Waveguide E-Plane Triple-Insert Filter

J. Bornemann, and F. Arndt

ABSTRACT

A triple planar integrated circuit filter with all-metal inserts and an additional abrupt waveguide step-wall discontinuity is introduced which achieves ultra-broadband high attenuation in the second stopband. The theory is based on field expansion into suitable eigenmodes which allows direct inclusion of both the higher-order mode interaction at all step discontinuities and the finite thickness of the metal inserts. Computer optimized design data for a four-resonator Ka-band prototype at 27 GHz midband frequency provide a minimum stop-band attenuation of 50 dB between 28 and 42 GHz (80 dB between 30 and 41.6 GHz).

INTRODUCTION

All-metal inserts, mounted in the E-plane of rectangular waveguides, require no supporting dielectrics and achieve low-cost filters with low passband insertion loss, [1]-[5]. For the commonly used single inserts, [1]-[3], however, the attenuation

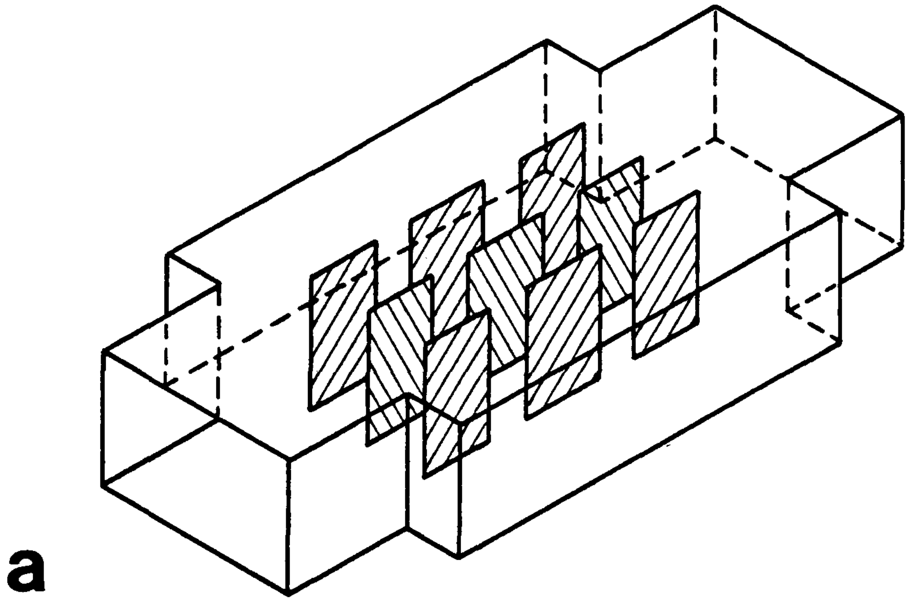

Fig. 1

Waveguide E-plane triple metal insert filter with additional step-wall discontinuity

a general view

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in the second stopband - especially for filters with midband frequencies in the near of the band limit of the corresponding waveguide mount - may be often too low and too narrow-band, [4],

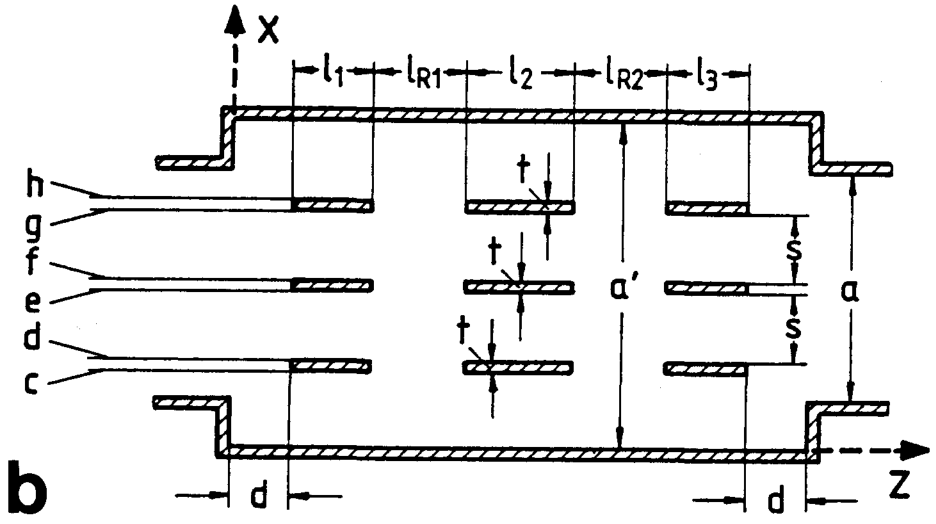

Fig. 1

Waveguide E-plane triple metal insert filter with additional step-wall discontinuity

b dimensions for the field theory treatment and the computer optimization

for many purposes. This is due to two effects which are characteristic for the common single insert design: 1) Beyond the cutoff frequency within the strip sections, the power is increasingly transported directly by then propagating waves which destroy the filter behaviour of the inductive strip-coupled resonators, [4]; 2) the relatively narrow side-wall distance, e.g. relatively high cutoff frequency, of the standard waveguide resonator sections used in [1]-[3],[4], leads to a second passband (at 2 $\lambda_g/2$), already for relatively low frequencies because of the highly nonlinear relation between guide-wavelength λ_g and frequency. For alleviating the first problem a double insert filter has already been suggested [5]. Ultra-broadband stopband behaviour, however, may be achieved only by appropriately attacking both effects in due combination.

In this paper, therefore, an E-plane triple metal insert filter within an abruptly increased waveguide is suggested (Fig. 1). The triple insert reduces the critical distance between the inserts and the waveguide sidewall, considerably. The increase of the waveguide housing width influences the cutoff frequency within the resonator sections favourably so that the second passband may be shifted towards higher frequencies.

Moreover, the step-wall discontinuity effect is utilized directly as an additional inductive parameter for designing filters with high stopband attenuation. For all designs with improved stopband, only thin strips are required which are well appropriate for low-cost production by photoetching techniques.

THEORY

As in [2],[4],[5] the design of optimized filters is based on a rigorous field expansion into suitable eigenmodes. This allows direct inclusion of higher order mode interaction, finite strip thickness and the abrupt step-wall discontinuity effect in the optimization process to make the filter performance satisfy the given specifications.

For each corresponding subregion of the filter structure investigated (Fig. 1), the fields

$$\vec{E} = -j\omega\mu \; \nabla \vec{\Pi}_{hx}, \quad \vec{H} = \nabla \times \nabla \times \vec{\Pi}_{hx} \tag{1}$$

are derived from the x-component of the magnetic Hertzian vector potential $\vec{\Pi}_h$ which is assumed to be a sum of suitable eigenmodes satisfying the vector Helmholtz equation and the corresponding boundary conditions within the separate subregion i

$$\begin{aligned} \Pi^i_{hx} = \sqrt{\frac{2}{(q^i_1-q^i_2)b}} \sum_{m=1}^{M} \frac{1}{k^i_{2m}\sqrt{\omega\mu k^i_{zm}}} \left[A^{i+}_m e^{-jk^i_{zm}z} + A^{i-}_m e^{+jk^i_{zm}z}\right] \cdot \\ \cdot \sin\left[\frac{m\pi}{(q^i_1-q^i_2)} f^i_x\right] , \end{aligned} \tag{2}$$

where

$$k^{i\,2}_{zm} = \omega^2\mu\epsilon - \left(\frac{m\pi}{q^i_2-q^i_1}\right)^2 , \quad (f^i_x)' = \left(\frac{a'+a}{2} -x, x, x, e-x, g-x, a'-x\right)' ,$$

$q^i_2-q^i_1$: width of the corresponding waveguide section of the separate subregion i, cf. [2],[4],[5].

$A^{i\pm}_m$ are the still unknown eigenmode amplitudes of the forward and backward waves in the subregion i which are suitably normalized so that the power carried by a given wave of amplitude $1\sqrt{W}$ is 1W and the related amplitudes correspond directly to the interested scattering coefficients. By matching the field components at the interfaces of the adjacent subregions, the coefficients in (2) are determined after multiplication with the related orthogonal function. This leads to the scattering matrix of each discontinuity under consideration from the smaller to broader waveguide and transition from the broader waveguide to the structure of parallel four partial waveguides within the strip section (Fig. 1). The scattering matrices at the inverse discontinuities may simply be derived by interchanging the corresponding submatrices. The overall scattering matrix of the filter (Fig. 1) is calculated by directly combining the involved scattering matrices, including those of the homogeneous waveguide sections, which preserves numerical accuracy in contrast to the common treatment by transmission matrix parameters.

An optimizing computer program [2],[4],[5] varies the step-wall width a' and distance d, and the lengths l_i, l_{Ri} of the triple metal inserts and resonators, respectively, until the insertion loss within passband yields a minimum and the stopband attenuation an optimum. Given are the waveguide housing dimensions, number of resonators, metal insert thickness t and spacing s as well as the desired midband frequency. For computer optimization the expansion into nine eigenmodes has turned out to be sufficient. The final design data are proved by expansion into thirty-five eigenmodes.

RESULTS

A four resonator Ka-band (26-40 GHz) prototype with a midband frequency of 27 GHz is chosen for design example of the suggested waveguide E-plane triple insert filter with additional step-wall discontinuity (Fig. 1). The insertion loss in decibles as a function of frequency of the computer optimized triple insert filter (Fig. 2, solid line) shows a minimum stopband attenuation of 50 dB between 28 and 42 GHz, and of 80 dB between 30 and 41.6 GHz. For comparison, Fig. 2 also presents the calculated insertion losses of the corresponding double-insert (dashed line) and single-insert filters (dash-dotted line). The advantage of the triple-insert design is evident, although the compared double-insert filter is already of improved stopband attenuation since an increased-width resonator section was used there, too.

The four resonator Ka-band E-plane triple insert filter (Fig.2) has been realized by metal-etching techniques. The material of the three 190-μm-thick inserts is 99.9-percent pure copper. The measured values show excellent agreement with the theory (cf. Fig. 2). The measured minimum stopband attenuation between 28 GHz and 40 GHz was 50 dB (measuring limit of the test assembly).

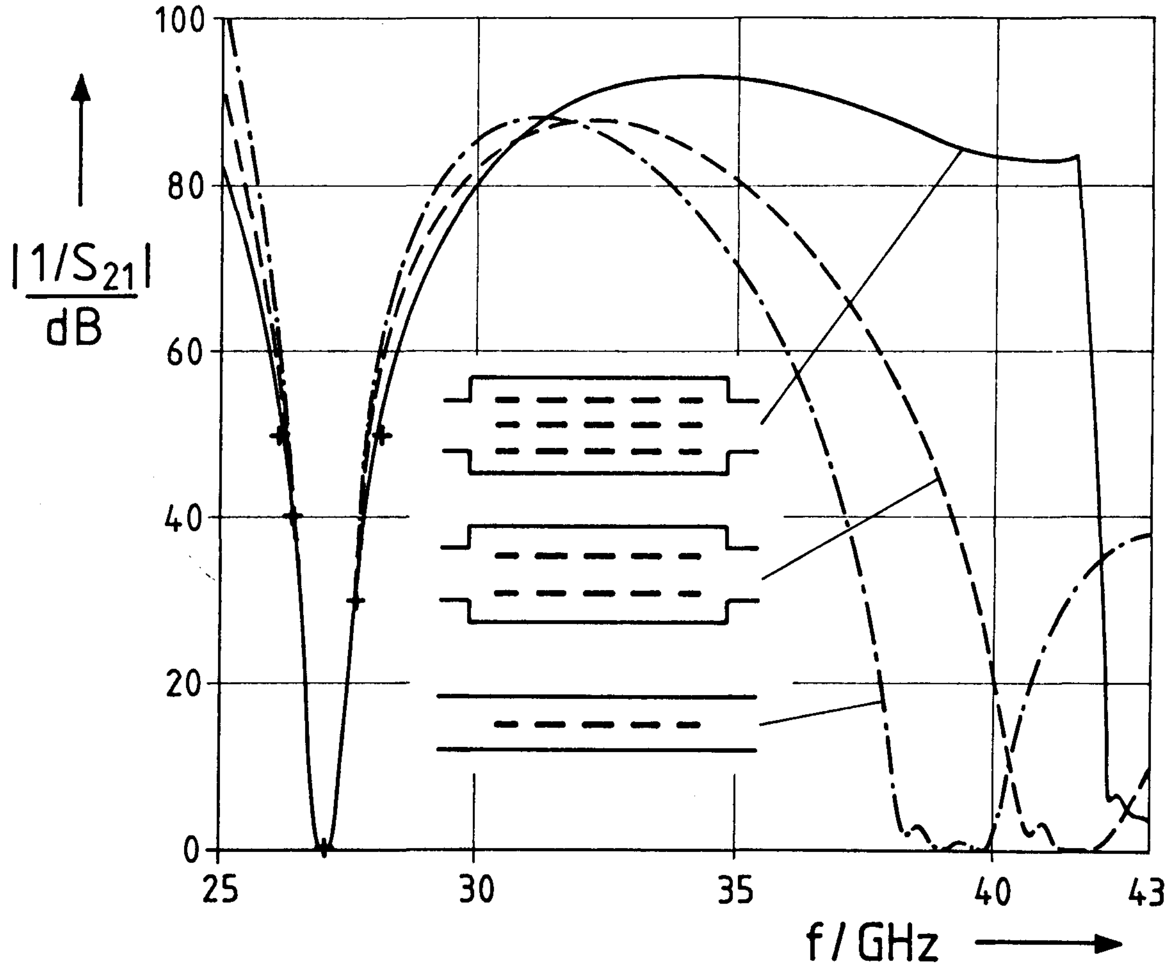

Fig. 2

Insertion loss in decibels as a function of frequency of computer optimized four-resonator E-plane circuit filters.

Midband frequency f_0=27 GHz. Waveguide housing dimensions a=2b=7.112 mm

———————	triple metal insert with step - wall discontinuity. Design data (cf. Fig.1): a'=11.4 mm, t=100 µm, s=2 mm, d=5.688 mm, l_1=l_5=0.342 mm, l_2=l_4=2.469 mm, l_3=3.167 mm, l_{R1}=l_{R4}=5.207 mm, l_{R2}=l_{R3}=5.29 mm
+++	measured
-----------	double metal insert with step-wall discontinuity. Design data (analogeous to Fig. 1): a'=7.8 mm, t=100 µm, s=1 mm, d=5.468 mm, l_1=l_5=0.225 mm, l_2=l_4=2.346 mm, l_3=2.615 mm, l_{R1}=l_{R4}=6.716 mm, l_{R2}=l_{R3}=6.829mm
-.-.-.-.-.-	single metal insert. Design data: t=190 µm, l_1=l_5=0.803 mm, l_2=l_4=2.92 mm, l_5=3.17 mm, l_{R1}=l_{R4}=7.33 mm, l_{R3}=l_{R2}=7.399mm.

CONCLUSION

An ultra-broadband high attenuation behaviour in the second stopband of E-plane integrated circuit filters is achieved by triple metal inserts, together with an abrupt step-wall discontinuity in the waveguide mount. Since the computer aided design is based on exact field theory methods, the effects of both the higher-order mode interaction at all discontinuities and the finite thickness of the metal inserts are included in the optimum filter design. Only thin metal inserts are required wich are well suited for low-cost mass production by photoetching techniques.

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