DOUBLE PLANAR INTEGRATED MILLIMETER-WAVE FILTER

J. Bornemann, F. Arndt, R. Vahldieck, and D. Grauerholz

ABSTRACT

A double planar integrated circuit filter is introduced, which achieves significant higher stop-band attenuation against higher frequencies than the common single planar circuit, especially for designs in the near of the waveguide band end. The theory is based on field expansion into suitable eigenmodes which allows direct inclusion of both higher-order modes and finite strip thickness. Computer optimized design data for a four-resonator Ka-band metal etched double planar integrated filter prototype provide minimum passband insertion-loss of 0.43 dB (measured: 1.8 dB) at 39.04 GHz and stopband attenuations of about 53 dB (measured: 48 dB) at 40 GHz, 100 dB at 50 GHz.

INTRODUCTION

Planar circuits mounted in the E-plane of rectangular waveguide are very attractive millimeter-wave components for many applications [1] - [7]. The advantage of these circuits include the potential of low passband insertion-loss filter designs, if large-gap fin-lines [5], [6], or pure metal inserts [6], [7], requiring no supporting dielectrics, are used.

In these low-insertion-loss filters, the resonators are connected by way of evanescent fields, where the portions with vertical fins or inductive strips are below cut-off frequency of the next higher-order mode, the H_{20}-mode. For passband designs in the near of waveguide band end, therefore, attainable stop-band attenuation against higher frequencies may be too low for some purposes, e.g. for diplexers.

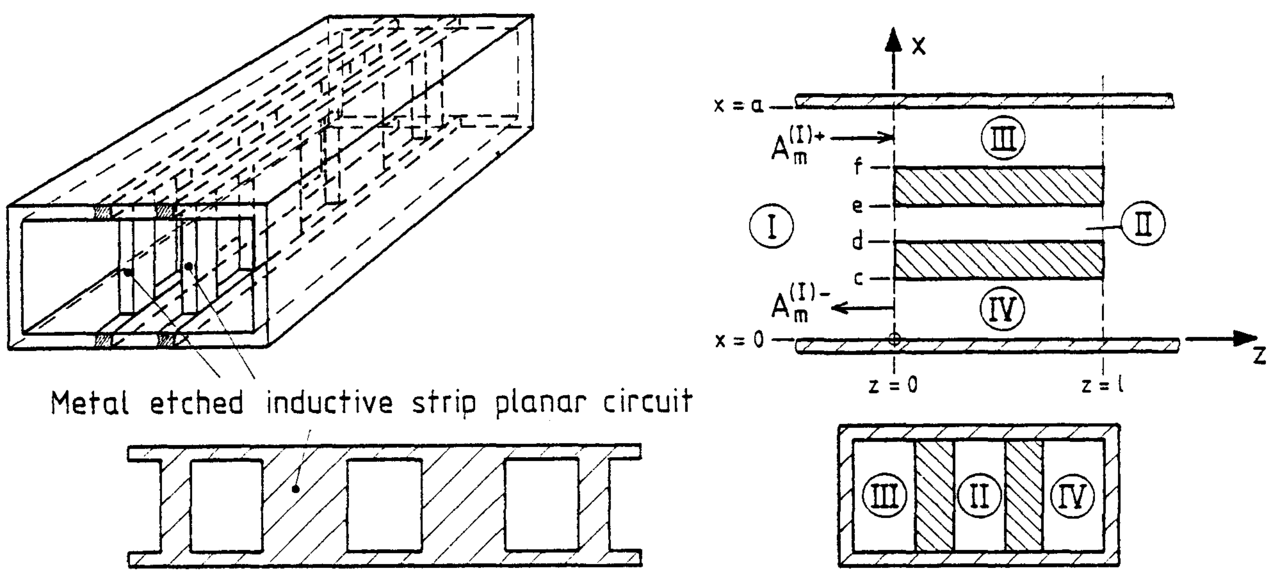


Fig. 1

Double planar integrated millimeter-wave filter

The authors are with the Microwave Department, University of Bremen Kufsteiner Str., NW 1, D-2800 Bremen 33, W.-Germany

This paper introduces a double planar integrated circuit filter (Fig. 1) which avoids this disadvantage. Similar to the low-insertion-loss filter calculations [5] - [7], the filter design is based on field expansion into suitable eigenmodes. This allows direct inclusion of both higher-order mode coupling, also below cut-off frequency, and of finite strip thickness. A simple optimization computer program leads to optimum design data for a 39 GHz Ka-band metal etched double planar integrated filter prototype. The measured frequency response shows good agreement between theory and experimental results.

THEORY

Like for the low-insertion-loss filters [5] - [7], the design of optimized double planar integrated millimeter-wave filters (Fig. 1) is based on field expansion into suitable eigenmodes, together with the field matching at the steps investigated. This allows considering of the higher-order mode excitation, up to a desired number of modes, and the finite thickness of the metallic strips.

For each subregion ν = I, II, III, IV (Fig. 1) the fields

$$\vec{E}^{(\nu)} = -j\omega\mu\,\nabla \times \vec{\Pi}_{hx}^{(\nu)}\,, \quad \vec{H}^{(\nu)} = \nabla \times \nabla\,\vec{\Pi}_{hx}^{(\nu)} \qquad (1)$$

are derived from the x-component of the magnetic Hertzian vector $\vec{\Pi}_h$ which is assumed to be a sum of suitable eigenmodes satisfying the wave equation and the boundary conditions at the metallic surfaces at x=0,c,d,e,f,a:

$$\Pi_{hx}^{(\nu)} = \sum_{m=1}^{\infty} A_m^{(\nu)\pm} \cdot T_m^{(\nu)} \cdot \sin\left[\frac{m\pi}{p^{(\nu)}} \cdot f^{(\nu)}\right] \cdot e^{\mp jk_{zm}^{(\nu)} z} \qquad (2)$$

$$T_m^{(\nu)} = \frac{1}{k_{zm}^{(\nu)}\sqrt{\omega\mu\,k_{zm}^{(\nu)}}} \cdot \begin{cases} \sqrt{\frac{2}{ab}}\,, & \nu = \mathrm{I} \\ \sqrt{\frac{2}{bc}}\,, & \nu = \mathrm{IV} \\ \sqrt{\frac{2}{(e-d)b}}\,, & \nu = \mathrm{II} \\ \sqrt{\frac{2}{(a-f)b}}\,, & \nu = \mathrm{III} \end{cases}$$

$$(f^{(\nu)})' = (x, e-x, a-x, x) \;; \quad (p^{(\nu)})' = (a, e-d, a-f, c)$$

$$k_{zm}^{(\nu)} = \sqrt{k^2 - \left(\frac{m\pi}{p^{(\nu)}}\right)^2}\,, \quad k^2 = \omega^2\mu\epsilon$$

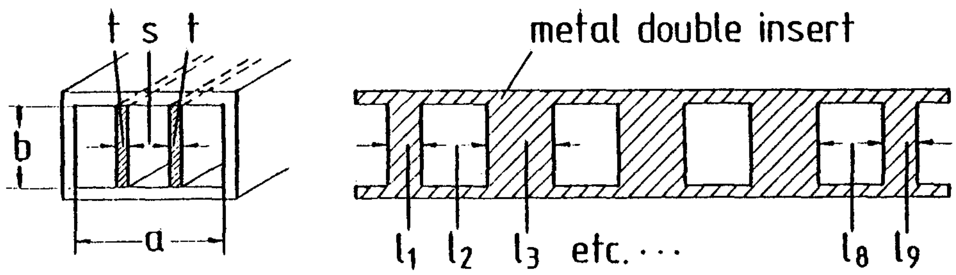
$A_m^{(\nu)\pm}$ are the still unknown eigenmode amplitudes of the forward and backward waves which are suitably normalized by T_m so that the power carried by a given wave is 1 W for a wave-amplitude coefficient of $\sqrt{1\,W}$.

By matching the tangential field components at the corresponding interfaces, the coefficients in (2) are determined after multiplication with the appropriate orthogonal function. This leads to the scattering matrix of each discontinuity. The two-port scattering matrix of the section of finite length l and the overall scattering matrix of the total filter section are calculated by directly combining the single scattering matrices [5] - [7]. Compared with the commonly used multiplication of transmission matrices, this procedure preserves numerical accuracy, since direct combination contains exponential functions with only negative argument.

An optimizing computer program varies the E-plane metal strip dimensions for given waveguide housing dimensions, number of resonators, metal insert thickness and spacing, until the insertion-loss within passband yields a minimum and the stopband attenuation an optimum. For computer optimization the expansion into nine eigenmodes at each discontinuity has turned out to be sufficient. The final design data are proved by expansion into thirtyfive eigenmodes.

RESULTS

A four-resonator double planar integrated Ka-band filter with passband (in the region of 39 GHz) near Ka-band end (40 GHz) is chosen for design example (Table I). The corresponding waveguide housing is WR 28. The metal insert thicknesses are chosen to be t=150 μm for metal etching techniques. The spacing between the double inserts is 1.8 mm.



Frequency-band waveguide housing	Number of resonators	Double insert thickness t and spacing s	$l_1 = l_9$ (mm)	$l_2 = l_8$ (mm)	$l_3 = l_7$ (mm)	$l_4 = l_6$ (mm)	l_5 (mm)	Midband-frequency (GHz)	3 dB-bandwidth (MHz)	Calculated min. passband insertion-loss (dB)
Ka - band a = 7.112 mm b = 3.556 mm WR 28	4	t = 150 μm s = 1.8 mm	0.403	3.637	2.448	3.689	3.646	39.04	210	0.43

Table I

Computer optimized design data for a double planar integrated millimeter - wave filter

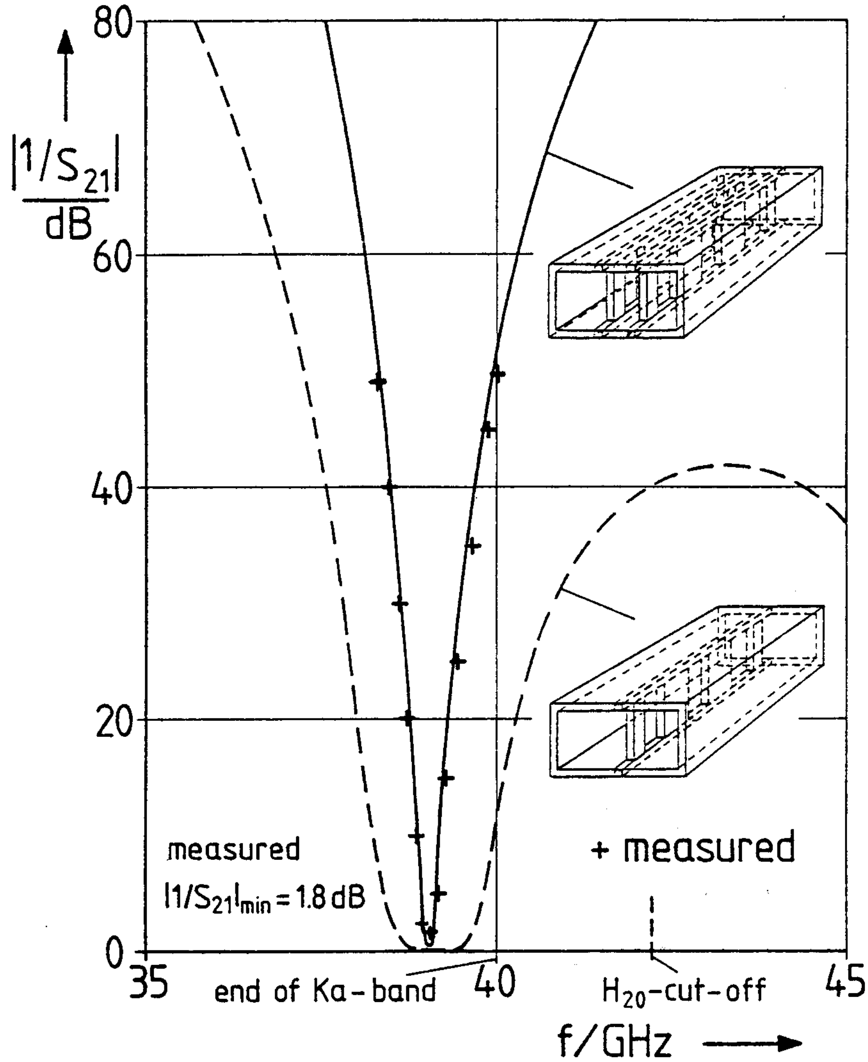


Fig. 2

Calculated and measured insertion-loss for a four-resonator double planar integrated Ka-band filter designed for passband near Ka-band end. Design data cf. Table I. --- single planar integrated filter for comparison.

Fig. 2 shows the calculated and measured insertion-loss as a function of frequency. Measurements are in good accordance with theory. For comparison the dashed line shows the calculated insertion-loss of a conventional single planar integrated four-resonator filter. This single planar circuit achieves a maximum stop-band attenuation against higher frequencies of only about 42 dB because beyond the corresponding cut-off frequency, the resonators are increasingly directly coupled by the propagating H_{20}-wave, whereas the double planar dircuit design still preserves evanescent fields between the metallic strips. This leads between 43 and 50 GHz to a calculated stopband attenuation of about 100 dB. The measured value at 40 GHz is already 48 dB. Fig. 3 shows the metal-etched double planar integrated Ka-band filter structure together with the waveguide housing and the 1.8 mm thick metal inset between the two filter inserts.

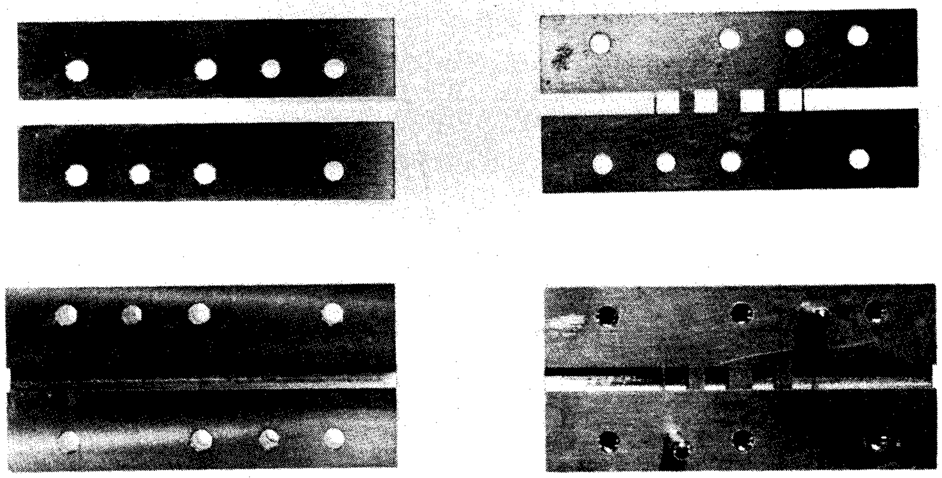


Fig. 3

Photograph of the metal-etched double planar Ka-band filter (cf. Table I) together with the wave-guide housing; the upper left quarter shows the 1.8 mm thick metal inset between the two filter inserts.

CONCLUSION

A new double planar integrated millimeter-wave filter is introduced. This filter type achieves better stopband behaviour against higher frequencies than the single planar circuit, especially for near wave-guide band end designs. The computer optimization is based on field expansion into suitable eigenmodes by which higher-order mode exciting and coupling effects as well as finite thickness of the metal inserts can be taken into account. Computer aided design leads to optimum filter data. A four-resonator double planar integrated Ka-band filter prototype, which can easily be manufactured by metal etching techniques, shows a measured minimum passband insertion loss of 1.8 dB at 39.04 GHz and a stopband attenuation of 48 dB at 40 GHz. Theory and experiment agree very well.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Rembold, the head of the microwave laboratory of AEG-Telefunken, Ulm, W.-Germany, and the members of his staff, especially Dr. Menzel, for financial support of this work.

REFERENCES

[1] P.J. Meier, "Integrated fin-line millimeter components". IEEE Trans. Microwave Theory Tech., vol. MTT-22, pp. 1209-1216, Dec. 1974

[2] P.J. Meier, "Millimeter integrated circuits suspended in the E-plane of rectangular waveguide". IEEE Trans. Microwave Theory Tech., vol. MTT-29, pp. 726-732, Oct. 1978

[3] B. Adelseck, H. Callsen, H. Hofmann, H. Meinel, and B. Rembold, "New millimeter wave components using quasiplanar lines". Frequenz, vol. 35, pp. 118-123, 1981

[4] K. Solbach, "The status of printed mm-wave E-plane circuits". IEEE Trans. Microwave Theory Tech., vol. MTT-31, pp. 107-121, Feb. 1983

[5] F. Arndt, J. Bornemann, D. Grauerholz, and R. Vahldieck,"Theory and design of low-insertion loss fin-line filters". IEEE Trans. Microwave Tech., vol. MTT-30, pp. 155-163, Feb. 1982

[6] J. Bornemann, R. Vahldieck, F. Arndt, and D. Grauerholz, "Optimized low-insertion-loss millimetre-wave fin-line and metal insert filters". The Radio and Electronic Engineer, (Journal of the Institution of Electronic and Radio Engineers), Vol.52, pp. 513-521, Nov./Dec. 1982

[7] R. Vahldieck, J. Bornemann, F. Arndt, and D. Grauerholz, "Optimized waveguide E-plane metal insert filters for millimeter-wave applications". IEEE Trans. Microwave Theory Tech., vol. MTT-31, pp. 65-69, Jan. 1983