Proposal of a New Folded Comb-Line Filter

Toshiaki Kitamura, Kentaro Yoshida, Masahiro Geshiro, and Toshio Ishizaki

***Abstract*—We propose a new type of comb-line filter that is suitable for miniaturization utilizing stratifying technology. It consists of a couple of composite resonators. Each resonator is composed of two sections of a microstrip and a coplanar waveguide fabricated on the microstrip ground plane which are connected through a piece of wire at an open end to set up a new folded comb-line filter. The filtering characteristics are investigated through experiments as well as numerical simulations by means of the FD-TD method. It is shown that the filtering characteristics can be much improved by removing part of the barrier in the coplanar-line portion of the resonator to alter the coupling.**

***Index Terms*—Attenuation pole, FD-TD method, folded comb-line filter.**

I. Introduction

HANDY portable telephones have come into wide use and their further compactness is strongly required. Miniaturization of microwave filters is inevitable to meet this requirement and ceramic laminated filters [1]–[4] are widely used in this application. In particular, the stratifying technology of ceramic using low-temperature co-fired ceramics (LTCC) is one of the key technologies to reduce the device dimensions [5]–[10]. This technology makes it possible to unify various kinds of devices in a multilayered structure. From such circumstances, the development of devices having congeniality with multilayered structures is becoming important.

In this paper, we propose a new type of comb-line filter that is suitable for miniaturization by means of stratifying technology. It consists of a couple of composite resonators. Each composite resonator is composed of a segment of microstrip line (MSL) and a segment of coplanar waveguide (CPW) fabricated on the microstrip ground plane. The two segments are connected through a piece of thin wire at an open end of each to set up a resonator of folded type. The other end of the MSL section is grounded; hence each composite resonator as a whole is of quarter wavelength. We investigate the filtering characteristics through experiments as well as numerical simulations by means of the FD-TD method. It is shown that the filtering characteristics can be largely improved by removing part of the barrier in the coplanar-line portion of the resonator to alter the coupling.

II. Basic Structure and Its Characteristics

Fig. 1 illustrates the structure of the folded comb-line filter that we propose in this paper. Two MSL resonators each one of which is terminated to the ground plane at one end through a piece of thin wire are arranged on the substrate. A narrower MSL with a characteristic impedance of 50 Ω is connected directly to each resonator as an I/O port. On the other hand, two CPW resonators are arranged in the ground plane each one of which is connected, at one end, to the open end of the MSL resonator on the other side of the substrate through a piece of thin wire. Hence the composite structure of the MSL and CPW sections makes up a quarter-wavelength resonator of folded type. Because the MSL resonators face to the CPW resonators wider than themselves, most part of electric field lines from the MSL arrive at the ground conductor via the center conductor of the CPW and the other part go directly to the ground conductor. The thickness and relative permittivity of the substrate are assumed to be 1.27 mm and 10.2, respectively. The other structural parameters are shown in Fig. 1 together with the coordinate system for the analysis.

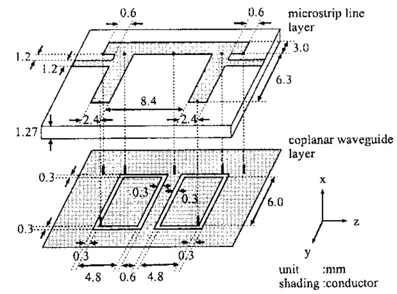

Fig. 1. Folded comb-line filter.

We investigate the filtering characteristics through experiments as well as numerical simulations by means of the FD-TD method. For experiments, a folded comb-line filter is manufactured on an RT/duroid 6010LM substrate of 1.27 mm thickness and 10.2 relative permittivity by using a computer-aided design (CAD)-installed automatic cutting machine. Some pieces of copper wire of 0.1 mm diameter are used to connect the conductors through the substrate. On the other hand, the same filter is modeled on a Yee's mesh consisting of $72 \times 60 \times 122$ homogeneous cells in our FD-TD code; each cell is set to be 0.15875 mm in the x direction and 0.3 mm in both y and z directions.

We show the frequency characteristics of the scattering parameters in Fig. 2. Here, the solid and dashed lines indicate the numerical and experimental results, respectively. As shown in this figure, a compact bandpass filter with two attenuation poles below and above the passband is realized. It is also shown that the experimental results are in good agreement with the numerical ones.

The higher frequency response above 3 GHz, which is not shown in this figure, is different from standard comb-line filters. The controll of the sprious passband is another problem to be solved.

Manuscript received June 10, 2002; revised October 22, 2002. The review of this letter was arranged by Associate Editor Dr. Rüdiger Vahldieck.

T. Kitamura, K. Yoshida, and M. Geshiro are with the Graduate School of Engineering, Osaka Prefecture University, Osaka 599-8531, Japan (e-mail: kitamura@uopmu.ees.osakafu-u.ac.jp.).

T. Ishizaki is with the Matsushita Electric Industrial Co., Ltd., Osaka 571-8501, Japan.

Digital Object Identifier 10.1109/LMWC.2003.811672

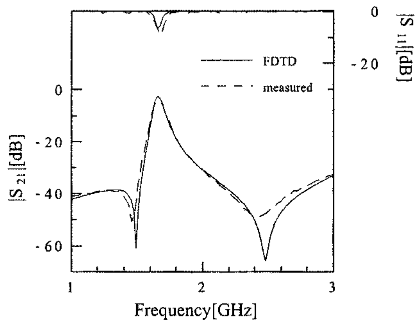

Fig. 2. Frequency characteristics of scattering parameters.

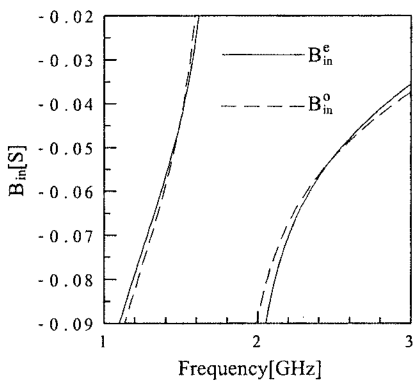

Fig. 3. Frequency characteristics of the input susceptances of the even and odd modes.

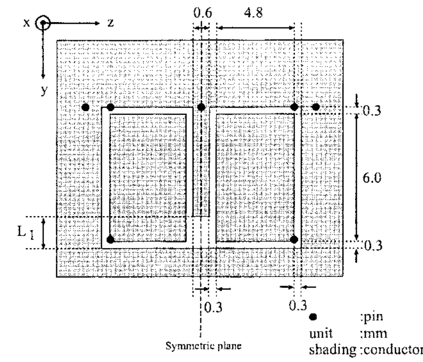

Fig. 4. Metallization pattern on the ground plane.

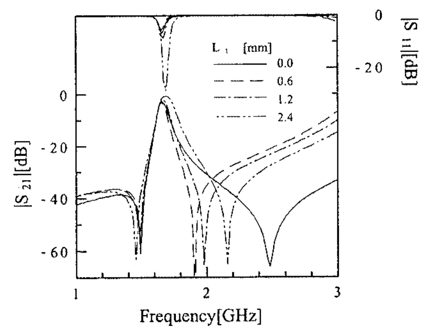

Fig. 5. Frequency characteristics of scattering parameters with L_1 as a parameter.

The experimental results, however, exhibit deterioration in some degree in the insertion and return losses about the center frequency of passband. The insertion losses of numerical and experimental results are 2.697 dB and 4.481 dB, respectively, at the center frequency of the passband.

Hands of those who have less skill in manipulating the cutting machine may bring about some cutting errors in fabricating filters. Overcutting into the substrate not only causes the reduction of effective dielectric constant but also enhances radiation into the air and substrate. We have actually observed in our measurements that some of electromagnetic energy stored in the structure is lost in a very narrow band of frequencies at the center of the passband. Hence it is considered that further refinement in the fabrication process can diminish such discrepancies in both of the insertion and return losses in Fig. 2.

It is well known that comb-line filters have attenuation poles at the frequencies where the input susceptances of the even and odd modes are equal to each other [11]. Fig. 3 illustrates the frequency characteristics of the input susceptance of the even and odd modes, B_{in}^{e} and B_{in}^{o}, respectively, when the width of the CPW is 4.8 mm. Input susceptances are calculated from $S_{11}(f)$ at the observation point set on the input port [11]. For the even mode, we excite electric fields in phase on two excitation planes each one of which is placed in the input and output ports at the same distance from the center axis of the comb-line filter so that we have an equal voltage on both composite quarter-wavelength resonators. On the other hand, electric fields having the opposite signs are excited on both resonators for the odd mode. In Fig. 3, the curves of input-susceptance of both modes have two intersections at 1.49 GHz and 2.48 GHz, which correspond with the attenuation-pole frequencies in Fig. 2.

III. Dependence of the Filtering Characteristics on Coupling Between the Resonators

In this section, we propose a method to improve the filtering characteristics of the folded comb-line filter by changing the coupling between the resonators.

As mentioned in Section II, attenuation-pole frequencies are determined from the intersections of the input-susceptance curves of the even and odd modes. It is, therefore, possible to alter the attenuation-pole frequency by changing the inclination of the input-susceptance curves slightly. In order to achieve this, we here remove part of the conductor barrier in the coplanar-line portion of the resonator.

Fig. 4 illustrates the metallization pattern on the ground plane. The conductor between the CPW resonators is removed partly to control the resonator coupling. We investigate the filtering characteristics with L_1, the length of the removed portion of conductor, as a parameter. The other structural parameters are all the same as the basic structure shown in Fig. 1.

Fig. 5 shows the frequency characteristics of the scattering parameters with L_1 as a parameter. Here, the solid line corresponds to the result shown in Fig. 2 for the case where $L_1 =$ 0.0 mm.

It is understood from this figure that the parameter L_1 exclusively affects the attenuation-pole frequency above the passband; hence we can arrange it just around the passband by adjusting L_1. The center frequencies are about 1.67 GHz for any value of L_1. The band width is, however, slightly

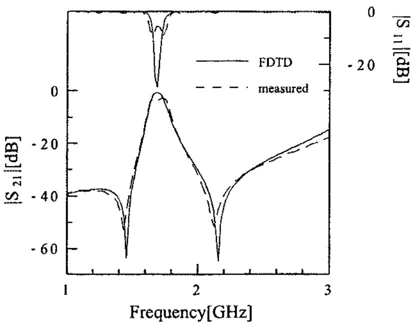

Fig. 6. Frequency characteristics of scattering parameters when $L_1 = 2.4$ mm.

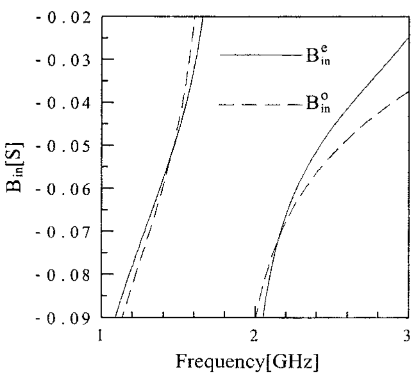

Fig. 7. Frequency characteristics of the input susceptances of the even and odd modes when $L_1 = 2.4$ mm.

altered depending upon the attenuation-pole frequency which is controlled by changing L_1.

Next, we show, in Fig. 6, the comparison of the scattering parameters between the numerical and experimental results when $L_1 = 2.4$ mm. It is recognized that the numerical results by means of the FD-TD method are in good agreement with the experimental ones as a whole. The insertion losses of numerical and experimental results are 0.772 dB and 2.589 dB, respectively, at the center frequency of the passband.

Fig. 7 shows the frequency characteristics of the input susceptances of the even and odd modes when $L_1 = 2.4$ mm. We can make sure that the intersections between both curves take place at 1.46 GHz and 2.16 GHz and that they correspond with the attenuation-pole frequencies in Fig. 6. In comparison with Fig. 3 which corresponds to the case where $L_1 = 0.0$ mm, it is understood that the input susceptance curve of the even mode in Fig. 7 has a steeper slope above the passband. Hence, in the case where $L_1 = 2.4$ mm, the intersection between the susceptance curves of both modes moves and comes down closer to the passband.

IV. Conclusions

In this paper, we have proposed a new type of comb-line filter that is suitable for miniaturization by means of stratifying technology. It consists of two MSL resonators on a substrate and two CPW resonators in the ground plane on the other side of the microstrip substrate. Each of the MSL resonators is connected with one CPW resonator through a piece of thin wire to form a composite resonator of folded-type. The filtering characteristics have been investigated through experiments as well as numerical simulations by means of the FD-TD method. It has been shown that a compact bandpass filter with two attenuation poles below and above the passband is realized. It has also been shown that the filtering characteristics can be largely improved by removing part of the conductor barrier in the coplanar-line portion of the resonator to alter the coupling. Furthermore, it has been confirmed that the experimental and numerical results are in good agreement with each other. At the next stage, we would like to abstract an equivalent circuit and establish the details of design method.

References

[1] T. Ishizaki, M. Fujita, H. Kagata, T. Uwano, and H. Miyake, "A very small dielectric planar filter for portable telephones," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 2017–2022, Nov. 1994.

[2] T. Ishizaki, T. Uwano, and H. Miyake, "An extended configuration of a stepped impedance comb-line filter," *IEICE Trans. Electron.*, vol. E79-C, no. 5, pp. 671–678, May 1996.

[3] T. Ishizaki, T. Kitamura, M. Geshiro, and S. Sawa, "Study of the influence of grounding for microstrip resonators," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 2089–2093, Dec. 1997.

[4] T. Kitamura, M. Geshiro, T. Ishizaki, T. Maekawa, and S. Sawa, "Characterization of triplate strip resonators with a loading capacitor," *IEICE Trans. Electron.*, vol. E81-C, no. 12, pp. 1793–1799, Dec. 1998.

[5] H. Miyake, S. Kitazawa, T. Ishizaki, H. Ogawa, and I. Awai, "A study of a laminated band elimination filter comprising coupled-line resonators using low temperature co-fired ceramics," *IEICE Trans. Electron.*, vol. E82-C, no. 7, pp. 1104–1109, July 1999.

[6] Y. Rong, K. A. Zaki, J. Gipprich, M. Hageman, and D. Stevens, "LTCC wide-band ridge waveguide bandpass filters," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 1836–1840, Sept. 1999.

[7] J. Kassner and W. Menzel, "A drop-on band-pass filter for millimeter-wave multichip modules on LTCC," *IEEE Microwave Guided Wave Lett.*, vol. 9, pp. 456–457, Nov. 1999.

[8] Y. Rong, K. A. Zaki, M. Hageman, D. Stevens, and J. Gipprich, "Low-temperature co-fired ceramic (LTCC) ridge waveguide bandpass chip filters," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 2317–2324, Dec. 1999.

[9] J. Y. Sheen, "A compact semi-lumped low-pass filter for harmonics and spurious suppression," *IEEE Microwave Guided Wave Lett.*, vol. 10, no. 3, pp. 92–93, Oct. 2000.

[10] K. Kageyama, K. Saito, H. Murase, H. Utaki, and T. Yamamoto, "Tunable active filters having multilayer structure using LTCC," *IEEE Trans. Microwave Theory Tech.*, vol. 49, no. 12, pp. 2421–2424, Dec. 2001.

[11] T. Kitamura, Y. Horii, M. Geshiro, and S. Sawa, "A dual-plane comb-line filter having plural attenuation poles," *IEEE Trans. Microwave Theory Tech.*, vol. 50, no. 4, pp. 1216–1219, Apr. 2002.