On the Design of Novel Compact Broad-Band Planar Filters

Wolfgang Menzel, *Fellow, IEEE*, Lei Zhu, *Senior Member, IEEE*, Ke Wu, *Fellow, IEEE*, and Frank Bögelsack

***Abstract*—On the basis of impedance steps and coupled-line sections as inverter circuits, novel wide-band and very compact filters are presented. The application of alternately high- and low-impedance lines presented to the connected transmission-line resonators partly reduces their lengths to a quarter-wavelength only. In addition, effective techniques are demonstrated to reduce spurious stopband resonance resulting from a remaining half-wavelength resonator. Both suspended stripline (SSL) and microstrip filters were designed, fabricated, and tested, proving this concept in an excellent way. For the prototype filters, center frequencies around 6 GHz were selected. Bandwidths are between 2.5–3.25 GHz, and insertion-loss amounts to around 0.25 dB for the microstrip filters and 0.5 dB (including the transitions to coaxial line) for the SSL filters, respectively. For the selected center frequency and on a substrate with a dielectric constant of 10.8, the smallest microstrip filter is only 15 mm $\times$5 mm in size.**

***Index Terms*—Broad-band planar bandpass filter, impedance inverter circuits, multipole resonator.**

I. INTRODUCTION

TODAY, broad-band and multiband applications are renewing the interest in the design of planar broad-band filters with low-loss and improved stopband performance. Recently, a coupling structure as shown in Fig. 1 has been proposed and investigated as an inverter element for bandpass filters [1]. With strong coupling and small size, this structure is a good candidate for very compact and broad-band filter design. It already provides one or two return-loss zeros, but its strong frequency dependence prevents the application of state-of-the art filter design procedures, and an extensive optimization procedure is necessary. Furthermore, as will be shown later, the symmetry of this structure, i.e., having the same widths of an input and output line, is not very advantageous for an advanced filter design.

In this paper, a modified approach for understanding the behavior of such a structure is presented, leading to an improved filter synthesis and new concepts for the design of very compact broad-band filters. According to the two-pole bandpass response, the structure of Fig. 1 can equally be decomposed into three different discontinuities (two impedance steps and a coupling section) and two transmission-line sections. Regarding the discontinuities as elementary impedance inverters, and the transmission-line sections as quarter-wave resonators, the whole structure, as described above, can alternatively be interpreted as a two-resonator filter. In this case, the two resonant frequencies may be overlapped or split depending on the geometrical conditions of the structure, as shown in Fig. 1. With these ideas in mind, more complex and high-performance filter structures can be conceived [2].

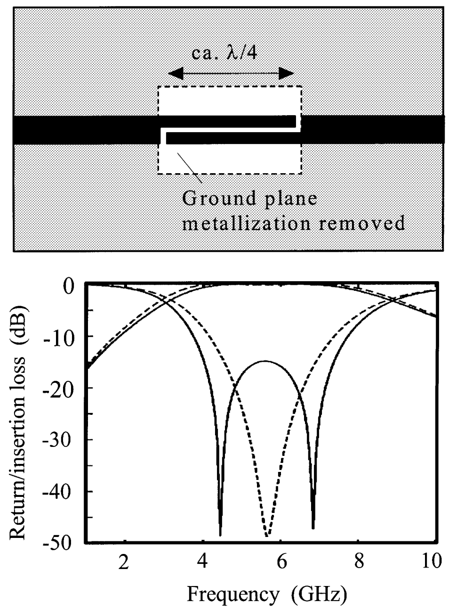


Fig. 1. Coupling/inverter structure and computed scattering parameters for two different widths of the ground plane gap (from [1]).

In Section II, a first straightforward application of the involved inverter principles is presented, resulting in both microstrip and suspended stripline (SSL) filters. The results of these filters demonstrate the feasibility of this concept; they suffer, however, from performance limitations in stopband behavior. Therefore, three different approaches are developed, investigated, and tested successfully in Section III to achieve a broad-band rejection above the passband.

II. NOVEL DESIGN OF BROAD-BAND FILTERS

Based on the considerations given above, a five-pole resonator filter, as shown in Fig. 2, can be designed. Four impedance steps—now with different geometries—and two coupling sections form six inverters, thus, this resonator filter consists of four quarter-wavelength sections and one low-impedance half-wavelength transmission line. The

Manuscript received January 8, 2002; revised July 28, 2002.
W. Menzel and F. Bögelsack are with Microwave Techniques, University of Ulm, D-89069 Ulm, Germany (e-mail: wolfgang.menzel@ieee.org).
L. Zhu is with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798 (e-mail: ezhul@ntu.edu.sg).
K. Wu is with the Department of Electrical and Computer Engineering, Ecole Polytechnique, University of Montreal, QC, Canada H3C 3A7 (e-mail: wuke@grmes.polymtl.ca).
Digital Object Identifier 10.1109/TMTT.2002.807843

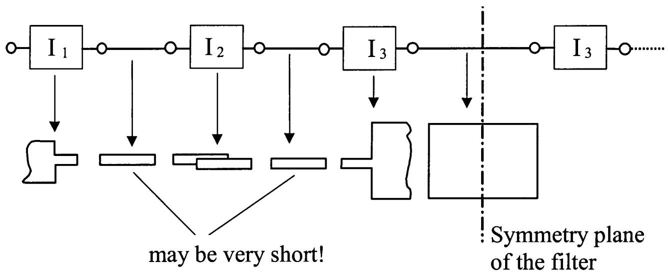


Fig. 2. Concept of the novel five-resonator filter.

quarter-wave resonators are part of the coupled-line sections; if the coupling length is close to a quarter wavelength, the remaining lengths get very small, and the filter becomes very compact.

Assuming 50-Ω external feeding lines and a minimum linewidth of 0.1 mm on a soft substrate of 0.635-mm thickness and a dielectric constant of 10.8, as used here (yielding a characteristic impedance of around 100 Ω), a minimum coupling coefficient $|S_{21}|$ of approximately -0.5 dB is possible for the impedance step forming the first inverter; therefore, only broad-band-featured filters are expected.

Preliminary designs of both microstrip and SSL filters were done on the basis of standard filter design [3] using transmission-line resonators coupled by series capacitances or shunt inductances as inverters. The discontinuities of the filter structure under investigation—impedance steps and coupling sections now acting as inverters—then are selected such that they exhibit the same $|S_{21}|$ as the respective original inverter circuits. Finally, the resonator lengths are adjusted to compensate for phase deviations of the new inverters compared to the original ones. For filters of very wide bandwidths and frequency-dependent inverter properties, this procedure provides a limited design accuracy only; therefore, it is followed by a number of optimization steps using either an in-house method of moments [4], [5] and/or a commercial simulator.[1]

The layout of a first microstrip filter fabricated on a 0.635-mm-thick substrate with a dielectric constant of 10.8 is given at the top of Fig. 3. The narrow coupled lines have a width of 0.125 mm, separated by a gap of 0.125 mm, while the center resonator has a length of 8.17 mm and a width of 4.56 mm (equivalent to a line impedance of 12.6 Ω). Consequently, the coupled-line sections are critical areas for fabrication. At the bottom of Fig. 3, theoretical and experimental scattering parameters of the filter are plotted versus frequency, and a detailed view on experimental passband insertion loss and group delay is presented in Fig. 4. Center frequency is approximately 6.0 GHz, bandwidth is approximately 3.0 GHz (50%). The theoretical return-loss curves clearly demonstrate the five-pole resonator performance of the filter. Measurements were done using a thru-reflect line (TRL) calibration with reference planes on the microstrip level. The experimental insertion loss agrees very well with theoretical prediction.

Measured insertion-loss amounts to 0.25±0.1 dB over the passband between 4.5–7 GHz. Some discrepancies between theory and experiment can be stated for the return loss. Metallization thickness (important in the coupling sections) is not included in the computation, and the small size of the filter structures and the extremely low return loss are very sensitive with respect to computation accuracy (discretization of the structure) and fabrication tolerances. For such broad-band filters, group-delay variations are also of great importance. Within the passband, maximum variation of group delay is below 0.2 ns (Fig. 4). With a length of only approximately 20 mm and a width of 5 mm, this five-resonator microstrip filter is extremely compact compared to a free-space wavelength of 50 mm at center frequency.

[1]*SONNET*, ver. 6.0a, Sonnet Software Inc., Liverpool, NY, 1999.

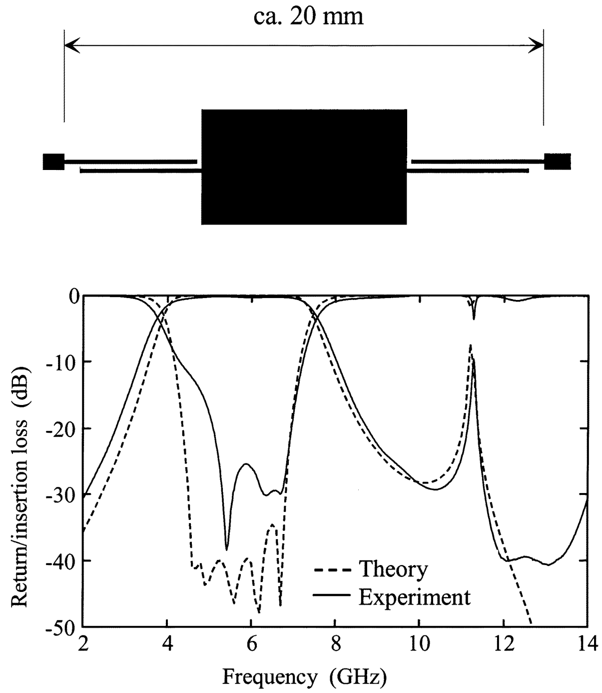


Fig. 3. Layout, theoretical, and experimental results of a first microstrip filter (width of input lines: 0.62 mm, widths of coupled lines: 0.125 mm, coupling slot: 0.125 mm, coupling length: 4.69 mm, length of first resonator: 5.33 mm, length of second resonator: 5.13 mm, width of central resonator: 4.56 mm, length of central resonator: 8.17 mm, substrate material RT Duroid 6010, substrate thickness: 0.635 mm, dielectric constant 10.8).

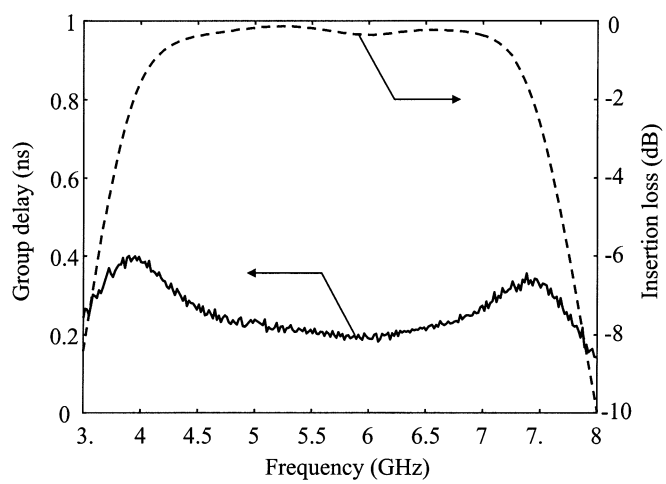


Fig. 4. Experimental insertion loss and group delay of the microstrip filter within the passband.

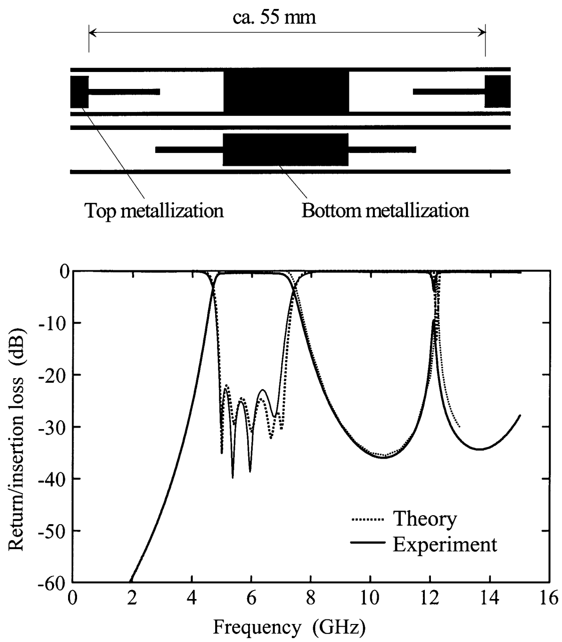


Fig. 5. Layout, theoretical, and experimental results of an SSL filter (width of input lines: 4 mm, widths of coupled lines: 0.75 mm, coupling length: 0.5 mm, length of first resonator: 9.75 mm, length of second resonator: 9.25 mm, width of central resonator: 4.5 mm, length of central resonator: 17.25 mm, substrate material RT Duroid 5880, substrate thickness: 0.254 mm, mounted in a channel 5 mm × 5 mm).

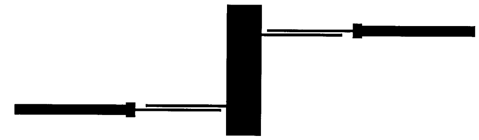


Fig. 6. Layout of the microstrip filter with the central resonator connected at the voltage minima for the full —wavelength resonance (width of input line: 0.56 mm, coupling length: 4.5 mm, length of first resonator: 5.19 mm, length of second resonator: 4.88 mm, width of central resonator: 2.06 mm, length of central resonator: 7.75 mm, remaining data as with Fig. 3).

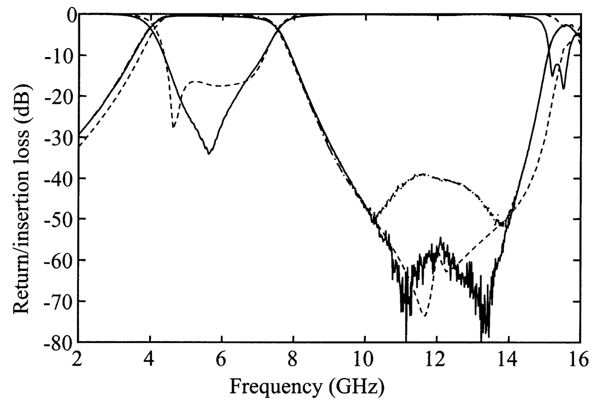


Fig. 7. Theoretical and experimental return and insertion loss of the filter according to Fig. 6 (dashed lines: theory, dashed–dotted lines: experiment without absorbers, solid lines: experiment with absorbers at the substrate edges).

As an alternative, a similar filter was realized using an SSL. SSL is well suited for filter design due to its low loss and a possibility of including broadside coupling [6]. As substrate material, a Duroid substrate of 0.254-mm thickness and a dielectric constant of 2.2 was chosen, mounted in a channel of 5 mm ×5 mm. For the coupled-line sections, a strip width of as wide as 0.75 mm yields a line impedance of as high as 150 Ω, thus lower coupling coefficients compared to the former example can be realized. Together with broadside coupling with its wide range of coupling coefficients, this leads to much more relaxed requirements for computation accuracy and fabrication tolerances. Filter layout and theoretical, as well as experimental, results for this filter are given in Fig. 5. Center frequency is again 6 GHz, bandwidth is approximately 2.5 GHz. The insertion loss over the passband is better than 0.5 dB; in contrast to the microstrip filter, however, this includes the transitions to the coaxial line test equipment. With this filter, an excellent agreement between theory and experiment for both insertion and return loss can be observed.

III. Improved Filter Design

One major disadvantage of these two filters is the spurious response at the first harmonic frequency of the passband caused by a full-wavelength resonance of the central resonator. This spurious response, however, can be removed in two ways, as will be shown in the following. The first method reduces the excitation of the full-wavelength resonance by connecting the center resonator at points where the voltage of this resonance is at a minimum. This structure will be demonstrated by two examples of microstrip filters. In the second approach, the filter is extended to six resonators with a quarter-wavelength so that no half-wavelength resonance can occur.

If a transmission-line resonator is fed at a quarter of its length away from the ends, the fundamental half-wavelength resonance is still excited, but for the full-wavelength resonance, the feed point is at a voltage zero so that the resonator is not coupled at this frequency. This is equivalent to the fact that, at twice the center frequency of the filter, the open ends of the resonator are transformed into short circuits at the feeding points, resulting in transmission zeros at the respective frequency. Therefore, this technique can be applied to suppress the first spurious passband of the microstrip filter (Fig. 6). This technique, however, has no major influence on the next spurious passband at three times the center frequency (part of this can be seen at the upper frequency limit of Fig. 7).

To allow an effective design of this filter, some quasi-lumped elements were added to the first (and last) impedance steps. In this way, very slight adjustments were possible without refining the grid in the field solver. (Similar techniques were applied to the six-resonator SSL filter presented later on.) No optimization effort, however, was made to again demonstrate the five-pole filter behavior. Theoretical and experimental results are plotted in Fig. 7. Center frequency is 6 GHz, bandwidth is 2.6 GHz. A good agreement can be seen, except for the stopband attenuation given by the dashed–dotted line. A detailed analysis revealed that the coax-to-microstrip transition launched some surface waves coupling input and output ports directly. Placing some absorbing material to the edges of the substrate, these surface waves could be suppressed, and the solid line for the insertion loss in Fig. 7 is obtained. Passband insertion loss is slightly higher than that of the first filter because the tapped coupling

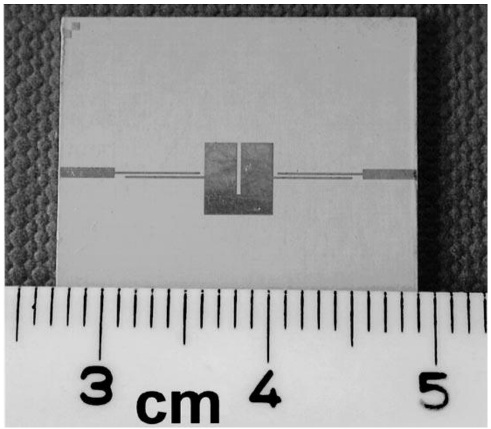


Fig. 8. Photograph of the folded microstrip filter (coupling length: 4.63 mm, length of first resonator: 5.25 mm, length of second resonator: 4.88 mm, height of central resonator: 4.5 mm, lateral dimension of central resonator: 4.25 mm, slot in central resonator: 3.25 mm × 0.25 mm, all other data as in Fig. 3).

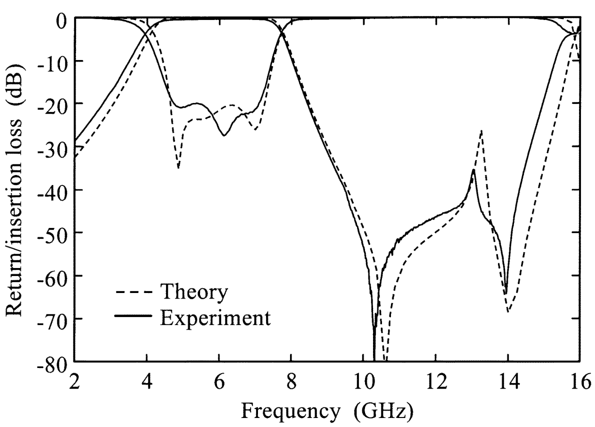


Fig. 9. Theoretical and experimental filter characteristics of the folded microstrip filter.

of the center resonator results in an increased radiation of the center half-wavelength resonator, as compared to the filter shown in Fig. 3. In addition, the filter now requires more substrate surface.

To achieve a compact size of the filter, the central resonator is folded. In addition, the electric-field lines at the ends of the resonator have opposite directions leading to a reduced radiation in this way. Once again, during the optimization of this filter, no effort was taken to reproduce the five-pole bandpass behavior. A photograph of this filter is shown in Fig. 8. With a length of approximately 15 mm only, this filter is even smaller than that first presented. A very good agreement is found between theory and experiment (Fig. 9). In the stopband region, again, some surface waves launched by the transitions to the coaxial measurement system created some problems; these, however, were reduced by absorbing material placed at the substrate edges (approximately 3–4 mm away from the filter). Center frequency is close to 6 GHz with a bandwidth of 2.8 GHz. Passband insertion loss amounts to 0.2 dB only, and a measured stopband attenuation of more than 30 dB can be found in the frequency range from 9.5 to 14.5 GHz.

To reveal the nature of the insertion loss peak around 13 GHz, current density was calculated at this frequency and compared

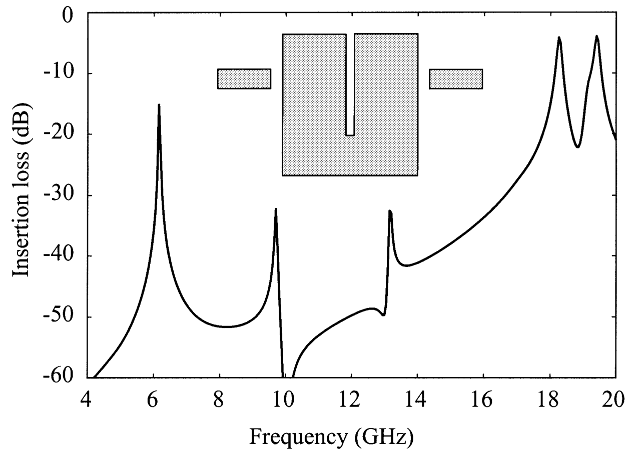


Fig. 10. Resonance behavior of the central folded microstrip resonator.

to that at center frequency of the filter. At the *outer edge* of the *two-dimensional* center resonator structure, an increased current density with 1.5 wavelength behavior is observed at 13.1 GHz, while at 6 GHz, the current density concentrates around the slot area of the resonator. In addition, resonance frequencies of this resonator were calculated separately using a weak gap coupling, resulting in resonances at 6.1, 9.7, 13.1, 18.25, and 19.5 GHz (Fig. 10). The first resonance frequency is that intended for the filter passband, the second one is suppressed due to the specific selection of the feeding point, and the remaining ones contribute to the peak at 13.1 GHz and the next higher order passband above 16 GHz.

For an alternative approach, a shunt inductance as an additional inverter is placed in the center of the former half-wavelength resonator of the filter. This inductance is realized by a (very short) short-circuited shunt stub providing a rather low impedance, compared to the quite high impedance of the next inverters (impedance steps from low to high transmission-line impedances). Thus, the resulting two new central resonators become quarter-wavelength resonators, and the next spurious response occurs at three times the passband frequency. This design is shown at the example of the SSL filter. A generalized block diagram and the layout of such a filter based on an SSL is shown in Fig. 11. Basically, this type of filter can be regarded as a half-wavelength impedance step filter [3] where series capacitances are introduced in the center of the high-impedance lines and shunt inductances in the low-impedance lines. In this way, the order of the filters is doubled, half-wavelength resonators are turned into twice the number of quarter-wavelength resonators within the same or even reduced space (when the capacitances are realized by side coupling) and, what is very important, the spurious response at twice the passband frequency is removed.

The SSL design of such a filter has been done including optimization based on SONNET. The shunt inductance in the center simply was realized by (symmetrical) shorting sections toward the edges of the mounting channel. First experimental results (plotted as the solid line in Fig. 12) were disappointing; but the problem was recognized and finally fixed. To reduce the computational effort and optimization time, the filter was designed with a substrate in an ideal quadratic waveguide channel,

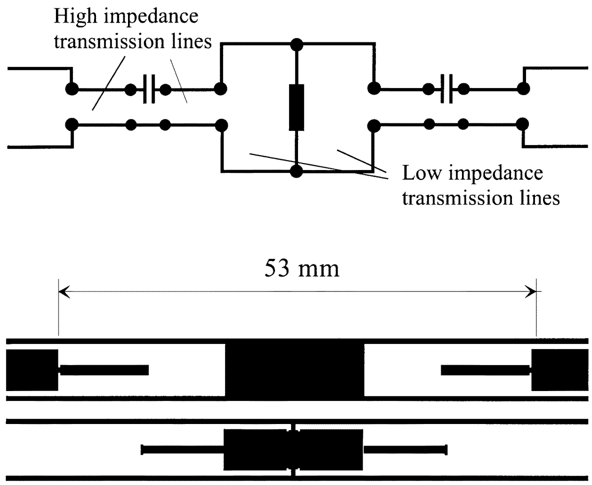


Fig. 11. Equivalent circuit and basic layout of a modified six-resonator SSL filter (width of input lines: 4 mm, width of first resonator: 1 mm, length of first resonator: 10 mm, width of second resonator: 0.75 mm, length of second resonator 2: 9.25 mm, coupling length: 0.75 mm, width of central resonator: 4.5 mm, length of central resonator: 15.5 mm, width of shorting strips 0.5 mm).

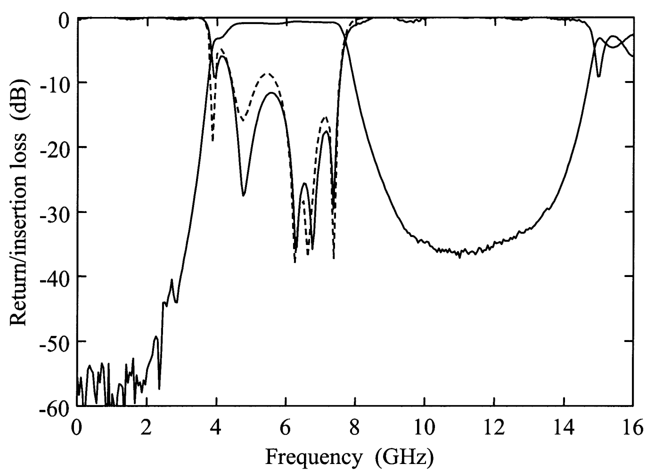


Fig. 12. Return and insertion loss of the six-resonator SSL filter including the effect of the clamping grooves (solid lines: experiment, dashed line: theory approximating the clamping grooves by longitudinal via metallization).

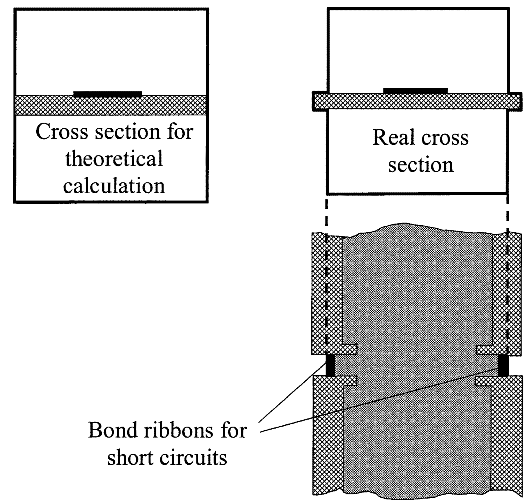


Fig. 13. Different cross sections of the SSL filter and placement of bond ribbon vias.

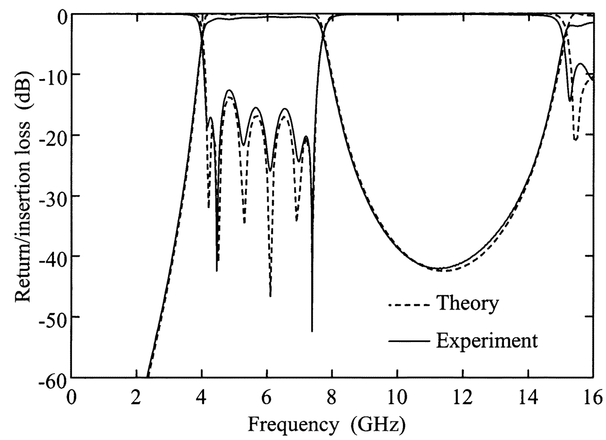


Fig. 14. Theoretical and experimental results of a modified six-resonator SSL filter.

as shown in Fig. 13 (top left). In practice, however, the substrate has to be clamped in grooves at the side of the waveguide channel (Fig. 13, top right). Consequently, the shunt inductances at the central resonator exhibit an increased inductance.

An approximate calculation of this effect was done using a wider channel for the computation and introducing longitudinal via walls at the sides. The return loss calculated with this approach is included in Fig. 12 as a dotted line. In principle, the measured performance is approximated reasonably well. Following this, the substrate was cut away in the clamping area close to the shunt inductances, and the short circuit was realized connecting bond ribbons around the substrate edges at exactly the positions as the short circuits were assumed for the original design. The measured results are plotted in Fig. 14, compared to the design curves. Center frequency is 6 GHz, bandwidth amounts to 3.25 GHz. An excellent agreement can be stated between theory and experiment. No spurious response remains at around 12 GHz, and the filter edges are steeper than before due to the additional resonator. Furthermore, this six-pole resonator filter is even smaller than its five-pole counterpart, as shown in Fig. 5.

IV. Conclusion

A new concept for wide-bandwidth filters has been presented. Alternatively, impedance steps and coupled-line sections are used as inverters. As a consequence, a five-resonator filter of this type includes one half-wavelength and four quarter-wavelength resonators, leading to a very compact filter. In a second step, the spurious passband response at twice the center frequency due to the half-wavelength resonator is removed either by contacting the center resonator at field minima for the harmonic resonance or by introducing a shunt inductance in its center, increasing the filter degree by one, and dividing the center resonator into two quarter-wavelength resonators. Design and results of four five-pole filters and one six-pole resonator filter have been presented. An excellent agreement between design and measurement, in conjunction with low loss and very compact size, is observed for the given examples.

REFERENCES

[1] L. Zhu, H. Bu, and K. Wu, "Aperture compensation technique for innovative design of ultra-broadband microstrip bandpass filter," in *IEEE MTT-S Int. Microwave Symp. Dig.*, Boston, MA, June 1999, pp. 315–318.

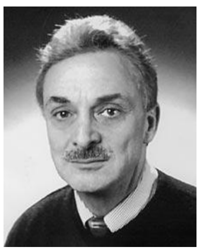
[2] W. Menzel, L. Zhu, K. Wu, and F. Bögelsack, "Compact broadband planar filters," in *31st Eur. Microwave Conf.*, vol. 2, London, U.K., Sept. 2001, pp. 41–44.

[3] G. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance Matching Networks, and Coupling Structures*. Norwood, MA: Artech House, 1980.

[4] 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.*, pt. I, vol. 47, pp. 1589–1602, Sept. 1999.

[5] ——, "Characterization of unbounded multiport microstrip passive circuits using an explicit network-based method of moments," *IEEE Trans. Microwave Theory Tech.*, vol. 45, pp. 2114–2124, Dec. 1997.

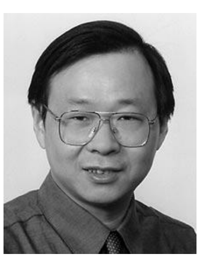
[6] W. Schwab, F. Bögelsack, and W. Menzel, "Multilayer suspended stripline and coplanar line filters," *IEEE Trans. Trans. Microwave Theory Tech.*, vol. 42, pp. 1403–1407, July 1994.



Wolfgang Menzel (M'89–SM'90–F'01) received the Dipl.-Ing. degree in electrical engineering from the Technical University of Aachen, Aachen, Germany, in 1974, and the Dr.-Ing. degree from the University of Duisburg, Duisburg, Germany, in 1977.

From 1979 to 1989, he was with the Millimeter-Wave Department, AEG, Ulm, Germany [now the European Aerospace, Defense, and Space Systems, (EADS)]. From 1980 to 1985, he was Head of the Laboratory for Integrated Millimeter-Wave Circuits. From 1985 to 1989, he was Head of the entire Millimeter-Wave Department. During that time, his areas of interest included planar integrated circuits (mainly on the basis of fine-line techniques), planar antennas, and systems in the millimeter-wave frequency range. In 1989, he became a Full Professor with the University of Ulm, Ulm, Germany. His current areas of interest are multilayer planar circuits, waveguide filters and components, antennas, millimeter-wave and microwave interconnects and packaging, and millimeter-wave application and system aspects.

Dr. Menzel is currently an associate editor for the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES. From 1997 to 1999, he was a Distinguished Microwave Lecturer for Microwave/Millimeter Wave Packaging. From 1997 to 2001, he chaired the German IEEE Microwave Theory and Techniques (MTT)/Antennas and Propagation (AP) Chapter.



Lei Zhu (S'91–M'93–SM'00) was born in Wuxi, Jiangsu Province, China, in June 1963. He received the B.Eng. and M.Eng. degrees in radio engineering from the Nanjing Institute of Technology (now Southeast University), Nanjing, China, in 1985 and 1988, respectively, and the Ph.D. Eng. degree in electronic engineering from the University of Electro-Communications, Tokyo, Japan, in 1993.

From 1985 to 1989, he studied a variety of millimeter-wave passive and active circuits, and leaky-wave antennas using the grooved nonradiative dielectric waveguide (GNRD). From 1989 to 1993, he conducted research on the full-wave characterization and optimization design of planar integrated transmission lines and components. From 1993 to 1996, he was a Research Engineer with Matsushita-Kotobuki Electronics Industries Ltd., Tokyo, Japan, where he undertook research and development in the development of planar integrated antenna elements and arrays with compact-size and high radiation gain/efficiency for application in wireless communications. From 1996 to 2000, he was a Research Fellow with Ecole Polytechnique de Montréal, Montréal, QC, Canada. Since July 2000, he has been an Associate Professor with the School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore. His current research works/interests include the study of planar integrated dual-mode filters, ultra-broad bandpass filters, broad-band interconnects, planar antenna elements/arrays, uniplanar coplanar waveguide (CPW)/coplaner stripline (CPS) circuits, as well as full-wave three-dimensional (3-D) method of moments (MoM) modeling of planar integrated circuits and antennas, numerical deembedding or parameter-extraction techniques, and field-theory-based computer-aided design (CAD) synthesis/optimization design procedures.

Dr. Zhu is currently a member of the editorial board of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES. He was the recipient of the Japanese Government (Monbusho) Graduate Fellowship (1989–1993). He was also the recipient of the 1993 First-Order Achievement Award in Science and Technology presented by the National Education Committee, China, the 1996 Silver Award of Excellent Invention presented by the Matsushita-Kotobuki Electronics Industries Ltd., Japan, the 1997 Asia–Pacific Microwave Prize Award presented at the Asia–Pacific Microwave Conference, Hong Kong, and the 2002 Japan Society for the Promotion of Science (JSPS) Invitation Fellowship for Research in Japan from the Japan Society for the Promotion of Science.

Ke Wu (M'87–SM'92–F'01) was born in Liyang, Jiangsu Province, China. He received the B.Sc. degree in radio engineering (with distinction) from the Nanjing Institute of Technology (now Southeast University), Nanjing, China, in 1982, and the D.E.A. and Ph.D. degrees in optics, optoelectronics, and microwave engineering (with distinction) from the Institut National Polytechnique de Grenoble (INPG), Grenoble, France, in 1984 and 1987, respectively.

He conducted research in the Laboratoire d'Electromagnetisme, Microondes et Optoelectronics (LEMO), Grenoble, France, prior to joining the Department of Electrical and Computer Engineering, University of Victoria, Victoria, BC, Canada. He subsequently joined the Department of Electrical and Computer Engineering, Ecole Polytechnique de Montréal (Faculty of Engineering, University of Montréal) as an Assistant Professor, and is currently a Full Professor and Tier-I Canada Research Chair in Radio-Frequency and Millimeter-Wave Engineering. He has been a Visiting or Guest Professor at Telecom-Paris, Paris, France, and INP-Grenoble, Grenoble, France, the City University of Hong Kong, the Swiss Federal Institute of Technology (ETH-Zurich), Zurich, Switzerland, the National University of Singapore, Singapore, the University of Ulm, Ulm, Germany, as well as many short-term visiting professorships with other universities. He also holds an honorary visiting professorship at the Southeast University, Nanjing, China, and an honorary professorship at the Nanjing University of Science and Technology, Nanjing, China. He has been the Head of the FCAR Research Group of Quebec on RF and microwave electronics, the Director of the Poly-Grames Research Center, as well as the Founding Director of the newly developed Canadian Facility for Advanced Millimeter-Wave Engineering (FAME). He has authored or coauthored over 320 referred papers, and also several book chapters. His current research interests involve hybrid/monolithic planar and nonplanar integration techniques, active and passive circuits, antenna arrays, advanced field-theory-based computer-aided design (CAD) and modeling techniques, and development of low-cost RF and millimeter-wave transceivers. He is also interested in the modeling and design of microwave photonic circuits and systems. He serves on the Editorial Board of *Microwave and Optical Technology Letters*.

Dr. Wu is a member of the Electromagnetics Academy. He has held many positions in and has served on various international committees, including the vice chairperson of the Technical Program Committee (TPC) for the 1997 Asia–Pacific Microwave Conference, the general co-chair of the 1999 and 2000 SPIE International Symposium on Terahertz and Gigahertz Electronics and Photonics, and the general chair of 8th International Microwave and Optical Technology (ISMOT'2001). He has served on the Editorial or Review Boards of various technical journals, including the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, the IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, and the IEEE MICROWAVE AND GUIDED WAVE LETTERS. He served on the 1996 IEEE Admission and Advancement (A&A) Committee, the Steering Committee for the 1997 joint IEEE Antennas and Propagation Society (IEEE AP-S)/URSI International Symposium. He has also served as a TPC member for the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) International Microwave Symposium. He was elected into the Board of Directors of the Canadian Institute for Telecommunication Research (CITR). He served on the Technical Advisory Board of Lumenon Lightwave Technology Inc. He is currently the chair of the joint IEEE chapters of MTT-S/AP-S/LEOS in Montréal, QC, Canada. He was the recipient of a URSI Young Scientist Award, the Institute of Electrical Engineers (IEE), U.K., Oliver Lodge Premium Award, the Asia–Pacific Microwave Prize Award, the University Research Award "Prix Poly 1873 pour l'Excellence en Recherche" presented by the Ecole Polytechnique de Montréal on the occasion of its 125th anniversary, and the Urgel-Archambault Prize (the highest honor) in the field of physical sciences, mathematics, and engineering from the French–Canadian Association for the Advancement of Science (ACFAS). In 2002, he was the first recipient of the IEEE MTT-S Outstanding Young Engineer Award. He was inducted as a Fellow of the Canadian Academy of Engineering (CAE) in 2002.

Frank Bögelsack received the Dipl.-Ing. degree in electrical engineering from the Technical University of Baunschweig, Baunschweig, Germany, in 1983, and the Dr.-Ing. degree in microwave technique from the University of Duisburg, Duisburg, Germany, in 1989.

From 1984 to 1989, he was with the Institute of Electromagnetic Theory and Engineering, University of Duisburg, where he was engaged in numerical computation of electromagnetic fields applied to microstrip discontinuity problems. His current research and teaching interests include electromagnetic theory, computer methods in electromagnetism, and microwave measurements.