# Compact Pseudo-Highpass Filters Formed by Cavity and Iris Resonators

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*Abstract* — **A new class of broadband waveguide filters for pseudo-highpass applications is presented. The cavities are initially designed for $TM_{110}$-mode operation with $TE_{10}$-mode bypass coupling to create transmission zeros below the passband. The broadband characteristic is achieved by utilizing the coupling irises as additional resonances, thus achieving a pseudo-highpass operation with a minimum of physical cavities. Several designs for passbands starting at around 10 and 12 GHz are presented, and bandwidths of up to 41 percent are achieved. The design process allows for implementation of either vertical or horizontal (inline) I/O ports. Both types are verified by measurements.**

## I. Introduction

Waveguide feed systems frequently require highpass filters, either in diplexer applications or as stand-alone components. The highpass or pseudo-highpass characteristics can be achieved by employing waveguide sections below cutoff, e.g. [1], [2], or using bandpass filters with wide passbands, e.g. [3] – [5]. In the latter category, the incorporation of cross-couplings to create transmission zeros can be used to increase the skirt selectivity of pseudo-highpass filters.

Recently, the design of bandpass filters utilizing $TM_{110}$-mode cavities and $TE_{10/01}$-mode bypass couplings was presented [6]. Based on this principle but, in addition, utilizing the resonances of coupling irises, e.g. [7], this paper focuses on a new class of wideband, pseudo-highpass filters. The advantages of this design are:

- fewer than half of the resonators are formed by actual cavities - this contributes to a compact design;
- transmission zeros are easily implemented - this results in an improved highpass performance;
- input/output ports can be inline or vertical - this permits a flexible implementation of these filters.

Fig. 1 depicts the basic arrangement of cavities and their connection to either vertical or horizontal (inline) input/output waveguide ports.

## II. Theoretical Approach

The basic design concept for inline $TM_{110}$-mode cavities including their capability to each create an individual transmission zero at finite frequencies is discussed in [6] and will not be repeated here. For accuracy and speed of the computer-aided design process, we are using the Coupled-Integral-Equations Technique (CIET) [8] for the inline portion of the filter. For the vertical input/output ports, the waveguide corners are presented by a down-scaled (two-port) version of the Mode-Matching Technique (MMT) originally developed for the waveguide six-port cross junction [9]. Optimization is carried out using a minimax-based algorithm, e.g. [10], on the error function

$$F=\sum_{i=1}^{n_s}\frac{G_{IL}(f_i)}{IL(f_i)}+\sum_{i=1}^{n_p}\frac{G_{RL}(f_i)}{RL(f_i)} \qquad (1)$$

where $n_s$ and $n_p$ are the number of frequency samples in the stopband and passband, respectively; $G_{IL}$ and $G_{RL}$ are the goal values for insertion loss and return loss and IL and RL their actual values during optimization. Note that the goal function is met as soon as each term in (1) is less than unity.

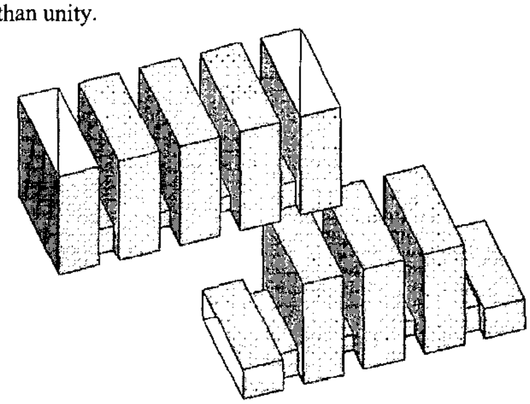


Fig. 1 Broadband waveguide filters for pseudo-highpass applications with vertical or horizontal input/output ports.

Initial dimensions for the three-cavity designs shown in Fig. 1 are derived from the guidelines in [6]. The non-resonating $TE_{10}$ mode is used to produce bypass coupling of the $TM_{110}$-mode resonators. Therefore, the design will produce three individual transmission zeros below the passband of the filter [6]. Subsequently, the coupling irises are chosen such that their resonance frequencies fall within the upper portion of the passband. Cavity and iris dimensions are then optimized to satisfy the goal function specified in (1) for a given number of frequency samples.

## III. Results and Discussion

### A. Vertical I/O Ports

Our first design is a pseudo-highpass filter for a 30 dB return-loss bandwidth of only 300 MHz beyond 10.04 GHz. The computed performance is shown as solid lines in Fig. 2. The three $TM_{110}$-mode resonances as well as the three transmission zeros below the passband are clearly visible. In order to verify this design, a prototype component was built and measured. The results are also shown in Fig. 2 (dashed lines). Without any tuning, excellent agreement with the predicted performance is obtained down to the measurement capability of approximately 70 dB.

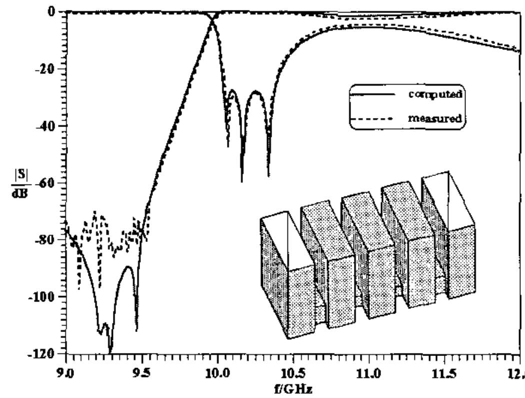



Fig. 2 Measured and computed performance of three-cavity $TM_{110}$-mode pseudo-highpass filter with verical input/output ports.

In order to enlarge the passband of this design without increasing the physical size of the filter, the two outermost irises were used as additional resonators. The resulting performance of the five-pole filter is shown as solid lines in Fig. 3, and it agrees well with results obtained from commercial software packages. The agreement between our results and those of the μWave Wizard© (dotted lines in Fig. 3) is excellent. The differences to HFSS (dash-dotted lines) are in an order of magnitude previously observed between HFSS and integral-equations-based filter analyses. Although the number of physical resonators remains at three, the additional two iris resonances enlarge the bandwidth to 35 percent.

### B. Inline I/O Ports

If the initial requirement for vertical input/output ports is dropped, a similar filter characteristic can be achieved with inline interfaces. The response shown in Fig. 4 utilizes three $TM_{110}$-mode resonators plus the resonances of all four irises. The performance of this seven-pole pseudo-highpass filter is shown as solid lines in Fig. 4 and is verified by the μWave Wizard© (dashed lines). Excellent agreement is obtained down to a minimum return loss of 26 dB over the entire filter bandwidth of 36 percent. Note that the inline configuration of Fig. 4 is slightly more compact than the one with vertical ports in Fig. 3. Between the interface waveguides at the input and output, the inline configuration spans 19.06mm x 18.67mm x 21.27mm versus 19.06mm x 19.69mm x 26.36mm for the one with vertical ports.

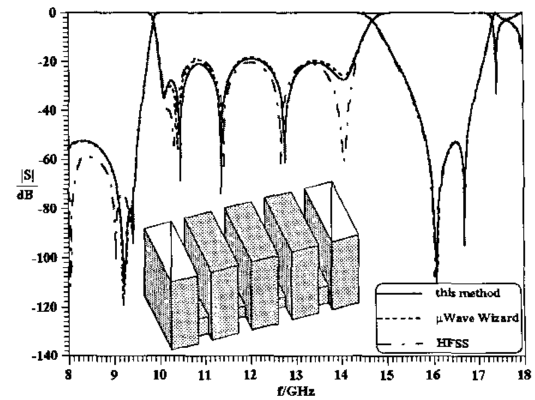



Fig. 3 Broadband pseudo-highpass performance of filter structure with vertical input/output ports; three cavity and two iris resonances are used.

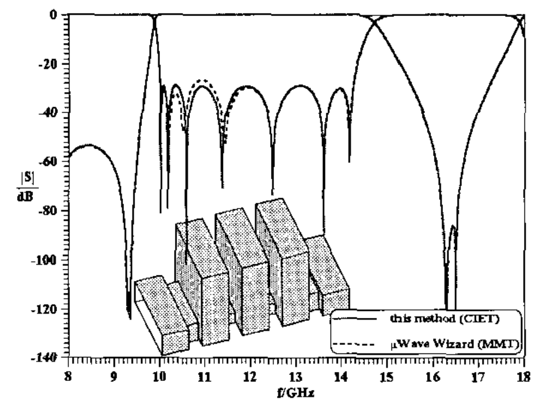


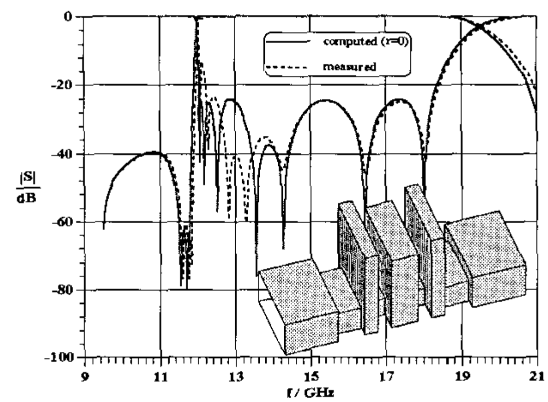

Fig. 4 Broadband pseudo-highpass performance of filter structure with horizontal (inline) input/output ports; three cavity and four iris resonances are used.

All designs presented so far (Figs. 2, 3, 4) utilize WR75 waveguide with reduced height (b=0.25a) for the port dimensions as specified by the requirements for the particular application. Due to possible $TE_{20}$-mode ($f_c$=15.7 GHz) excitation elsewhere in the circuit, the structures in Figs. 3 and 4 were investigated with respect to its $TE_{20}$-mode performance. The attenuation is better than 80 dB up to 17 GHz, with two very narrow passband peaks appearing between 17.1 and 17.5 GHz. Since this is well beyond the pseudo-highpass bandwidth, this issue is of no concern to the design of these components.

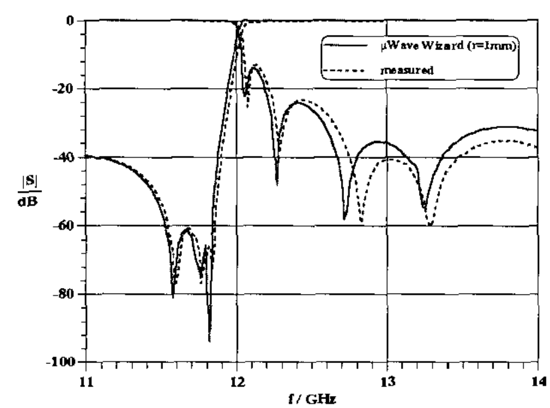
For experimental verification of the seven-pole inline configuration, the structure in Fig. 4 was redesigned for Ku-band application with standard ports (b=0.5a) and a roll-off frequency of 12 GHz.

Fig. 5a compares the optimized response with measured results. Measurements were performed in three different waveguide bands (X-, Ku- and K-band) utilizing waveguide transformers (for X- and K-band)

and separate calibrations in all three bands. Excellent agreement is achieved below 12 GHz and above 14 GHz. The discrepancy between design and measurements in the 12-to-14-GHz range is attributed to the 1mm-radius of the end-mill cutter, which was not included in the original design. Fig. 5b shows an enlargement of the frequency range in question and compares the measured results with a μWave-Wizard© analysis including the radius of 1 mm. Very good agreement is obtained. Moreover, measurements and computations in Figs. 5a and 5b confirm not only the seven return-loss poles created by the three $TM_{110}$-mode cavities and the four irises but also the three transmission zeros below the passband caused by the $TE_{10}$-mode bypass couplings of the cavities [6]. This is a verification of the design process for compact pseudo-highpass filters. The prototype achieves a minimum return loss of 23 dB over a frequency range of 12.21 – 18.35 GHz (41 percent). The measured insertion loss in this frequency range is less than 0.02 dB.




(a)




(b)

Fig. 5 Comparison between calculated and measured responses of broadband pseudo-highpass filter with inline I/O ports;
(a) measured and calculated results using the CIET and neglecting the end-mill cutter radius;
(b) measured and calculated results using the μWave Wizard with radius r=1mm.

Fig. 6 shows photographs of the machined Ku-band pseudo-highpass filter and its components. Two symmetric parts of the lower right structure were joined to produce the upper left component, which was then completed by the lid (lower left) to form the final filter (upper right). The overall length of this filter, including 10 mm of Ku-band waveguide at the input and output, is only 46 mm.

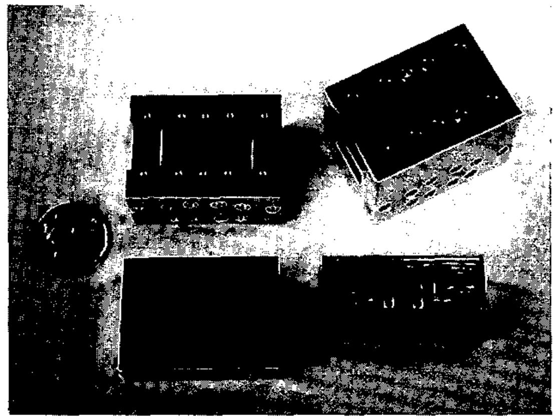


Fig. 6 Photograph of the Ku-band pseudo-highpass waveguide filter (upper right), its individually machined components and size comparison to a 1-Swiss-Franc coin.

## VI. Conclusion

The new class of broadband waveguide filters presented in this paper is suitable for compact pseudo-highpass applications. By utilizing three $TM_{110}$-mode and four iris resonances, a 41 percent bandwidth is obtained with only three physical cavities. Moreover, due to the operation with $TM_{110}$-mode cavities, transmission zeros can be placed close to the lower band edge and, therefore, increase the skirt selectivity of the pseudo-highpass filter. The measured prototypes verify the design process and confirm the number of return-loss poles as well as the number and locations of the transmission zeros.

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## References


[1] C.C.H. Tang, "Nonuniform waveguide high-pass filters with extremely steep cutoff," IEEE Trans. Microwave Theory Tech., Vol. 12, pp. 300 -309, May 1964.

[2] F.C. Medeiros, "A wideband millimetre wave multiplexer," IEE Colloquium Microwave Filters and Multiplexers, pp. 3/1 -3/4, Nov 1990.

[3] S.B. Cohn, "Design relations for the wide-band waveguide filter," Proc. IRE, pp. 799-803, July 1950.

[4] G.L. Matthaei, "Design of wide-band (and narrow-band) band-pass microwave filters on the insertion loss basis", IRE Trans. Microwave Theory Tech., Vol. MTT-8, pp. 580-593, Nov. 1960.

[5] D.A. Leedom and G.L. Matthaei, "Bandpass and pseudo-high-pass quasi-optical filters," IEEE Trans. Microwave Theory Tech., Vol. MTT-18, pp. 253–259, May 1970.

[6] U. Rosenberg, S. Amari and J. Bornemann, "Inline $TM_{110}$-mode filters with high design flexibility by utilizing bypass couplings of non-resonating $TE_{10/01}$ modes," IEEE Trans. Microwave Theory Tech., Vol. 51, pp. 1735-1742, June 2003.

[7] U. Rosenberg, S. Amari and J. Bornemann, "Mixed-resonance compact in-line pseudo-elliptic filters," in 2003 IEEE MTT-S Int. Microwave Symp. Dig., pp. 479-482, Philadelphia, USA, June 2003.

[8] J. Bornemann, U. Rosenberg, S. Amari and R. Vahldieck, "Edge-conditioned vector basis functions for the analysis and optimization of rectangular waveguide dual-mode filters," IEEE MTT-S Int. Microwave Symp. Dig., pp. 1695-1698, Anaheim, USA, June 1999.

[9] J. Bornemann and J. Uher, "Modal analysis and design of the dual-band orthomode junction," Proc. ANTEM 2002, pp. 303-306, Montreal, Canada, July/Aug. 2002.

[10] K. Madsen, H. Schaer-Jacobsen and J. Voldby, "Automated minimax design of networks," IEEE Trans. Circuits Systems, Vol. CAS-22, pp. 791-796, Oct. 1975.