimal insertion loss (better than -1.0 dB) from DC to 9.4 GHz. A potentially wide stopband exists from 10 to 20 GHz, which can be exploited by cascading several periods in series.

III. MEASURED RESULTS

To analyze the slow-wave characteristics of the periodic structure, a series cascade of unit-cells is built on standard 25-mil Duroid substrate with dielectric constant $\varepsilon_r = 10.2$. Phase information is extracted from a network analyzer and unwrapped to obtain the slow-wave factor. Fig. 4 depicts the measured results from 0.25 to 9.75 GHz. A

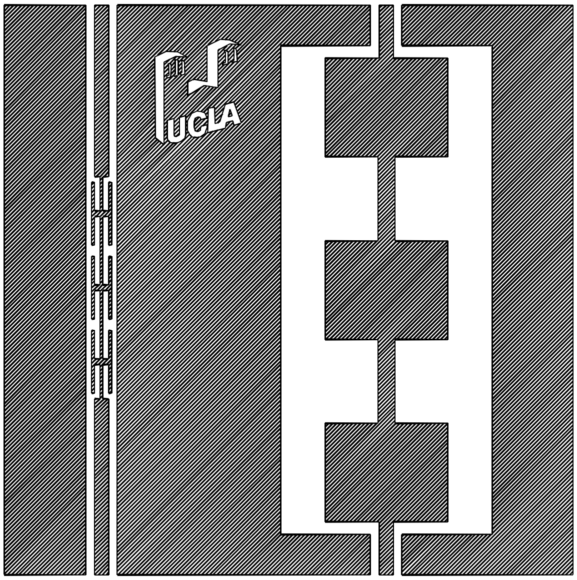

Fig. 5. Mask illustrating reduced size of 3-cell proposed periodic filter vs. 3-stage conventional CPW stepped-impedance filter. Actual mask size is 1” by 1”.

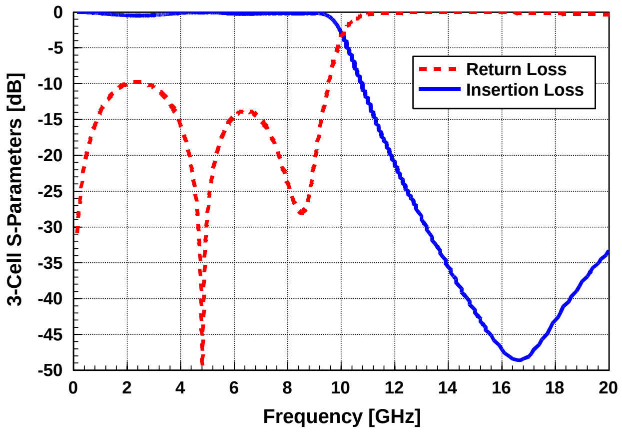

Fig. 6. Simulated MoM response of 3-cell periodic filter.

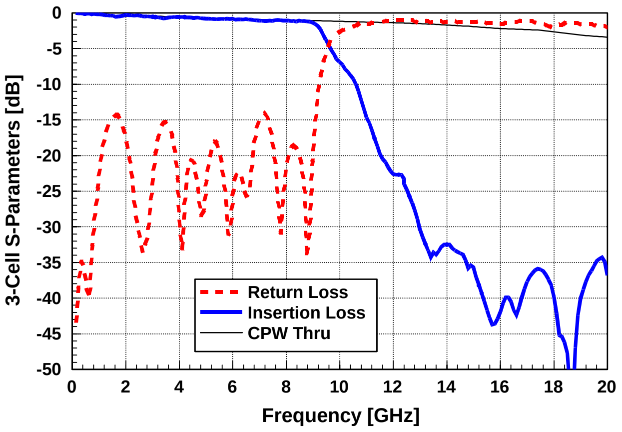

Fig. 7. Measured response of 3-cell periodic filter.

slow-wave factor ranging from 3.3-4.4 is recorded in this frequency range. The increased inductance and capacitance per unit cell result in a slow-wave enhancement factor that is 1.4-1.8 times higher than that of a reference 50Ω CPW line on the same substrate. Above these frequencies, the phase velocity increases exponentially, establishing a broad stopband effect that begins when the unit cell length equals half the guided wavelength in the periodic transmission line. We believe that the slow-wave factor of the periodic structure can be further enlarged by narrowing the width of the inductive branch or by bringing the two branched arms closer to the ground planes, but this comes at the cost of tighter fabrication precision.

An immediate and straightforward application of this slow-wave periodic structure is a miniature lowpass filter. Traditionally, slow wave structures have not been used extensively as passive filters because of the large number of periods needed to establish deep attenuation levels and the associated increase in insertion loss of these structures. Moreover, reducing the size of filters generally tends to reduce the filter performance [14]. To demonstrate the filtering capabilities of the proposed structure, a series cascade of 3 unit-cells is fabricated and measured. Since the proposed periodic structure is entirely integrated into the CPW signal line itself, the filter size is dramatically reduced. For illustrative purposes, a mask of the 3-cell proposed periodic filter is shown in Fig. 5 alongside a conventional 3-stage CPW stepped-impedance lowpass filter with about the same cutoff frequency. A twofold reduction in filter length and a tenfold reduction in filter area is achieved. Fig. 6 and Fig. 7 depict the simulated and measured responses of the newly proposed filter, respectively. Despite the extremely small size of the periodic filter, spurious-free response and deep attenuation levels (–35 dB) can be observed in the stopband of the periodic structure. In fact, the attenuation levels achieved from just 3 cells of the proposed CPW structure are comparable to those of equivalent microstrip configurations that utilize the combined effects of a lowpass filter *and* a periodically etched ground plane [15]. An important consideration in any periodic structure is its associated loss. CPW MIS transmission lines are not used

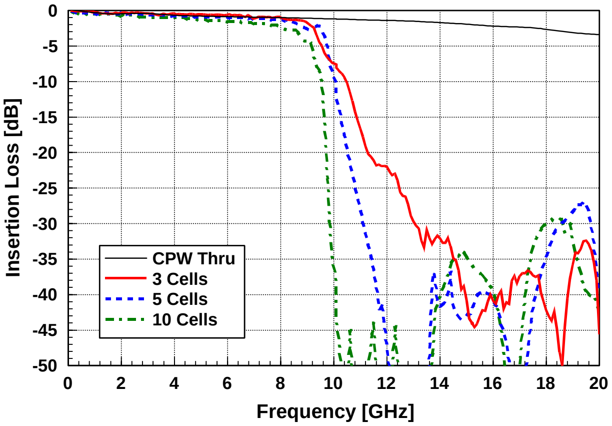

Fig. 8. Effect of additional periodic cells on filter rolloff.

in practice due to their high loss, particularly at frequencies above 5 GHz. The insertion loss of the proposed periodic filter in the passband region, where the periodic structure serves as a slow-wave transmission line, compares very well to that exhibited by a standard 50Ω CPW line up to 9 GHz, where we begin to see the effects of the filter rolloff take effect. Finally, since the filter is based on the construction of periodic structures, filter synthesis is greatly simplified. A sharper rolloff can be accomplished simply by inserting more cells, as demonstrated in Fig. 8, while the cutoff frequency can be adjusted by controlling the length of the unit cell.

IV. CONCLUSION

We have presented a novel periodic structure for CPW transmission lines. In the passband, the slow-wave effect is enhanced up to 1.65 times over a reference 50Ω CPW line on the same substrate. Taking up no more space than a standard CPW transmission line, the periodic structure offers very easy fabrication, very low insertion loss, and is intrinsically matched. A 3-cell series cascade results in a miniature low-pass filter that offers high attenuation levels in the stopband while reducing filter area size by 90%. This novel periodic structure should find a wide variety of applications in microwave integrated circuits and help to significantly reduce MMIC chip sizes.

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