THEORETICAL CHARACTERIZATION AND EXPERIMENTAL VERIFICATION OF A NOVEL COMPACT BROADBAND MICROSTRIP BANDPASS FILTER

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ABSTRACT

A novel compact broadband microstrip bandpass filter is proposed and developed on a basis of the frequency-distributed coupling behavior of the parallel-coupled microstrip line (PCML) and the multi-mode resonance of the stepped-impedance line resonator. Comprehensive investigation in this work is dedicated to a physical insight into its operating mechanism and theoretical characterization of its broadband filtering performance through the use of its complete equivalent circuit network. In final, such a microstrip filter is designed, fabricated and measured, providing an excellent verification on its attractive features such as multiple transmission poles, broad passband and size-compactness.

I. INTRODUCTION

Planar transmission line band-pass filter (BPF) [1-2] has extensively been studied and exploited as one of key building blocks in the design of RF and microwave integrated circuits and systems. Regardless of different layout configuration of planar BPFs developed to date, there is a common operating mechanism, as detailed in [1], where the multiple line resonators with the length quarter-, half- or full-wavelength at the central frequency are linked together through the introduction of shunt capacitive or series inductive coupling elements between two adjacent line resonators in order to formulate the multiple transmission poles within the passband. Furthermore, the design procedure is in general implemented under the approximate assumption that each line resonator is perceived as equivalent shunt or series LC resonator and each coupling element is modeled as the lumped (or frequency-independent) J-inverter or K-inverter parameter over the frequency range of concern. As a natural result, this traditional theory is only reasonably available for the design of BPF with relative narrow bandwidth (< 20%), which was also described in [1].

In [3], an aperture-compensated parallel-coupled microstrip line (PCML) was presented to enhance the coupling between two coupled lines and characterized as an equivalent frequency-distributed J-inverter network over a wide frequency range. In this case, a unique operating mechanism of broad bandpass filter is formulated by effectively using the unity values of normalized J-inverter susceptance of PCLM and two resonant modes of a line resonator. This BPF has four transmission poles with the bandwidth of about 70%. Afterwards, a stub-loaded line resonator was developed in [4] to relocate its second resonant frequency close to its first one towards the exploitation of a broad BPF using the traditional PCML with relatively weak coupling. Very recently, a novel broad BPF with five transmission poles is reported in [5] by using the stepped-impedance line resonator [6]. In this work, our main effort is made to provide a physical insight into the operating mechanism of the BPF structure in [5], theoretically characterize and optimally design such a broad BPF, and finally give an experimental verification of its attractive bandpass behavior, that is, five-pole broad pass bandwidth.

II. FREQUENCY-DISTRIBUTED COUPLED MICROSTRIP LINE

With the use of our own EM package as detailed in [7-8], the traditional PCML may be characterized as an equivalent J-inverter nework with the J-susceptance and two electrical line lengths. J-susceptance used here allows us understanding better the couping behavior of this PCML over a wide frequency range and also explaining in depth the operating mechanism of this broadband BPF. Fig.1 describes the extracted J-inverter network parameters. The results show us that the normalized J-susceptance (J/Y_0) is definitely varied as a function of the frequency and its maximum value happens at the frequency where the electrical line lengths ($\theta/2$) is slightly larger than 90^0 or longer than the quarter-wavelength because of equivalent open-end capacitance of two microstrip lines. According to [3], this PCML itself can hardly lead to the emergence of transmission poles since $(J/Y_0)_{max}=0.425$ is much smaller than the unity. But, we eventually understand that the transmission poles can also be realized by lowering the charateristic impedance of one or two microstrip lines at the two sides of this PCML. Fig.2 depicts the S-parameters of such a PCML structure driven by two low-impedance microstrip lines with wide strip widths. The results in Fig.2 indicate that one and two transmission poles can be achieved by widening the strip width from *0.125mm* to *1.00mm* and *1.35mm*, respectively, without any need of a backside aperture over the PCML section as in [3].

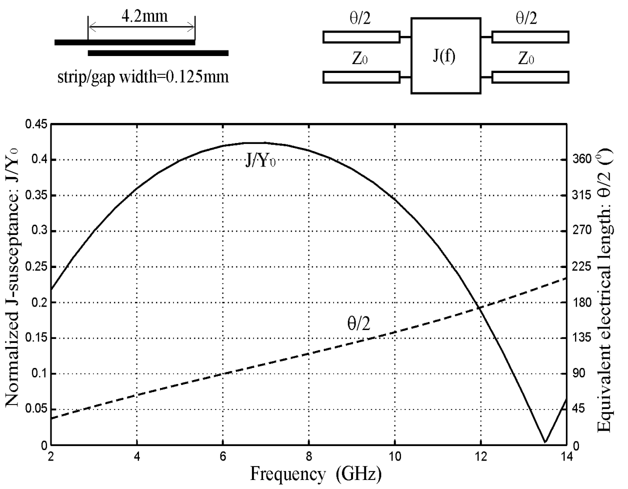


Fig.1 Extracted PCML J-inverter parameters: J-susceptance & electrical line lengths

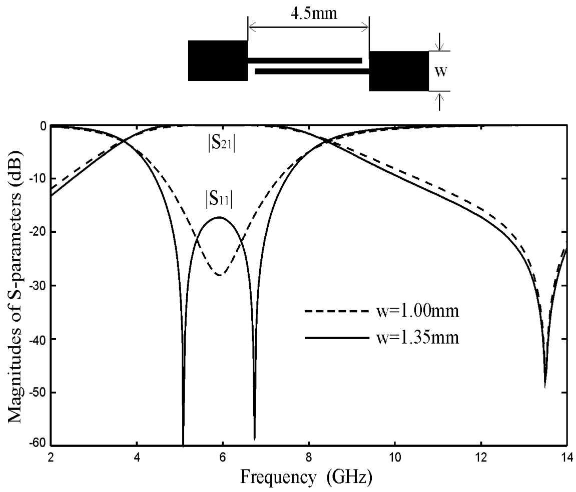


Fig.2 S-parameters of such a PCML driven by two low-impedance microstrip lines

III. MULTI-MODE MICROSTRIP LINE RESONATOR

Now, our attention is shifted towards the characterization of multi-mode resonances of a stepped-impedance line resonator, which consists of the low-impedance microstrip line with wide strip width at the central part and two high-impedance ones with narrow strip width at the two sides. Fig.3 depicts the layout and equivalent circuit network of such a line resonator launched by two external feed lines through the two PCML sections. Still, the PCML is perceived as a J-inverter network with weakly coupling J-susceptance and two electrical line lengths. Fig.4 describes the simulated insertion loss (S_{21}) of the line resonator structure with different strip widths (W_l) of the central microstrip line on a basis of its equivalent network. In Fig.4, the terms of F_{01}, F_{02}, F_{03} and F_{04} represent the first-, second-, third- and fourth-order resonant frequencies of this line resonator, respectively. At the case of $W_l=0.625mm$, all these four frequencies are separated in an approximately identical interval between two adjacent ones. As W_l is widened to *2.25mm* and further to *4.565mm*, it can be observed from Fig.4 that F_{01} rises up and F_{03} falls down towards F_{02} simultaneously to a great extent. Meanwhile, F_{04} seems almost kept unchanged regardless of W_l. Together with the frequency-distributed coupling PCML as discussed above, this stepped-impedance line resonator brings a great possibility in building up a novel broadband microstrip BPF with five transmission poles, in which its passband is dominantly determined by the first and third resonant frequencies, that is, F_{01} and F_{03}.

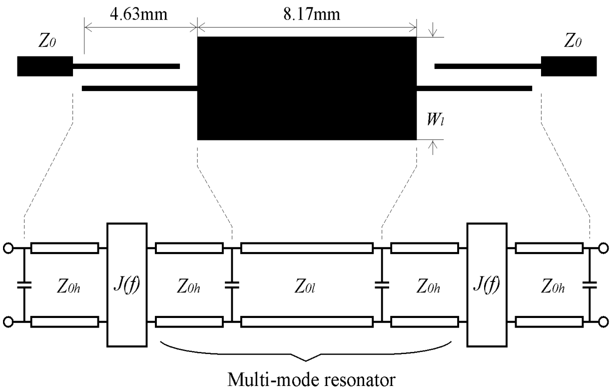


Fig. 3 Layout and equivalent circuit network of the stepped-impedance line resonator with two PCML sections.

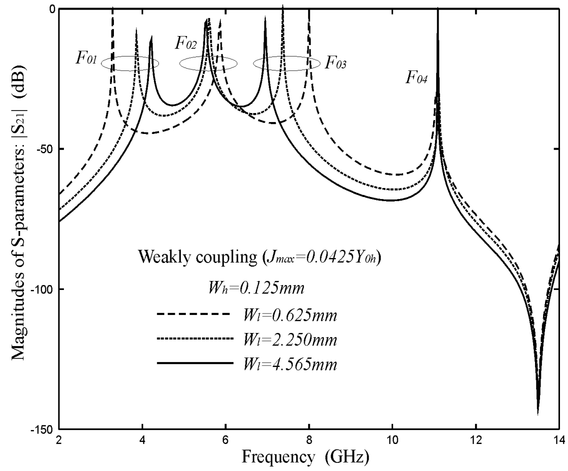
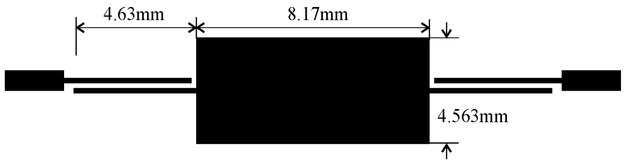


Fig.4 Simulated S-parameters of this line resonator structure with different strip widths of central microstrip line section.

IV. BROADBAND MICROSTRIP BANDPASS FILTER



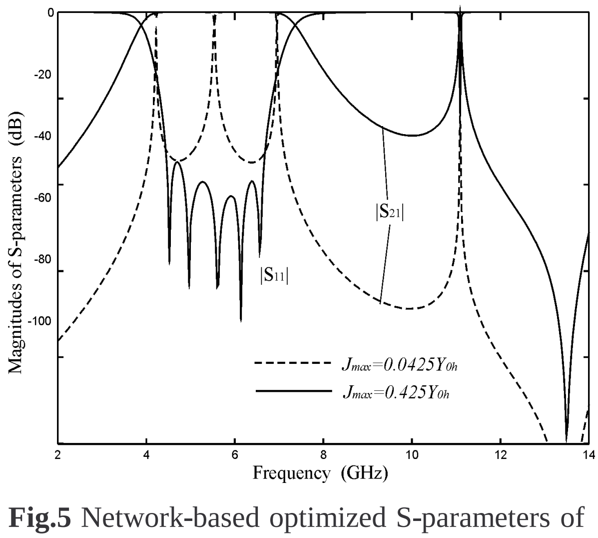


Fig.5 Network-based optimized S-parameters of the five-pole broad BPF together with one of cases in Fig.4.

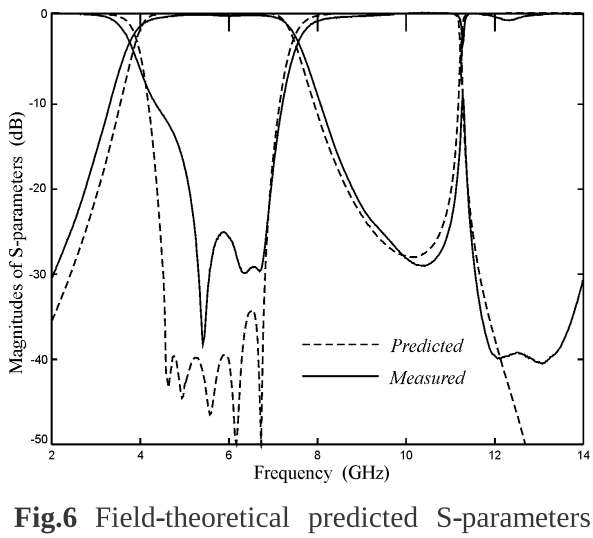


Fig.6 Field-theoretical predicted S-parameters of such a broad BPF as compared with its measured results.

Following the above physical explanation, our effort here is made to the optimization design of the proposed broad BPF by suitably enhancing the coupling degree of two PCML sections, as indicated in the upper part of Fig.5-6. Fig.5 depicts the initially optimized S-parameters of the BPF with the same dimension of the line resonator as that in the last case of Fig.4, on a basis of the equivalent circuit network as in Fig.3. The results in Fig.5 show us an excellent broad bandpass behavior with the approximate *0-dB* insertion loss (S_{21}) over the bandwidth (BW) of about *50%*. Meanwhile, the return loss (S_{11}) is lower than *–40dB* with five transmission poles over the 3-dB-down BW of about *60%*. It can be understood that these poles are attributed by the first three resonant modes of the stepped-impedance line resonator as discussed in Fig. 4 and frequency-distributed coupling behavior of two PCML sections driven by low-impedance microstrip line at its either side. Next, the central microstrip line with wide strip width is further characterized as an equivalent two-port admittance network, based on our field-theoretical EM package [7-8], for accurate optimization of such a broad BPF. In final, a filter sample is fabricated and measured to provide an experimental verification on the proposed broadband BPF. Fig.6 depicts the relevant predicted and measured S-parameters of this BPF, in good agreement with each other, over the wide frequency range (*2.0* to *14.0 GHz*). But, we still can find some visible distortion for the measured S11 in the lower band within the passband and it may be caused by the intolerable effect of coupled-line conductor thickness in the two PCML sections.

V. Conclusions

In this work, a novel broadband microstrip bandpass filter with size-compactness and five transmission poles is presented by constructing a stepped-impedance line resonator. After our physical explanation on its operating mechanism is made on a basis of its equivalent circuit network, our effort is focused on the theoretical characterization of this filter structure and then experimental verification of the predicted bandpass behavior. Both predicted and measured results are in good agreement with each other, exhibiting well its broad bandwidth of about *60%* under the *3-dB*-down definition. In addition, this filter has a very compact size with the overall length shorter than one guided-wavelength at the central frequency: *f=5.7GHZ.*

References

[1] Matthaei, G., Young, L., Jones, E.M.T.: *Microwave filters, impedance matching networks, and coupling structures*. Artech House, 1980.

[2] S. B. Cohn, “Parallel-coupled transmission-line-resonator filter”, *IRE Trans. Microwave Theory Tech*., vol. MTT-6, pp.223-231, Apr., 1958.

[3] L. Zhu, H. Bu and K. Wu: “Aperture compensation technique for innovative design of ultra-broadband microstrip bandpass Filter”, *IEEE Inter. Microwave Symp. Dig.*, pp.315-318, Boston, June 2000.

[4] L. Zhu, H. Bu, K. Wu and M. S. Leong, “Miniaturized multi-pole broad-band microstrip bandpass filter: Concept And Verification,” *Proc. of 30th Eur. Microwave Conf.*, (No.: EuMC34-339), Paris, France, Oct. 3-5, 2000.

[5] W. Menzel, L. Zhu, K. Wu and F. Bogelsack, “Compact broadband planar filters”, Accepted for publication in *31th Eur. Microwave Conf.*, London, UK, Sep. 25-27, 2001

[6] M. Makimoto, S. Yamashita, “Bandpass filters using parallel coupled stripline stepped impedance resonators,” *IEEE Trans. Microwave Theory Tech.*, vol.MTT-28, no.12, pp.1413-1417, Dec. 1980.

[7] L. Zhu and K. Wu, “Unified equivalent-circuit model of planar discontinuities suitable for field theory-based CAD and optimization of M(H)MIC’s”, *IEEE Trans. Microwave Theory Tech.*, vol.MTT-47, no.9, Part I, pp.1589-1602, Sept. 1999.

[8] L. Zhu and K. Wu, “Characterization of unbounded multiport microstrip passive circuits using an explicit network-based method of moments”, *IEEE Trans. Microwave Theory Tech.*, vol.MTT-45, no.12, Part I, pp.2114-2124, Dec. 1997.