ASYMMETRIC IRIS COUPLED CAVITY FILTERS WITH STOPBAND POLES

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ABSTRACT

An improved type of asymmetric iris coupled cavity filters is introduced which utilizes the dual mode resonance and interference characteristics of the fundamental mode and the next higher order odd mode in suitably optimized resonators. This design achieves additional stopband poles which may advantageously be employed to improve the edge steepness and the rejection characteristic in the second stopband. Based on the modal scattering matrix method, the rigorous design takes into account both the finite iris thickness and the higher order mode interaction at all step discontinuities. Computer-optimized design examples of asymmetric inductive and resonant iris coupled resonator filters for the waveguide Ku- (12 - 18 GHz), and W-band (75 - 110 GHz), respectively, demonstrate the improved stopband behaviour. The theory is verified by available measured results.

INTRODUCTION

Direct coupling of cavities by irises is a common technique to produce simple waveguide bandpass filters for a wide variety of applications, [1] - [7]. Owing to the nonlinear relation between guide wavelength and frequency, and to the frequency dependency of the coupling elements, however, for this type of filters, high edge steepness and attenuation requirements at the second stopband are often difficult to meet. For many purposes, therefore, such as for channel filters, when frequency selectivity and high stopband attenuation are considered to be important filtering properties, it may be highly desirable to improve the rejection quality. This paper introduces the rigorous computer-aided design for an improved direct coupled filter type (Fig. 1) with asymmetric iris coupling, which utilizes advantageously the dual mode resonance and interference characteristics of the fundamental mode and the next higher order odd mode in suitably optimized resonators.

The design is based on the orthogonal expansion method which yields directly the modal S-matrix of the single key-building block discontinuity required, the asymmetric double-step junction of rectangular waveguides of different cross-sections. The immediate modal S-matrix combination of all interacting structures includes the higher-order mode coupling effects, the finite thickness of all irises, and allows the stopband characteristic to be included in the filter design. An optimizing computer program varies the filter parameters until passband and stopband insertion loss correspond to predicted values. The evolution strategy method [7], i.e. a modified direct search where the parameters are varied statistically, is applied which requires no differentiation step, and, hence, helps to circumvent the problem of local minima.

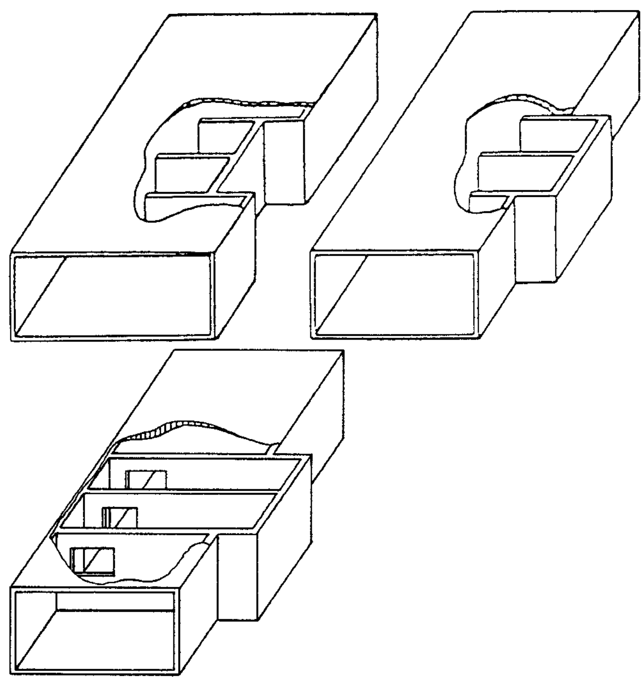


Fig. 1: Asymmetric iris coupled cavity filters

The advantages of the improved design are such that additional stopband poles are achieved using degenerate cavity modes, analogous to the dual-mode approach of orthogonal circular-waveguide filters [8], [9], and that, on the other side, convenient milling and spark eroding techniques from a solid block, for the inductive iris type, or metal-etching techniques, for the resonant iris type, allow simple and low-weight filter constructions. Computer-optimized examples for asymmetric coupled three- and four-resonator filters in the waveguide Ku- (12 - 18 GHz) and W-band (75 - 110 GHz) demonstrate the improved stopband characteristic by attenuation values of more than 80 dB and by a high edge steepness in the otherwise critical second stopband. The theory is experimentally verified by available measured results.

THEORY

For the computer-aided design of the improved filter structures (Fig. 1), the modal S-matrix method [6], [7], is applied. Only one single key-building block discontinuity is required, to include all general cases under consideration: the asymmetric double-step junction of two waveguides of different cross-sections (Fig. 2). Note that for the corresponding inverse discontinuity merely the port designations of the related modal scattering matrix need to be interchanged. The total scattering matrix of the filter structure is formulated by suitable direct combination of the individual modal scattering matrices of the double-step junction and the inverse discontinuity, respectively, by an iteration process already described in [6], [7], and by including appropriately the known scattering matrices of a homogeneous waveguide section, for adequate consideration of the iris thicknesses and the resonator lengths. This procedure preserves numerical accuracy, avoids instabilities, and requires no symmetry of modes [6], [7].

The fields

$$\vec{E} = \frac{1}{j\omega\epsilon} \nabla \times \nabla \times (\vec{Q}_{ez}) + \nabla \times (\vec{Q}_{hz}) \qquad (1)$$
$$\vec{H} = -\frac{1}{j\omega\mu} \nabla \times \nabla \times (\vec{Q}_{hz}) + \nabla \times (\vec{Q}_{ez})$$

in the homogeneous subregions I, II (Fig. 2) are derived from the z-components of the electric (e) and magnetic (h) vector potentials, respectively,

$$Q^o_{ez} = \sum_{i^o} N^o_{i^o} \cdot T^o_{ei^o} \cdot (A^{o\pm}_{ei^o} \cdot e^{\mp jk^o_{zei^o} z})$$

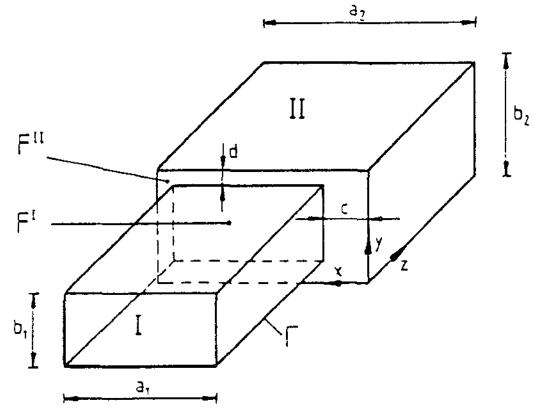


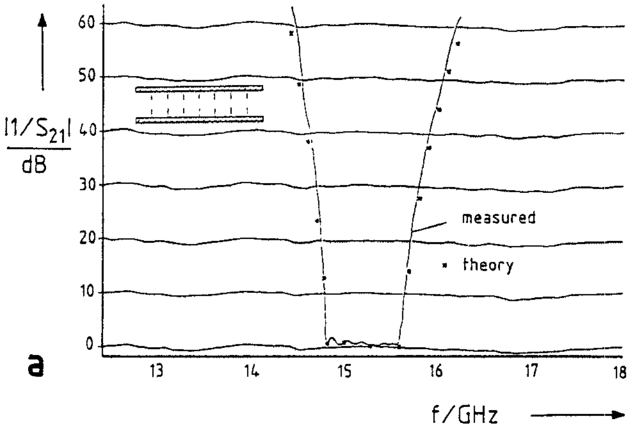
Fig. 2: Key building block discontinuity asymmetric double-step junction

$$Q^o_{hz} = \sum_{i^o} N^o_{i^o} \cdot T^o_{hi^o} \cdot (A^{o\pm}_{hi^o} \cdot e^{\mp jk^o_{zhi^o} z}) , \qquad (2)$$

where o = I,II (number of subregions), i^o is the index for all TE-, and TM-modes in each subregion, N are the normalization factors due to the complex power, and T are the eigen- functions in the corresponding subregions, [6]; A^+ are the amplitude coefficients of the forward (-), A^- of the backward (+) waves, and k_z are the wavenumbers of the corresponding TE- and TM-modes.

By matching the tangential field components at the common interfaces at the individual step discontinuities, the wave amplitude coefficients of (2) can be related to each other after multiplication with the appropriate orthogonal functions, [6], [7]. This yields the key building block two-port modal scattering matrix of the asymmetric double-step junction [6]. The series of step discontinuities, for a complete filter structure, is calculated by direct combination of the single modal scattering matrices [6], [7].

A computer program was written using the preceding relations and utilizing the evolution strategy method, cf. [7], for optimizing the geometrical parameters for given specifications, including the stopband characteristic. For the optimization, sufficient asymptotic behaviour has been obtained by consideration of 15 TE- and TM-modes for the general double-step junction (for the resonant iris coupled filter), and by 20 TE_{m0}-modes for the asymmetric step discontinuity in the waveguide width (for the inductive iris coupled filter), respectively. In the resonator sections, the TM_{mn}- and TE_{mn}- modes are considered up to the order m=3, n=2, for the rectangular iris filter case, and TM_{m0}-modes up to m=5, for the inductive iris filter case, respectively. The final design results are verified by an inclusion of 36 TM- and TE-modes (together with 15 TM-, 15 TE-modes in the resonator region), and 40 TM_{m0}-modes (together with 20 modes in the resonator region), respectively.



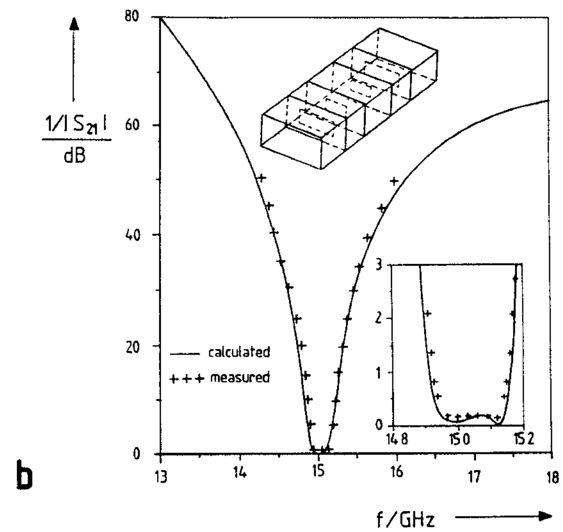


Fig. 3: Calculated and measured insertion loss of available iris coupled cavity filters.
a) Inductive iris coupled filter with seven
b) Resonant iris coupled filter with three resonators

RESULTS

Fig. 3 shows the calculated and measured scattering parameters of optimized inductive iris (Fig. 3a) and resonant iris coupled filters (Fig. 3b) for the Ku-band (12 - 18 GHz, R140 waveguide housings: 15.799mm × 7.899mm). Good agreement between theory and the available measurements may be stated.

The insertion loss in decibels of a computer-optimized Ku-band asymmetric inductive iris coupled three-resonator filter is presented in Fig. 4. Due to the interactions of the fundamental mode with the higher order cavity modes of the asymmetric filter, an improved stopband characteristic towards higher frequencies is achieved (solid line), similar to the behaviour of an elliptic function filter. The comparison with a conventional symmetric filter (dashed line) of nearly the same passband characteristic demonstrates the improvement of the stopband behaviour of the asymmetric filter type. The two additional attenuation peaks yield an increased skirt selectivity towards higher frequencies as well as higher stopband attenuation within a certain frequency range.

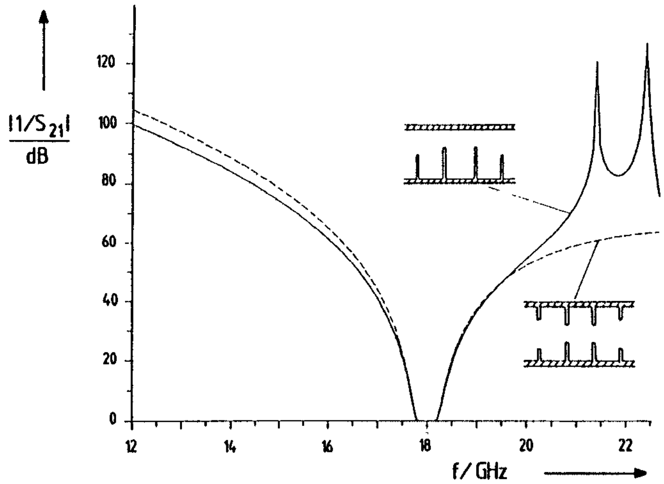


Fig. 4: Filter characteristic of a computer-optimized asymmetric inductive iris coupled three-resonator filter (solid line) in the Ku-band (waveguide R140 housing: 15.799mm × 7.899mm) compared with the characteristic of a conventional symmetric iris filter (dashed line).

The characteristic of computer-optimized asymmetric inductive iris coupled filters with resonators of increased width are shown in Fig. 5. The very high skirt selectivity obtained (Fig. 5, solid line) in the otherwise critical second stopband may illustrate the design potential inherent in this type of filters by taking full advantage of all relevant parameters. Modified types, e.g. a three-resonator design type with antipodal asymmetric irises (Fig. 5, dashed line), have also been investigated, providing, however, a poorer stopband characteristic.

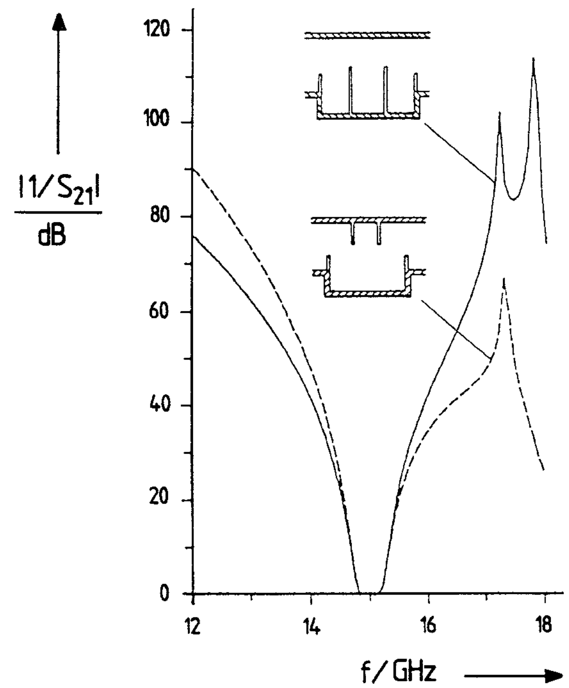


Fig. 5: Filter characteristic of a computer-optimized asymmetric inductive iris coupled three-resonator filter with resonators of increased width (solid line) compared with the characteristic of a modified asymmetric filter type (dashed line)

Fig. 6 shows the insertion loss in decibels of a computer-optimized asymmetric iris coupled three-resonator filter in its resonant iris version designed for a pass-band at about 94 GHz in the waveguide W-band (75 - 110 GHz, R900 waveguide housing: 2.54mm × 1.27mm). High stopband attenuation is achieved up to about 140 GHz together with a slightly improved skirt selectivity. The thickness of the irises is chosen to be 50μm in order to enable metal etching techniques.

CONCLUSION

Improved asymmetric iris coupled cavity filters may be designed by utilizing advantageously the dual mode resonance and interference characteristics of the fundamental mode and the next higher order odd mode in suitably optimized resonators. This design achieves additional stopband poles, similar to the behaviour of elliptic function filters, which may be employed to improve the skirt selectivity and the rejection characteristic in the otherwise critical second stopband. Based on the modal scattering matrix method, the rigorous design takes into account both the finite iris thickness, and the higher order mode interaction at all step discontinuities, and, hence, allows the stopband characteristic of the filter to be included in the optimization procedure.

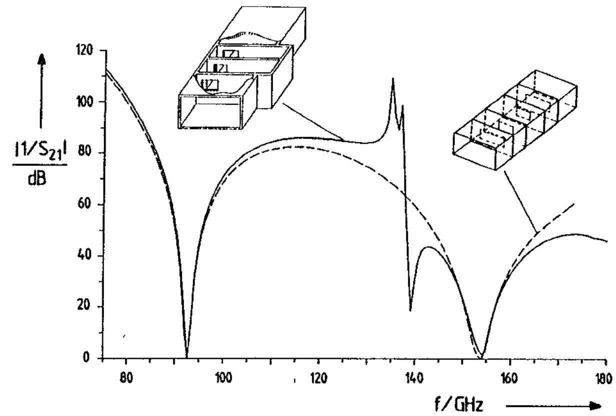


Fig. 8

Fig. 6: Filter characteristic of a computer-optimized asymmetric resonant iris coupled three-resonator filter (solid line) in the W-band compared with the characteristic of a conventional symmetric iris filter (dashed line)

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