A Capacitively Coupled Waveguide Filter with Wide Stop-Band

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ABSTRACT — **Concept, design and results of waveguide filter with improved stop-band performance are presented. The usual spurious pass bands of standard waveguide filters are suppressed incorporating low-pass filter structures into the coupling elements of the filter. Both a two and three resonator filters have been designed at 35 GHz. With the three resonator filter, a harmonic frequency rejection of (theoretically) more than 120 dB can be achieved.**

I. INTRODUCTION

Standard metal waveguide filters often suffer from poor stop-band behavior. Typical resonator length in such filters is λ/2. Due to the waveguide dispersion the λ resonance occurs at frequencies of 1.6 … 1.7 times the center frequency only (Fig. 1).

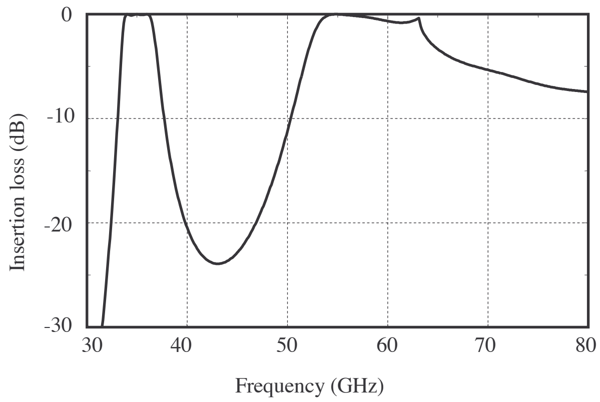

Fig. 1: Typical insertion loss behaviour of an iris-coupled waveguide filter (WR28 waveguide).

Consequently, for applications like harmonic suppression of oscillator or multiplier circuits, such filters can be applied only together with additional low-pass filters. Improvements are possible based on evanescent mode filters [1], or some designs use lossy elements connected via waveguide sections with cut-off frequencies slightly above the filter passband [2, 3]. Some improvements can be achieved, too, using impedance stepped resonators [4]. Recently, a method has been presented which includes low-pass filter elements in the filter inverters [5]. This techniques is applied in this paper, replacing each inverter or iris of the waveguide filter by short low-pass filter sections as described in [6]. Depending on these filter sections, wide stop-band performance can be achieved. This is demonstrated at the example of two Ka-band filters at 35 GHz.

II. GENERAL DESIGN PROCEDURE

The starting arrangement for the test filters consists of half-wavelength resonators with capacitive shunt coupling. The coupling elements then are replaced by a small low-pass filter arrangement. Each low-pass filter was designed to have, at the center frequency of the filter, the same insertion loss magnitude $|s_{21}|$ as the original coupling capacitor; the phase angles later on are adjusted by correcting the lengths of the adjacent resonators.

All waveguide structures including the final filters were calculated using a mode matching technique. Assuming an excitation of discontinuities and the complete filter with the TE_{10} mode, and extending the capacitive irises over the complete waveguide width, only TE_{1n} and TM_{1n} modes have to be included into the calculations, leading to an efficient and fast computation.

III. TWO-RESONATOR FILTER

A very simple low-pass structure as shown in Fig. 2 was used for the first filter design. The insertion loss of the two different low-pass filters sections is plotted in Fig. 3, the center frequency is indicated by the dotted line.

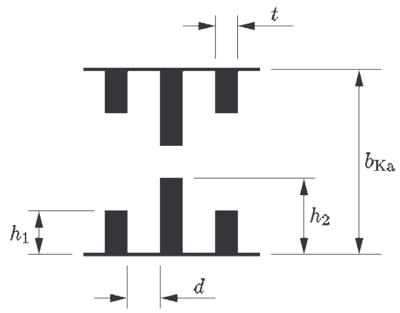

Fig. 2: Cross section of a filter inverter realized as a low-pass filter (b_{Ka} = 3.56 mm, t = 0.5 mm, d = 1.1 mm, h_1 = 0.65 mm/0.2 mm, h_2 = 1.41 mm/1.48 mm; the two numbers for h_1 and h_2 relate to the outer and inner inverters of the filter, respectively.

A high attenuation can be observed for the low-pass structure replacing the outer inverters up to frequencies of 80 GHz (and above). The second structure, however, provides only a moderate low-pass filtering performance. According to the longitudinal extension of the new coupling sections, the resonator themselves become shorter than usual.

To compensate for the different frequency dependencies of the low-pass structures compared to the original inverters, an optimization of the complete filter was done using the mode matching procedure as mentioned above. The resonator lengths thus were determined to 2.6 mm each, the final dimensions of the low-pass inverters are given in Table I (see Fig. 2 for the definition of the quantities).

	Outer inverter	Center inverter
h_1	0.84 mm	0.2 mm
h_2	1.5 mm	1.47 mm
d	1.1 mm	1.1 mm
t	0.5 mm	0.5 mm

TABLE I
Dimensions of the low-pass filter elements for the two-resonator filter.

The resulting filter structure was fabricated using four separate parts – two side plates and two comb-like parts including the filter/low-pass irises – and screwed together. A photograph of the filter with one of the side plates removed is shown in Fig. 4.

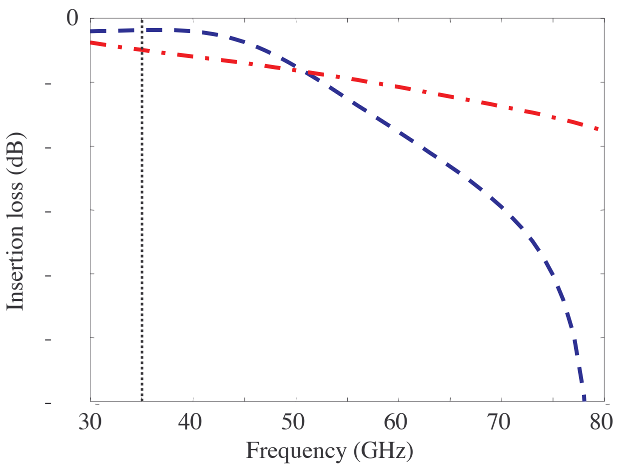

Fig. 3: Insertion loss behavior of the two low-pass structures for the two-resonator filter (dashed line: outside coupling sections, dash-dotted line: center coupling section). At the center frequency of the filter, the insertion loss should be equal to that of the respective ideal inverter.

The filter performance is plotted in Figs. 5 and 6 around the center frequency and in a wider band, respectively. Minimum passband insertion loss is 0.25 dB. Excellent agreement between theory and experiment can be stated in both figures. Above about 50 GHz, measurement results are limited due to the noise floor of the scalar network analyzer, and higher order modes excited at the filter start to form resonances in the Ka-band waveguide, reflected in the taper to the V-band waveguide of the measurement system. Spurious responses occur around 48 GHz and 51 GHz, but at the first harmonic frequency of the filter, an attenuation of more than 80 dB are achieved.

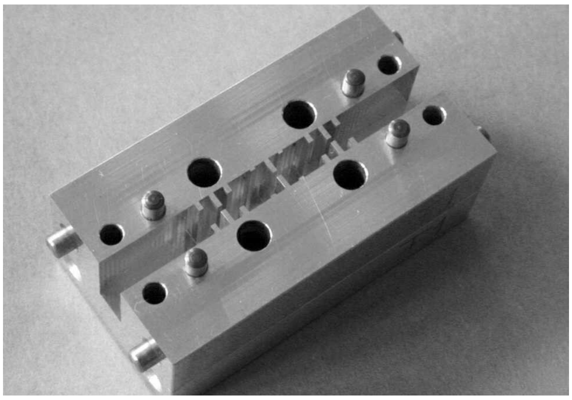

Fig. 4: Photograph of the realized waveguide filter with one side part removed.

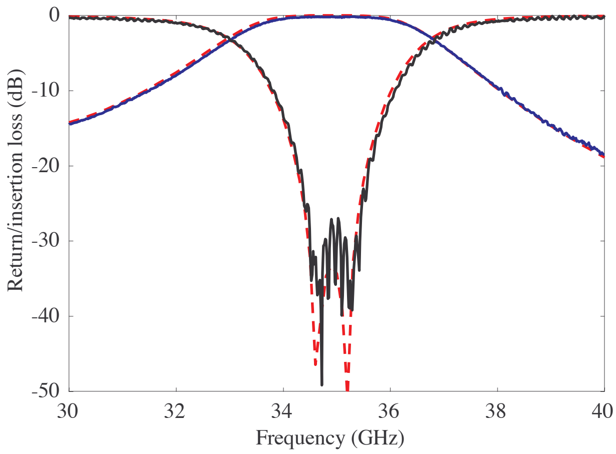

Fig. 5: Theoretical (dashed lines) and experimental (solid lines) results for the two-resonator filter around the passband.

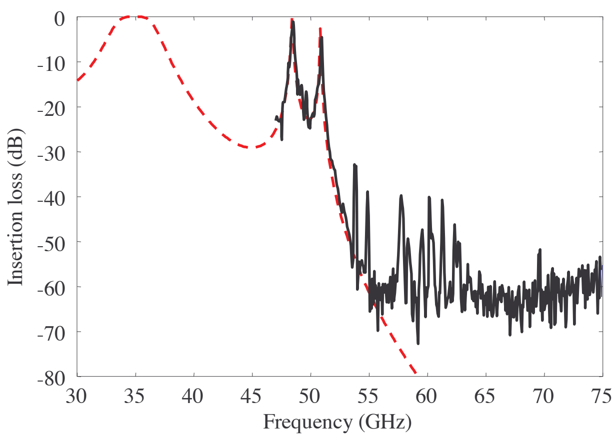

Fig. 6: Theoretical (dashed line) and experimental (solid line) insertion loss for the two-resonator filter up to 75 GHz.

VI. Three-Resonator Filter

To improve the filter performance and to avoid the spurious responses as seen above, a new filter design was made based on three resonators and low-pass type inverters with four irises each, as shown in Fig. 7. Both inner and outer inverters of the filter now exhibit a pronounced low-pass behavior as shown in Fig. 8.

Due to the low-pass characteristic of the coupling elements, some problems occur with the filter performance for frequencies below the center frequency. To improve this performance, as with the two-resonator filter, an optimization of the complete filter was done using mode-matching computations.

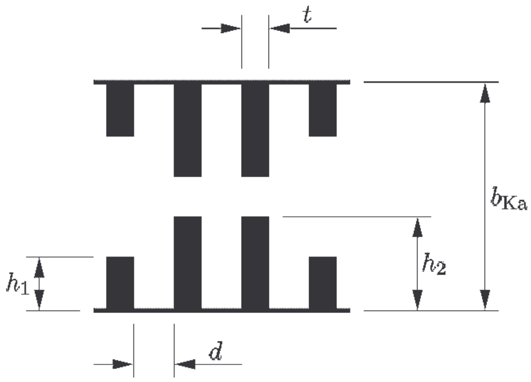

Fig. 7: Cross section of a filter inverter realized as a low-pass filter with four irises.

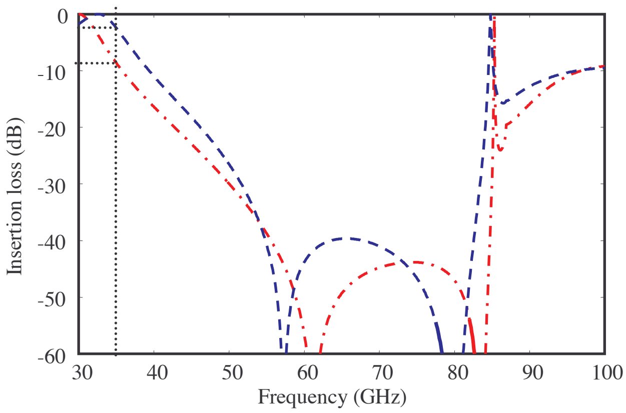

Fig. 8: Insertion loss behavior of the two low-pass structures (dashed line: outside coupling sections, dash-dotted line: center coupling sections). At the center frequency of the filter, the insertion loss should be equal to that of the respective ideal inverter.

The final dimensions of the irises are given in Table II, the resonator lengths were determined to 0.74 mm and 0.64 mm, respectively. In this case, the resonators are even shorter than with the first example, and in principle, some kind of "modulated" periodic structure results.

The resulting filter was fabricated and assembled in the same way as with the first example. A photograph is shown in Fig. 9. Measurements were done both around the filter passband as well as at selected higher frequencies to prove the stop-band behavior. Theoretical and experimental passband return and insertion loss is shown in Fig. 10. As can be seen from the results, the quasi-periodic structure of the filter introduced a fourths return loss pole. Theory and experiment show an excellent agreement. Insertion loss is between 0.6 dB and 1 dB, including the effects of the -10 dB return loss.

	Outer inverters	Interior inverters
h_1	0.54 mm	0.44 mm
h_2	1.54 mm	1.56 mm
d	0.57 mm	0.57 mm
t	0.5 mm	0.5 mm

Table II
Dimensions of the low-pass filter elements for the three-resonator filter (see Fig. 7 for the definition of the quantities).

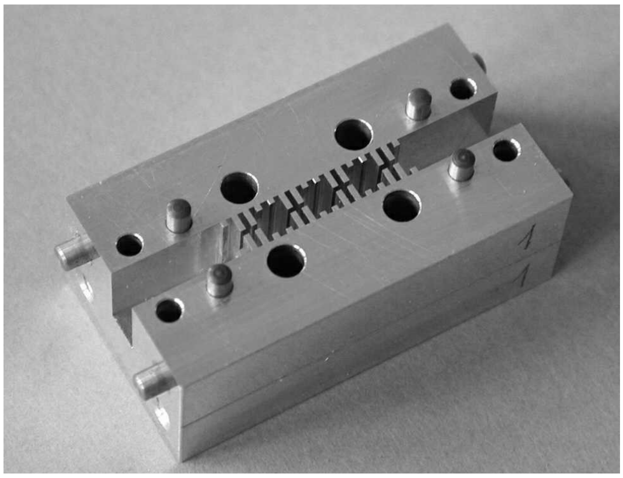

Fig. 9: Photograph of the realized waveguide filter with one side part removed.

Further measurements have been done in the 50 – 75 GHz and 80 – 110 GHz range (Fig. 11). Some problems occurred in the 75 GHz to 80 GHz range, therefore, these results were omitted. The noise floor of the scalar measurements is -60 dB to -50 dB. The sharp peak at about 52 GHz cannot be seen in the measurement, apparently, this resonance is associated with a high Q and attenuated strongly even due to slight circuit losses only. The spurious passband at 85 GHz (see the low-pass filter performance, Fig. 8) and the complete filter performance up to 110 GHz match well with theory. The strong ripple of the measured results in the W-band stems from standing waves at higher order modes (TE_{11} and TM_{11}) excited at the filter discontinuities (Ka-band wave-guide!) and reflected at the tapers used for measurement (Ka- to W-band).

VI. CONCLUSION

Design and performance of 35 GHz waveguide filters have been demonstrated providing improved stop-band attenuation due to low-pass filter structures integrated into the coupling elements of the filters. The three-resonator filter shows a good stopband attenuation up to 83 GHz; a first harmonic passband rejection of theoretically more than 120 dB results for this relatively wide-band three-resonator filter. Further improvements are possible using reduced size low-pass elements.

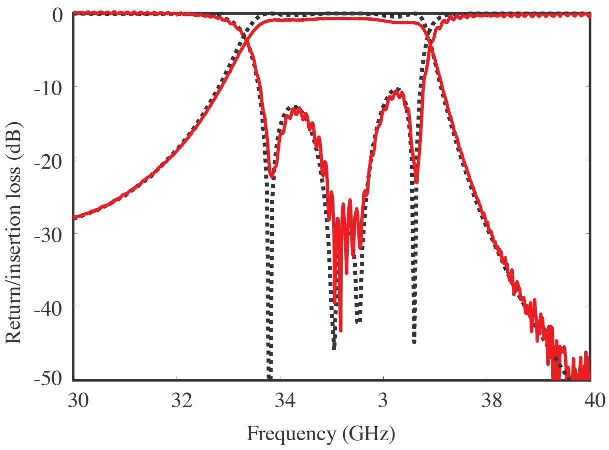

Fig. 10: Theoretical (dotted lines) and experimental (solid lines) insertion and return loss of the realized filter around the center frequency.

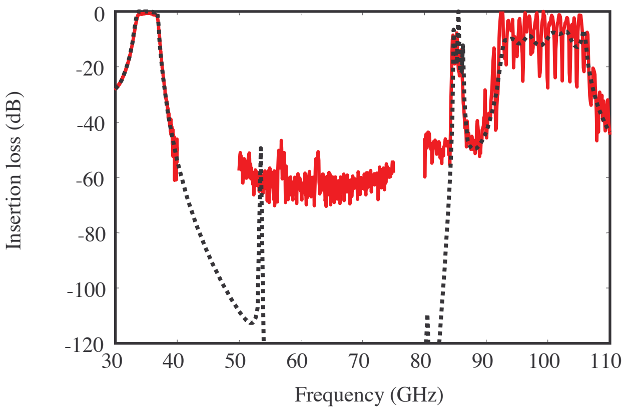

Fig. 11: Wideband theoretical (dotted lines) and experimental (solid lines) insertion loss of the realized filter.

REFERENCES

[1] R.V. Snyder. "Broadband Waveguide Filters with Wide Stopbands Using a Stepped-Wall Evanescent Mode Approach." IEEE International Microwave Symposium 1983, pp. 151-153.

[2] B.M. Schiffman, G.L. Matthaei and L. Young. "A Rectangular-Waveguide Filter Using Trapped-Mode Resonators." Transactions on Microwave Theory and Techniques, Vol. MTT-13, Sept. 1965, pp. 575-580.

[3] Menzel, J. Machac. "Waveguide bandpass filters with attenuation of higher-order pass bands." 23rd Europ. Microw. Conf., 1993, Madrid, Spain, pp. 606-607.

[4] M. Makimoto and S. Yamashita. "Bandpass Filters Using Parallel Coupled Stripline Stepped Impedance Resonators." Int. Symp. on Microwave Theory and Techniques, 1980, pp. 1413-1417.

[5] C. Quendo, E. Rius, C. Person and M. Ney. "Integration of optimized low-pass filters in a bandpass filter for out-of-band improvement." Transactions on Microwave Theory and Techniques, Vol. MTT-49, Dec. 2001, pp. 2376-2383.

[6] R. Levy. "Tapered Corrugated Waveguide Low-Pass Filters." Transactions on Microwave Theory and Techniques,Vol. MTT-21, Aug. 1973, pp. 526-532.