TE_{10}-MODE FILTERS FORMED BY MULTILAYERED DIELECTRIC SLABS IN WAVEGUIDES BELOW CUTOFF

R. Vahldieck, J. Bornemann, F. Arndt and W.J.R. Hoefer

A B S T R A C T

A new type of dielectric resonator filter is being introduced, utilizing longitudinal multilayered dielectric slabs rather than transverse dielectric plates. The length of each slab coincides with the length of the filter enclosure. Ladder-shaped metal inserts are sandwiched between the dielectric slabs determining the resonator and coupling sections. The metal insert dimensions can be fabricated very accurately using low-cost photolithographic techniques. Compared with conventional TE10-mode dielectric resonator filters the new design shows also improved filter performance.

I N T R O D U C T I O N

Conventional dielectric resonator filters can be realized by axially spaced transverse dielectric plates which are located in a rectangular waveguide operating below cutoff [1]. The filter enclosure is embedded between two standard waveguides operating above cutoff. The resonators are coupled via evanescent-mode waveguide sections. Since substrate materials with high ε_r, good temperature profile and low $\tan\delta$ are available, these filters become increasingly attractive when extremely short filter components are required.

On the other hand, however, the accurate fabrication of these filters is difficult and expensive because it requires precision machining. Furthermore, the resonator plates must be adjusted mechanically in the filter housing leading to inaccurate coupling lengths. In addition, the electrical filter performance of these structures is sometimes not sufficient. Especially, when substrate materials with low permittivity are used, their stopband attenuation towards higher frequencies is only moderate and the suppression of spurious responses is poor. In this configuration the filters behave more like a highpass as soon as the reduced size waveguide section operates above cutoff.

A potential solution, which eliminates the spurious responses up to higher frequencies, has been proposed recently [4]. In this solution the dielectric plates were coupled via a triple waveguide structure. This measure increases the cutoff frequency in the individual subsections of the

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coupling region significantly and provides a better stopband attenuation and passband separation as well. However, also this configuration was difficult to manufacture and not suitable for mass-production. A similar solution, published in [5], utilizes a ladder - shaped finline filter realized on a substrate material with high permittivity inserted in a waveguide section operating below cutoff. The advantage of this solution is obvious since the ladder-shaped insert can be fabricated with low - cost photolithographic techniques and the resonator and coupling sections are automatically adjusted in a single design procedure. On the other hand, the resonator section is filled only partly with dielectric material increasing the resonator length considerably.

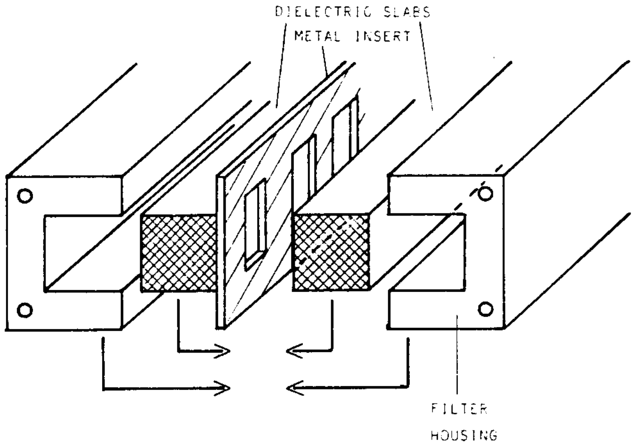


Fig. 1 TE_{10}-mode filter formed by a double-layered dielectric slab in a waveguide operating below cutoff

The present contribution proposes a new solution which preserves the advantages of the previous attempts without complicating the manufacturing of the component. The main feature of this solution is to use longitudinal multilayered dielectric slabs rather than transverse dielectric plates (as in conventional dielectric resonator filters). Each dielectric slab coincides in length and heigth with the filter housing. The resonator and coupling sections can be realized by simply using thin ladder-shaped metal inserts sandwiched between the slabs (see Fig.1 for the example of a double layered substrate). Laminating the substrates together and embedding the resulting block between the splitted waveguide housing yields finally the filter component. The advantage of this procedure is obvious: instead of machining transverse dielectric resonator plates and adjust them mechanically in the filter enclosure, the lengths of the resonator and coupling sections are determined by the ladder dimensions of the insert(s). The insert(s) itself can be fabricated very accurately with low-cost photolithographic techniques and the resonators are automatically adjusted in a single design procedure.

T H E O R Y

The calculation of the filter structure is based on a rigorous field theory treatment of the individual waveguide step discontinuities [4]-[8]. The overall S-matrix of the filter component accounts for the effect of finite metallization thickness and the interaction of fundamental and higher order modes generated at discontinuities. An efficient optimization routine optimizes the lengths of the resonator and coupling sections for minimum insertion loss in the passband and maximum stopband attenuation.

Since the transition empty waveguide to waveguide bi-and tri-furcation as well as the transition standard waveguide to a narrower waveguide section has been treated already in [6]-[8], only the principal steps for calculating the scattering matrix of a three- layered dielectric waveguide section (the resonator section) will be given. The fields in each subregion

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

can be derived from the axial component of the Hertz vector potential Πmz

$$\left.\begin{aligned} \Pi mz^{1-2} &= \sum_n T_n^{1-2} \cos(kx_n x) \\ \Pi mz^{\nu} &= \sum_n (F_n^{\nu} \cos(kx_n^{\nu} x) + R_n^{\nu} \sin(kx_n^{\nu} x)) \end{aligned}\right\} \cdot A^{\pm\,1,\nu}_n \cdot \exp^{\mp jkz_n^{1,\nu} z} \tag{2}$$

$\nu = 2-4$

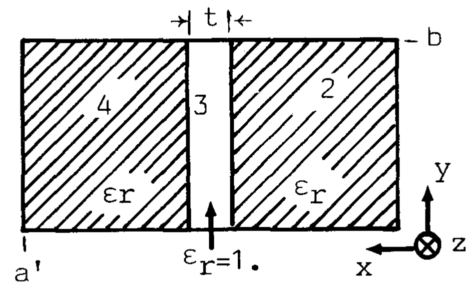
which is a sum of orthogonal eigenfunctions. $A^{\pm}$ denotes the amplitudes of the incident and reflected waves at each discontinuity.
In the empty waveguide $kx = n\cdot\pi/a$ is known and the propagation constant kz is simply determined by $kz = \sqrt{\omega^2\mu_0\varepsilon - (m\cdot\pi/a)^2}$. The resonator section, however, is inhomogeneously filled with dielectric material (Fig.4) and kx is unknown. Therefore, $kz = \sqrt{\omega^2\mu_0\varepsilon_0\varepsilon_r - (kx)^2}$ must be determined by solving an eigenvalue equation $B \cdot X = 0$, resulting directly from matching the tangential field components (Ey and Hz) at the common interfaces between the subregions [9],[10]. The scattering matrix of the step transition empty waveguide/resonator section is then obtained by matching the transverse field components (Ey and Hx) at z=0. Utilizing the orthogonality relation between the modes, forward and backward wave amplitudes of the individual subregions can be related to each other

$$Ey^1 = \sum_{\nu} Ey^{\nu}$$

$$N_e \cdot (A^{+1} + A^{-1}) = M_e \cdot (A^{+\nu} + A^{-\nu}) \tag{3}$$

$$Hx^1 = \sum_{\nu} Hx^{\nu}$$

$$N_h \cdot (A^{+1} - A^{-1}) = M_h \cdot (A^{+\nu} - A^{-\nu}) \tag{4}$$



N_e and N_h are diagonal matrices and M_e as well as M_h containing the coupling integrals and the field expansion coefficients F_n and R_n (2). For further details the reader is referred to [9] and [10]. The scattering matrix at z=0 follows directly from (3) and (4).

$$\begin{bmatrix} A^{-1} \\ A^{+\nu} \end{bmatrix} = S_o \begin{bmatrix} A^{+1} \\ A^{-\nu} \end{bmatrix} \tag{5}$$

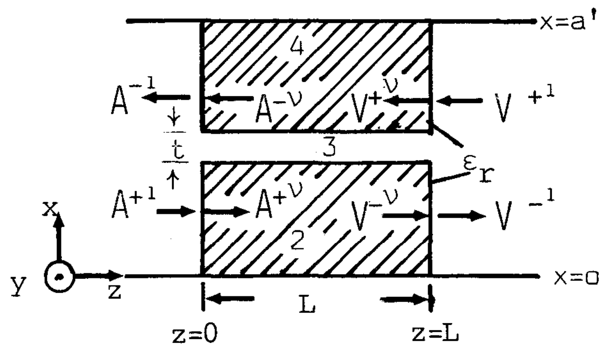


Fig. 4 Double-layered dielectric resonator section. t corresponds to the metal insert thickness.

The procedure to calculate the scattering matrix at the discontinuity $z=L$ (6) is identical. The scattering coefficients of the entire resonator section of finite length L are then obtained by replacing the inner wave amplitudes $A^{\pm\nu}$ and $V^{\pm\nu}$ (Fig.4) in (5) and (6) as shown in [10].

$$\begin{bmatrix} V^{-1} \\ V^{+\nu} \end{bmatrix} = S_L \begin{bmatrix} V^{+1} \\ V^{-\nu} \end{bmatrix} \tag{6}$$

The algorithm to combine the scattering elements of the resonator section with those of the waveguide bi-or trifurcation is given in [7].

RESULTS

Fig.2 shows a comparison between a conventional dielectric resonator filter (curve 1) and the new design using a single metal insert (curve 2) or a twin metal insert (curve 3). Even though the harmonic passband of the new design appears at the same frequency compared with a conventional dielectric resonator filter, the second stopband is improved (more than 15.dB) and a third stopband occurs towards higher frequencies while the conventional design show a genuine highpass behaviour.

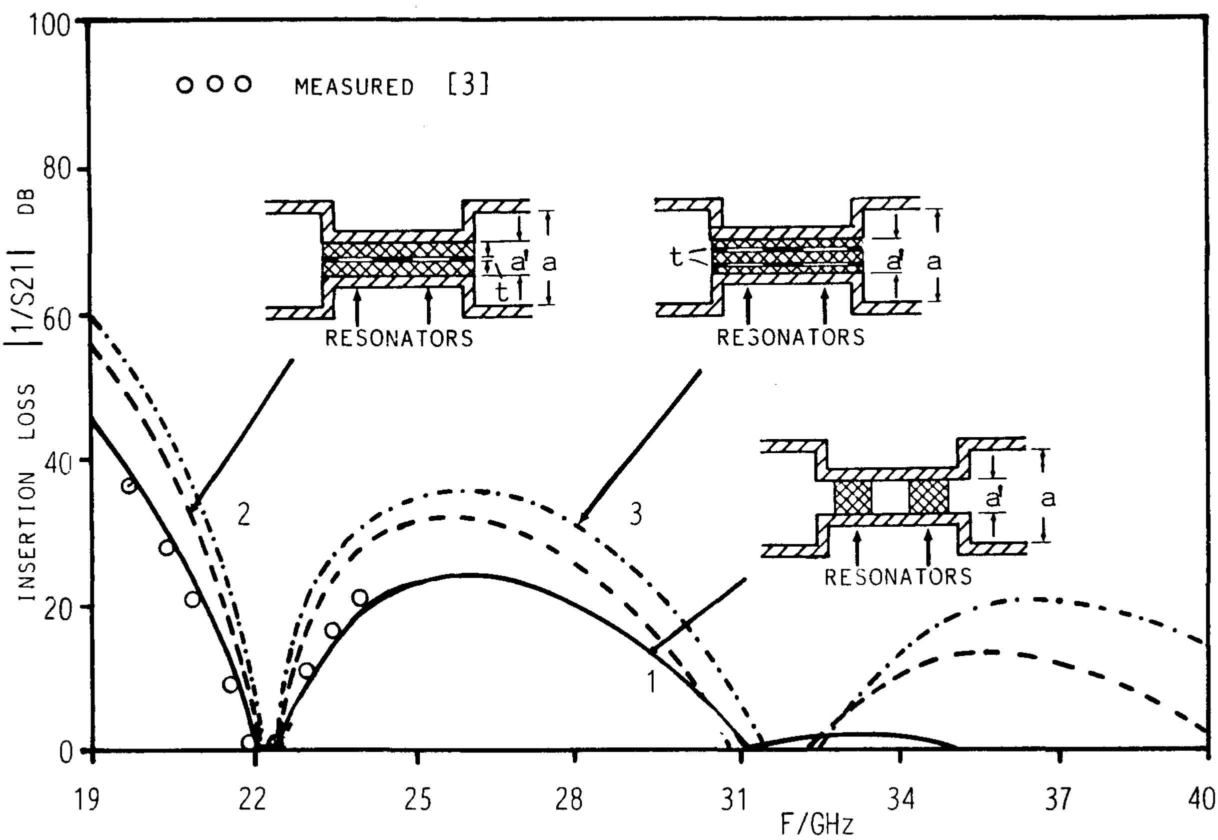


Fig. 2 Comparison between a conventional TE_{10}-mode dielectric resonator (curve 1) filter and a double (curve 2) and triple layered (curve 3) dielectric slab filled TE_{10}-mode filter. a=10.7mm, a'=5.689mm, b=4.32mm

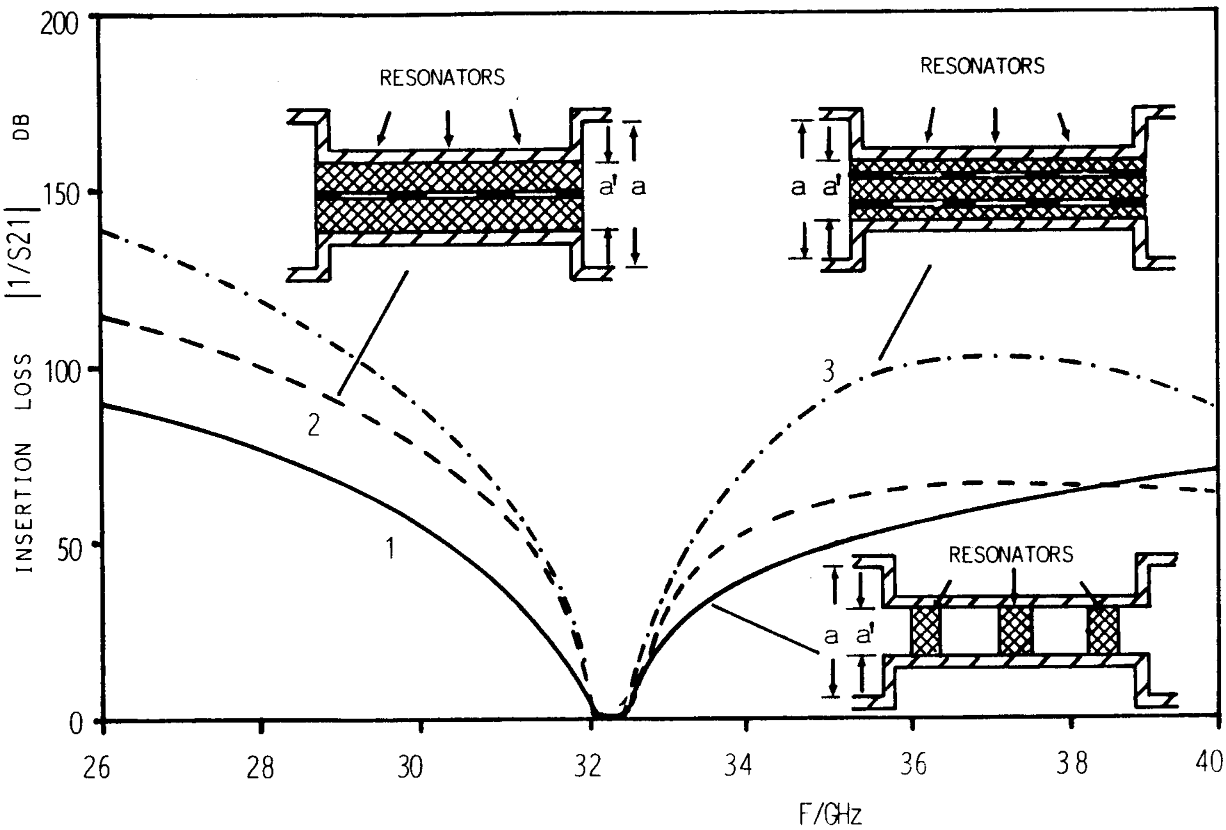


Fig. 3 Dielectric resonator filters with high dielectric constant material. Curve 1: conventional design; curve 2: double-layered dielectric slab filled TE_{10}-mode filter; curve 3: triple-layered dielectric slab filled TE_{10}-mode filter. Common waveguide dimensions: a=7.112mm, b=3.556mm, a'=2.mm

The harmonic passband can be pushed up in frequency by using a substrate material with higher permittivity (this measure shortens also the resonator lengths). At the same time narrowing the waveguide enclosure, the second stopband attenuation is increased significantly. This is illustrated in Fig.3 were a conventional dielectric resonator filter (curve 1) shows the same characteristic as the new design with a single metal insert (curve 2). However, using three dielectric slabs separated by two metal inserts, the new design improves the stopband attenuation even further as illustrated in Fig.3, curve 3.

C O N C L U S I O N

A new design for dielectric resonator filters operating in waveguides below cutoff has been introduced. Using longitudinal multilayered dielectric slabs rather than transverse dielectric plates and separating the slabs by ladder-shaped metal inserts, all resonator and coupling sections are determined by the metal insert dimensions. The ladder-shaped inserts can be fabricated very accurately with low-cost photolithographic techniques and the resonators are automatically adjusted in a single design procedure. This is a considerable advantage over conventional dielectric resonator filters.

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