An Implementation of Harmonic-Suppression Microstrip Filters With Periodic Grooves

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***Abstract*—In this paper, a new parallel-coupled-line microstrip band pass filter (BPF) improving the harmonic suppression performance of the second harmonic signal ($2f_o$, twice the passband frequency) is described. It is found that the desired passband performance is improved and the harmonic passband signal is diminished by enforcing the consecutive patterns in coupled-line and increasing the number of grooves to the optimum values. The recalculation of design parameters such as space-gap between lines, line widths and lengths is not required due to the simple modification of the conventional filter by inserting periodic patterns. To evaluate the validity of this novel technique, order-3 Butterworth BPF centered at 2.5 GHz with a 10% fractional bandwidth (FBW) and order-5 Chebyshev BPF centered at 10 GHz with a 15% FBW were used. When five and three square grooves are used, over 30-dB suppression at second harmonic signal is achieved in simulation and experiment. Finally, the comparison between the characteristics of filters with square and semicircular periodic grooves has been carried out by using the simulated results.**

***Index Terms*—Harmonic suppression, periodic grooves.**

I. Introduction

THE PARALLEL-coupled-line theory has been used to construct harmonic-suppression microstrip filters widely applicable to transmitter/receiver in microwave and millimeter wave systems. Recently, the periodic structures employed in multisection microstrip technology have been interested as the name of photonic bandgap (PBG), electromagnetic bandgap (EBG), or defected ground structure (DGS). The fabrication of multisection bandpass or bandstop coupled-line filters is particularly easy in microstrip form for bandwidths less than 20%. The required design parameters of BPF can be easily derived for Butterworth and Chebyshev prototypes in many literatures [1]–[3].

Although this type of filter is general and easy to implement, it suffers from the presence of spurious passbands at harmonics of the desired frequency. For example, if the conventional parallel-coupled-line filter is used at the next stage of frequency converter in the typical RF communication module, it is very difficult to reject the harmonic signal that frequency converter generates. Consequently, these phenomena result in the degradation of system performance. To lower the rejection level of these harmonics, the lowpass filter or notch filter is connected to the bandpass filter in a series. But, this solution increases the overall size of RF module and introduces additional insertion losses. Hence it is necessary to obtain a design technology that can reduce the filter size and reject a harmonic signal.

Uniplanar compact photonic bandgap (UC-PBG) structure with periodic patterns etched in the ground plane has been proposed to reject harmonic signals and to reduce the total filter size, but the physical and electrical parameters of coupled lines must be recalculated in this structure [4]. Other PBG structures having Blackman, Cosine, Gauss, Hyperbolic Tangent, and Kaiser windows have been proposed by windowing the periodic patterns and the number of periods in the ground plane and using Bragg condition [5]–[7]. The harmonic rejection levels of the periodic structures with sinusoidal and triangular patterns reach the values of more than 45 and 50 dB, respectively, while these structures, as well as UC-PBG, have the increased size problem. Another method, defected ground structure (DGS) having a defected pattern of slot in the ground plane like PBG, is recently investigated to introduce a lowpass filter characteristics by increasing capacitance and inductance of transmission lines on the defected ground [8].

In order to overcome and improve the disadvantages caused by longitudinal and lateral displacement of each pattern of PBG and DGS on both sides of the substrates, "wiggly-line filter" using a continuous perturbation of the coupled-line width has been suggested [9]. In [9], the wave impedance is modulated so that the harmonic passband of the filter might be rejected while the desired passband response remains virtually unaltered. But the etching of sine wave on transmission line is not easy and the S_{21} near at harmonic frequency still remains.

In Section II, a modified structure is proposed by applying the above-mentioned ideas and Bragg condition to microstrip line to improve harmonic suppression characteristics. In addition, the design method of two filters operating at 2.5 and 10 GHz and the process of inserting periodic square grooves are given in Section II. In Section III, the simulation and measurement of filter with Bragg reflector are carried out. Conclusions in Section IV describe a brief summary of this paper and discussion.

II. Filter Design With/Without Rectangular and Square Grooves

A. Parallel-Coupled-Line Filter Design Without Rectangular and Square Grooves

In order to verify the performance of proposed novel filter and compare with the measurement results, Order-3 bandpass filter centered at $f_c = 2.5$ GHz with 10% fractional bandwidth is designed. The employed substrate has relative dielectric constant,

Manuscript received December 11, 2003; revised April 2, 2004. The review of this letter was arranged by Associate Editor J.-G. Ma.

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Digital Object Identifier 10.1109/LMWC.2004.832063

TABLE I
PHYSICAL PARAMETERS FOR THE ORDER-3 BUTTERWORTH BPF CENTERED AT 2.5-GHZ WITH A 10% FBW

n	Z_{0e} (Ω)	Z_{0o} (Ω)	w_n	s_n	l_n
1	77.66	38.0377	0.75	0.42	11.98
2	56.17	45.0622	1.09	1.70	11.54

TABLE II
PHYSICAL PARAMETERS FOR THE ORDER-5 CHEBYSHEV BPF CENTERED AT 10-GHZ WITH A 15% FBW

n	Z_{0e} (Ω)	Z_{0o} (Ω)	w_n	s_n	l_n
1	82.9367	37.6092	0.385	0.161	2.852
2	61.1600	42.3705	0.575	0.540	2.772
3	58.1839	43.8661	0.595	0.730	2.756

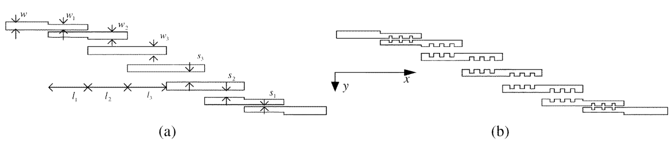

Fig. 1. With 10-GHz center frequency (a) conventional parallel-coupled-line BPF and (b) modified filter obtained by applying three square grooves to (a).

$\varepsilon_r = 10.2$ and thickness, $h = 1.27$ mm of Rogers RT/Duroid 6010. The equation to obtain the layout parameters of conventional parallel-coupled-line microstrip filter is very well known and can be found in classical microwave literatures [1]–[3]. The same specifications used for designing "wiggly-line filter" are applied to the design of rectangular- and square-grooved filters. In Table I, the used parameters for BPF design are described as section number n, the characteristic impedances of the even, Z_{0e} and odd mode, Z_{0o}, respectively, and the strip widths of input and output ports (Z_0), $w = 1.5$ mm. To improve the applicability of the modified filter regardless of filter type or frequency, we have designed order-5 Chebyshev bandpass filters centered at $f_c = 10$ GHz with $\mathrm{FBW} = 15\%$. The employed substrate has relative dielectric constant, $\varepsilon_r = 10.2$ and thickness, $h = 0.635$ mm. In Table II, the used strip widths of the input and output ports for the order-5 Chebyshev filter are all 0.59 mm.

B. Parallel-Coupled-Line Filter Design With Rectangular and Square Grooves

In the modification of conventional parallel-coupled-line filer proposed in this paper, the periodic square grooves are placed at the both sides of coupled-line symmetrically, where l_n is equal to $\lambda_g/4$ of the desired frequency and λ_g is guided wavelength. In Fig. 1(b), k_x is the wave number of TEM mode propagating at $+x$ axis. The condition for Bragg reflection is given as

$$2k_xD = 2\pi n \; (n = 1, 2, \ldots, \text{ an integer}) \tag{1}$$

where D is the period of the perturbation and is equally said to be beat wavelength [9]. For the desired center frequency f_c, the condition for generating Bragg reflection at harmonic frequency of $2f_c$ is written as in

$$\frac{8\pi D}{\lambda_{\mathrm{gc}}} = 2\pi \; (\text{ if } n = 1) \tag{2}$$

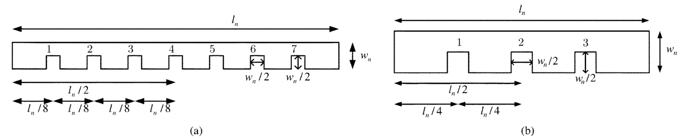

Fig. 2. (a) Modified $\lambda_g/4$ line in 2.5-GHz filter and (b) modified $\lambda_g/4$ line in 10-GHz filter.

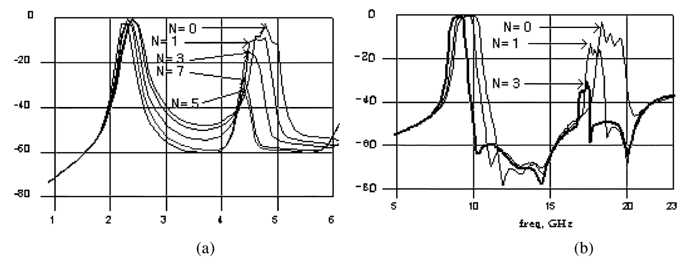

Fig. 3. Simulated results in dB (a) S_{21} for filter centered at 2.5 GHz with grooves and (b) S_{21} for filter centered at 10 GHz with grooves where N is the number of grooves on both sides of coupled-line in each section.

D can be obtained from (2) as $\lambda_{\mathrm{gc}}/4$, where λ_{gc} is the wavelength of the desired center frequency.

In Fig. 2(a) and (b), the general shapes of $\lambda_g/4$ line with square grooves are shown. From the several simulation results, it is found that the optimum length of each side of square grooves is a half of each coupled-line width under the condition of the center of each square being located at 1/8 and 1/4 of l_n. The number of the square grooves is one (groove position is 4), three (2,4,6), five (2,3,4,5,6), and seven (1,2,3,4,5,6,7) in 2.5-GHz filter from Fig. 2(a) while in 10-GHz filter from Fig. 2(b), one (groove position is 2) and three (1,2,3) grooves have been employed.

III. EXPERIMENTAL RESULTS

The calculated results were obtained by using Ensemble 4.0 of Ansoft and MWS 4.0 of CST based on MoM and FDTD algorithm, respectively. From the simulation results of the 2.5 and 10 GHz filters with grooves in Fig. 3, it is shown that the conventional coupled-line filter generates high signal level at the second harmonic and the more the number of groove increases, the more the second harmonic signal level and bandwidth decreases. Moreover, the center frequencies move to the lower. These phenomena are due to an increased path length of wave caused by inserting the periodic square grooves. The harmonic suppression characteristics of seven-grooved filter approaches to the worst because of the strong interferences caused by the small interval between the grooves deviating the range of $l_n/4 \sim l_n/8$. When the number of grooves is 3 in Fig. 3(b), it is shown that the harmonic rejection effect of more than 30 dB can be obtained. To verify the simulation results, 2.5-GHz filters were implemented and measured with the substrate data of $\varepsilon_r = 10.2$ and $h = 1.27$ mm of Rogers RT/duroid 6010. The measurements have been realized with a Agilent E8357A PNA Series Network Analyzer. Fig. 4 shows good agreements between simulation and experimental results. The more the number of groove increases from 0 to 5, the more the second harmonic signal decreases. When the number of grooves is 5 as shown

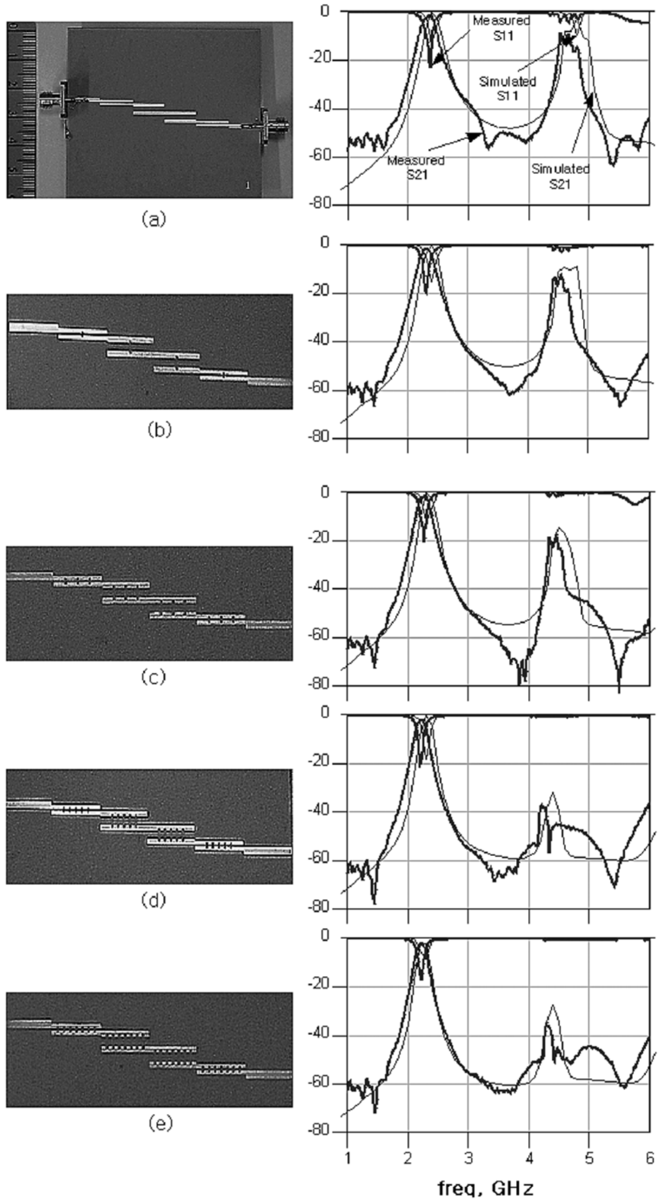

Fig. 4. Photographs of filter centered at 2.5 GHz with groove numbers of (a) 0, (b) 1, (c) 3, (d) 5, and (e) 7, and S-parameters with measured (thick blue line) and predicted results (thin black line).

in Fig. 4(d), the rejection level reaches the nearly -35 dB as the maximum value and there is no considerable improvement compared with the case of Fig. 4(e). As an additionally remarkable characteristics of the proposed filters, the cut-off rate of the proposed filters for stopband was improved about 10 dB by comparing with that of the conventional coupled-line filters. In Fig. 5, the filter characteristics has been investigated by using the semi-circular grooves in replacement of square and increasing the number of grooves. Harmonic rejection level more than 30 dB has been obtained when the optimum number of grooves, N approaches 5, whereas the harmonic signal level increases abruptly as N is larger than the optimum value. The reason is thought that the perturbation period is smaller than the optimum value by deviating the range from $l_n/4$ to $l_n/8$, thus the mutual coupling effects between the perturbation grooves increase considerably [10]–[12].

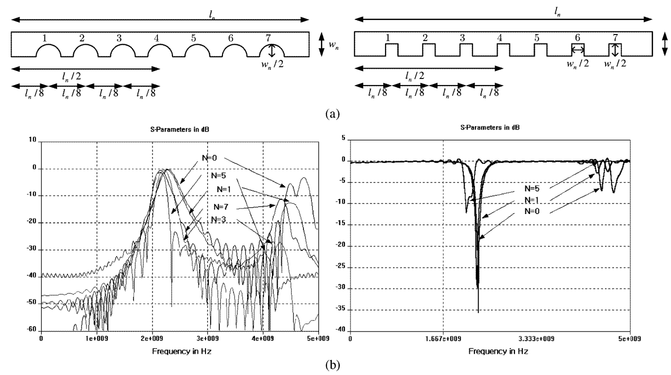

Fig. 5. (a) One of the sections in parallel-coupled-line filter with semi-circular and square grooves and (b) S-parameters ($|S_{21}|$ in left and $|S_{11}|$ in right) of filters with semi-circular periodic grooves where N is the number of the periodic grooves.

IV. Conclusion

The novel design method to improve the harmonic suppression characteristics at the twice passband frequency is suggested by applying the square grooves to meet Bragg condition from the conventional parallel-coupled microstrip bandpass filter. For the comparison between filter characteristics according to the shapes of groove, harmonic rejection filters with semi-circular and square periodic grooves have been studied. As a result, the harmonic rejection level approaches more than 30 dB and a good cut-off characteristics at the desired frequencies is obtained. In addition, the advantages of saving time, low cost, and easy fabrication process have been obtained without recalculating physical design parameters of conventional filter.

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