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GUIDED-WAVE CHARACTERISTICS OF PERIODICALLY NONUNIFORM COUPLED MICROSTRIP LINES FOR HARMONIC SUPPRESSION IN FILTER DESIGN

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1. Introduction

The parallel-coupled microstrip line was extensively characterized in the past and has been gaining a wide application in the bandpass filter design since 1958 [1]. However, one common and critical problem of this type filter design is to seriously suffer from spurious passbands at the harmonics of the operating frequency. So far, great effort has been made to suppression of these harmonic passbands [2]-[6]. In this way, the two effective methods have been successfully explored, i.e., equalization of modal phase velocities and differentiation of traveling route lengths for coupled even- and odd-mode. In [2], an overcoupled resonator was constituted to extend the odd-mode phase length, thus compensating the phase velocity difference between two modes. Recently, the strip-width modulation technique is developed to make up the "wiggle-line" filter with good harmonic suppression [3] over a wide frequency range. In parallel, the corrugated coupled microstrip line [4] is presented to extend the actual traveling path for the odd-mode such that the 1st-harmonic be suppressed by canceling the different velocity in the propagation behavior of two modes. Moreover, the square grooves [5] are periodically etched on the parallel-coupled lines and the coupled meander lines are constituted [6] to equalize the phase velocities of the odd- and even-mode field distributions for the same purpose.

Based on the above discussion, extensive investigation on the dispersion characteristics of these periodically nonuniform coupled microstrip lines (PNCML) become the most important issue in allowing one not only understanding the operating principle of these filters and also optimizing their filtering behaviors via simple and efficient synthesis procedure [1]. Consequently, guided-wave characteristics of the even and odd dominant modes in the PNCWL need to be promptly studied.

In [7], a spectral-domain approach is utilized to analyze the effective dielectric constants of the even- and odd-mode, i.e. β_e and β_o, in the periodically nonuniform coupled microstrip lines (PNCML). But, it does not take into account the frequency dispersion and also costs intensive numerical expenses, so that it may not be suitable for CAD-based design of microwave circuits. Very recently, FDTD algorithm is executed to analyze the propagation characteristics of PNCML [8]. Unfortunately, only the effective dielectric constants [7, 8] are calculated and no reported work to date has been carried out to derive characteristic impedances of these two modes regardless of any shaped PNCML. In this work, our developed hybrid method of moments and short-open calibration technique [9, 10], named "MoM-SOC", is extended to directly extract these unit-length transmission parameters from fullwave modeling of these PNCML with certain length. Obtained results are at first verified with the available quasi-static ones [11] for the uniform coupled lines. These parameters are then extracted and investigated to expose the fundamental guided-wave characteristics of the PNCML loaded with transverse slit in the quantitative manner. At final, one-stage coupled microstrip filter design example is given and predicted *S*-parameters are found in good agreement with the Momentum simulation.

2. MoM-SOC Extraction of PNCML

Fig. 1(a) depicts the cross-sectional view of a uniform coupled microstrip line, in which the microstrip lines are transversely spaced via coupling gap width (s). Fig. 1(b) indicates the geometrical sketch of the PNCML loaded with finite-number transverse slit, which is fed at the two sides by the two uniform coupled-lines in the MOM-SOC platform. The left- and right-side coupled feeding lines are simultaneously driven at their terminals or ports by a pair of delta gap sources in order to formulate a determinant admittance-type MoM scheme [9]. In order to excite the even- and odd-mode separately, the even- or odd-polarity of voltage sources are impressed between the two separated strip lines at both left- and right-side ports. Furthermore, the two feeding line lengths are sufficiently enlarged in

such a way that only the dominant modes can reach to the PNCML section with the two interfaces or terminals, i.e., R_1 and R_2., as in Fig. 1(b).
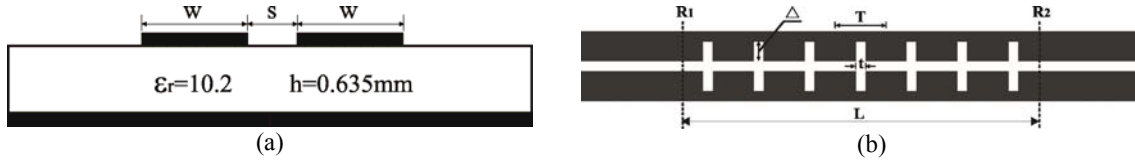

Fig. 1 (a) Cross-section of the uniform coupled microstrip line; (b) Layout for MOM-SOC modeling of a periodically nonuniform coupled microstrip line (PNCML).

After the SOC procedure is executed via ideal microstrip short- and open-end standards [9], the transmission line network parameters of the PNCML section for the two dominant modes can be effectively extracted and expressed here as two-port ABCD-matrix, respectively, with the four elements of $A^{\text{even,odd}}$, $B^{\text{even,odd}}$, $C^{\text{even,odd}}$, and $D^{\text{even,odd}}$. Following the detailed description in [10], the two sets of even- and odd-mode parameters can be derived,

$$Z_{oe,oo} = \sqrt{\frac{B^{\text{even,odd}}}{C^{\text{even,odd}}}} \qquad (1) \qquad \qquad \beta_{e,o} = \frac{1}{L}\left[n\pi + \cos^{-1}\left(\frac{A^{\text{even,odd}} + D^{\text{even,odd}}}{2} \right) \right] \qquad (2)$$

where n is the integer number.

3. Results and discussions
A. Unit-length transmission parameters

Based on the above-briefed MoM-SOC technique, a variety of PNCML structures with different depth (Δ) of the slit is investigated in terms of unit-length transmission parameters. In this case, the uniform coupled microstrip line structure is also included when Δ=0.0mm for verification in comparison with available data.
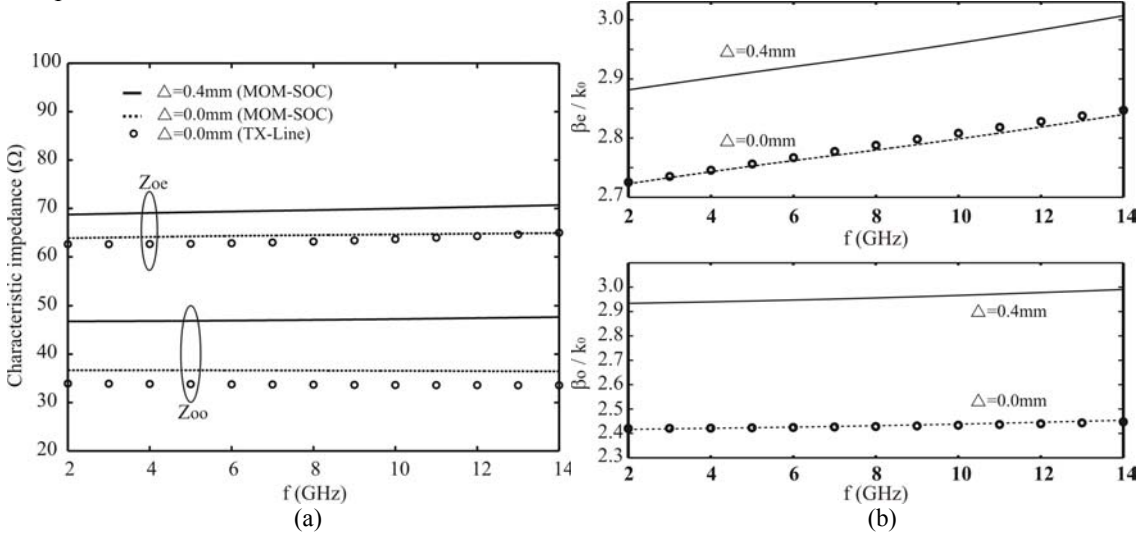

Fig. 2 Guided-wave characteristics of PNCML with different slit depths for even- and odd-mode, w=0.6mm, s=0.2mm, T=1.0mm, t=0.2mm, (a) Characteristic impedances; (b) Phase constants.

Fig. 2(a) and (b) depict the calculated characteristic impedance and phase constant of a finite-cell PNCML structure with the periodicity of T=1.0mm, respectively. In Fig. 2(a), the characteristic impedances of the even- and odd-mode rise up from 63.8 to 68.7Ω and from 36.6 to 46.8Ω, respectively, as Δ increases from 0.0mm (uniform) to 0.4mm. Meanwhile, in Fig. 2(b), the normalized odd-mode phase constant (β_o/k_0) is observed to increase more significantly with the degree from 2.42 to 2.93 than that from 2.72 to 2.88 for its even-mode counterpart (β_e/k_0), at the low frequency (2.0 GHz). This phenomenon can ve explained via [4] that a large portion of energy of the odd-mode is

concentrated at the central gap, while that of the even-mode at the outer metallic edges. Thus, in PNCML, as the odd-mode traveling path is enlarged, the effective phase velocity of the odd-mode becomes lower and its corresponding effective phase constant increases more dramatically while the even-mode phase constant is almost stably unchanged. In addition, the results with circle marker, in Fig. 2, are derived in [11] for the uniform line case (Δ=0.0mm) and they are found very reasonably matched to those from our MoM-SOC.

B. Transmission zeros

Following the previous work in [2], the transmission zero of the PCMCL section with the length of L can be accurately predicted using the equation (3).

$$\frac{Z_{oe}}{Z_{oo}} = \frac{\sin \beta_e L}{\sin \beta_o L} \qquad (3)$$

After the characteristic impedances and phase constants are calculated, the transmission zero for the total length of the resonator (L) can be obtained using the equation (3) as illustrated in Fig. 3. The two dotted lines denote the frequency-dependent functions: $Z_{oo}\sin\beta_e L$ and $Z_{oe}\sin\beta_o L$, respectively, with Δ=0.0mm. Meanwhile, the two solid lines corresponds with the PNCML with Δ=0.4mm. Here, two intersection points always satisfy the condition driven by the equation (3) and they can be considered as the solutions of this equation. As Δ increases from 0.0mm to 0.4mm, the zero point moves from 10.23GHz to 7.16GHz and the latter is around $2f_0$. As a result, the spurious response at $2f_0$ can be wholly removed out. For further analysis, the normalized phase constants with different Δ is calculated as a function of the ratio t/T at the frequency of about 7.16GHz. The results in Fig. 4 also prove that the zero point occurs around t/T=0.2.
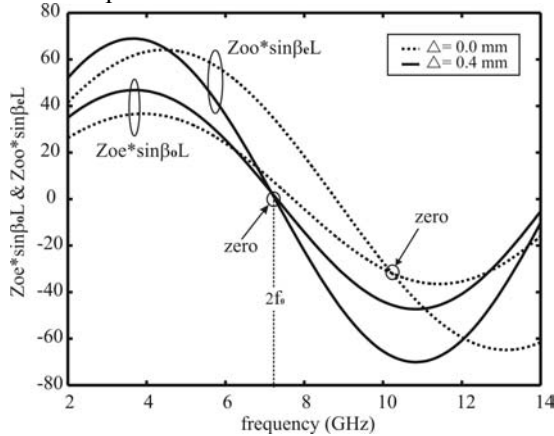

Fig. 3 Frequency-dependent graphs for allocation of the transmission zero at the desired frequency ($2f_0$), w=0.6mm, s=0.2mm, L=7.0mm, T=1.0mm, t=0.2mm.
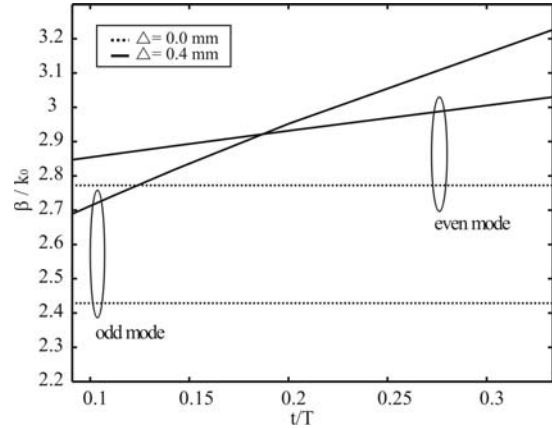
Fig. 4 Normalized phase constants with respect to the ratio t/T under the different slit depth (Δ), w=0.6mm, s=0.2mm, f=7.16GHz.

C. Design example of the filter

In this section, the above transmission-zero allocation technique is implemented to explore the harmonic-rejected PNCML bandpass filter, in which the zero frequency is suitably adjusted to that twice the fundamental passband, i.e. $2f_0$. Fig. 5(a) shows the layout of the PNCML section with the two single microstrip lines at its two sides while Fig. 5(b) the layout of the one-stage bandpass filter made up of such two PNCML sections. Relevant S-parameters of these filters can be simply calculated via equivalent cascaded transmission line network with the above-obtained parameters. Fig. 6 illustrates our predicted results together with those from the Momentum simulation, showing good agreement with each other for the case of Δ=0.4mm. In addition, the dashed line in Fig. 6 denotes the frequency response of the traditional parallel coupled microstrip filter with Δ=0.0mm. By looking at these two sets of graphs together, the upper stopband performance has been really improved by using the PNCML with Δ=0.4mm. In other words, this one-stage PNCML filter has effectively suppressed the 1st-harmonic spurious passband while achieving the preferably symmetrical passband response.

4. Conclusion

   Guide-wave characteristics of the PNCML structure loaded with transverse slit are extensively characterized using our fullwave MOM-SOC technique in terms of unit-length transmission parameters of equivalent uniform parallel-coupled transmission lines. In particular, our   effort has been primarily made to accurately predict the location of transmission zero for the finitely-extended PNCML section and further allocate it suitably to suppress the 1st-harmonic passband in the design of microstrip bandpass filters. Optimized results are evidently verified over a wide frequency range. Moreover, in addition to its attractive electrical behavior, this PNCML filter is expected to occupy very compact size due to the slow-wave propagation as illustrated in Fig. 2.

(a)   (b)

Fig. 5   Layouts of one stage PNCML section and filter, w=0.6mm, s=0.2mm, L=7.0mm, T=1.0mm, t=0.2mm.

(a)   (b)
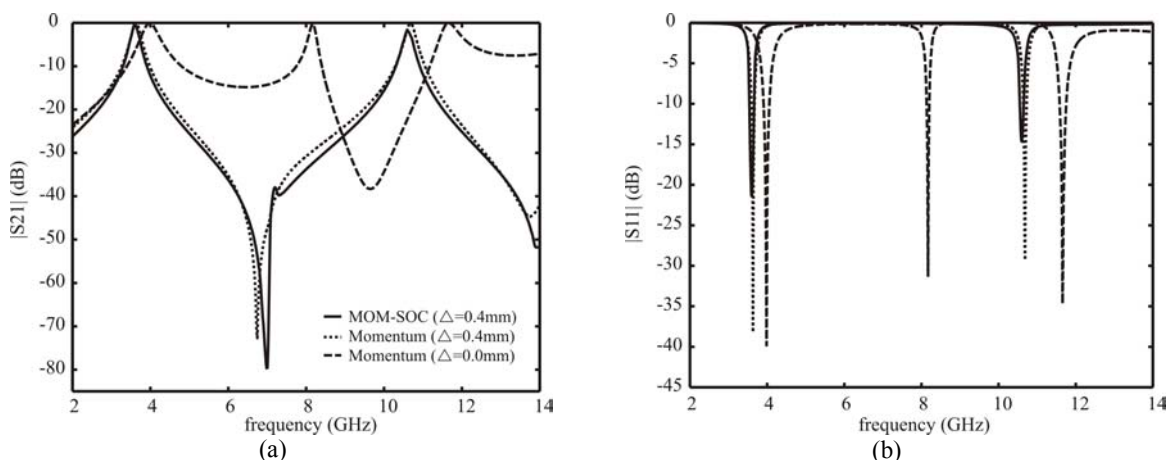
Fig. 6   S-parameters of the one-stage PNCML filters, w=0.6mm, s=0.2mm, L=7.0mm, T=1.0mm, t=0.2mm.

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