LOW-LOSS WAFFLE-IRON FILTERS FOR MULTIBAND FEEDERS OF REFLECTOR ANTENNAS

Mikhail B. Manuilov and Konstantin V. Kobrin
Rostov State University, Physical Faculty
Zorge Str., 5, Rostov-on-Don, 344104, Russsia
E-mail: manuilov@phys.rsu.ru

1. Introduction

Waffle-iron filters were originally developed as low-pass waveguide filters to suppress the harmonic frequencies generated by the transmitter [1, 2]. Their well-known advantages are both extended pass- and stop-band and low insertion loss over a pass-band. Besides, waffle-iron filters attenuate all propagating waveguide modes whose frequency lies in the stop-band of filter. From this viewpoint waffle-iron filters are very appropriate candidates for some satellite communications applications. For example, in reflector antennas of earth stations operating in S, C, X, Ku frequency bands multiband feeders are used. Typically, diplexers included into multiband waveguide feeder are implemented on the base of low-pass waffle-iron filters.

The classical synthesis methods discussed in [1, 2] ensure very high standard in design of such waveguide components as waffle-iron filters. But principal feature of these synthesis techniques is low-frequency equivalent circuit approach. That's why such techniques can't disclose and apply full potential of this kind of filters, for example, optimize insertion loss in pass-band and attenuation in stop-band. Therefore, a point of growing interest is electromagnetic CAD of waffle-iron filters [3-5]. This paper presents a full wave approach to CAD of waffle-iron filters including their analysis and numerical optimization.

2. Theory

A combined technique based on Generalized Scattering Matrix method/Galerkin's method has been employed for analysis of waffle-iron filters. It is assumed that waveguide structure under consideration (Fig. 1) consists of arbitrary number of multi-ridged waveguide sections and stepped transitions connecting filter with input and output waveguides. The solution is subdivided into following steps: (i) decomposition of filter into elementary basic blocks, (ii) solving eigenvalue problem for multi-ridged waveguide sections, (iii) solving key scattering problems for basic discontinuities, (iv) direct combination of all S-matrices and evaluation of total S-matrix of filter.

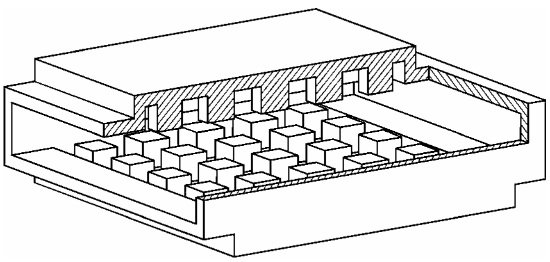


Fig. 1. Waffle-iron filter.

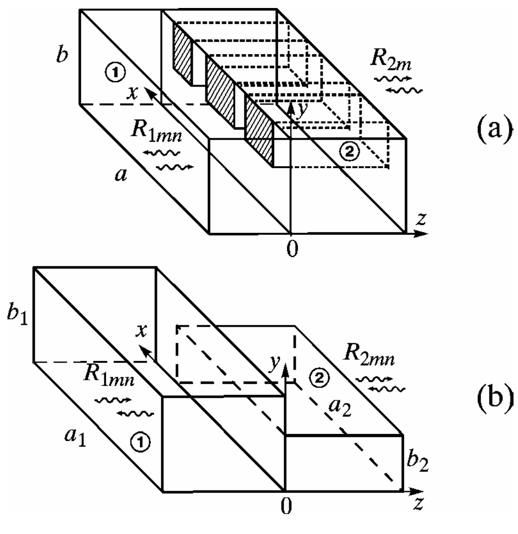
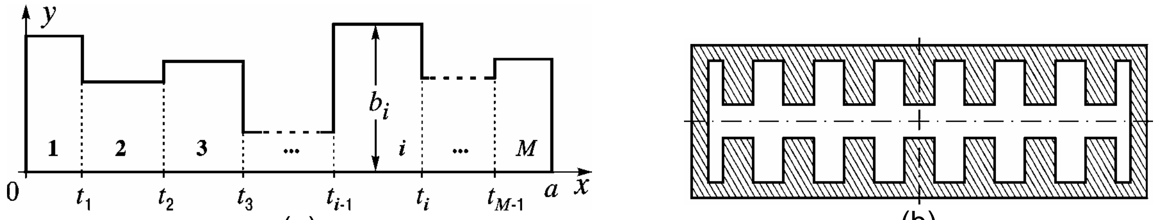


Fig. 2. Key scattering problems

ISBN: 89-86522-77-2 94460©KEES

Two discontinuities are considered as basic blocks of the structure: junction between rectangular and multi-ridged waveguide of the same size (Fig. 2, a) and double-plane step junction between two rectangular waveguides (Fig. 2, b).

The eigenvalue problem formulation for generalized multi-ridged waveguide is shown in Fig. 3. As the scattering problems above are solved in terms of H- and E-modes, two independent eigenvalue problems for both H- and E-modes of multi-ridged waveguide have been considered. We extended method proposed in [6] for ridged waveguide to most general case of waveguide with arbitrary number of ridges. The eigenvalue problems are reduced to the system of integral equations of the first kind for unknown electric field components on the common interfaces of regular regions in Fig. 3, a $(z = t_i, i = 1, 2, ..., M - 1)$.



(a) (b)

Fig. 3. Eigenvalue problem formulation: (a) cross section of generalized multi-ridged waveguide; (b) cross section of waffle-iron filter.

For the solution of integral equation system the Galerkin's method is utilized. Key point of this approach is a special choice of basis functions [7]. The unknown tangential electric field components on common interfaces are expanded into series of Gegenbauer or Chebyshev polynomials with weight factor taking into account field asymptotic at the edges. Such a choice of basis functions accelerates the convergence of the method. The algebraization of the problems in accordance with Galerkin's technique yields the final uniform system of linear algebraic equations. The cutoff frequencies of H- and E-modes are calculated as the zeros of the determinant of the matrix operator.

The key scattering problems for waffle-iron filters are shown in Fig. 2. The basic principle of the solution of both problems can be elucidated as follows. The electromagnetic fields in regular waveguide regions are written as modal expansions in terms of H- and E-modes. The cross-section eigenfunctions of multi-ridged waveguide are expressed in accordance with transverse resonance method as in [8]. Using orthogonality of waveguide modes we represent unknown amplitudes of scattered modes in terms of unknown tangential electric field on the aperture of discontinuity at $z = 0$. Enforcing the continuity of the tangential magnetic field on the aperture and substituting relations for amplitudes of scattered waves into corresponding equation yields integrodifferential equation for tangential electric field on the aperture. Actually the obtained integrodifferntial equation is the same one derived from equivalency principle for magnetic surface current density on the aperture.

For the algebraization of the key scattering problems under consideration Galerkin's method is employed. In case of double-plane step junction of rectangular waveguides (Fig. 2, b) weighted Gegenbauer or Chebyshev polynomials accounting for edge condition are used as in [9, 10] to improve the convergence of solution. By consideration of junction between rectangular and multi-ridged waveguides (Fig. 2, a) the common aperture is subdivided into rectangular subregions. The tangential electric field in subregions is approximated by expansions in terms of trigonometrical functions. After solving the final system of linear algebraic equations the generalized scattering matrices of all discontinuities are calculated. The total S-matrix of the filter is evaluated on the base of efficient combination procedure using only one matrix inversion.

3. Results

For verification of the presented theory the obtained results have been compared with experimental and theoretical data of some references (e.g. [8]) and with own experimental results. In all cases a good agreement is observed. For example, in Fig. 4 experimental and theoretical responses of low-pass waffle iron filter with 5 multi-ridged sections are shown. Some deviations of measured and calculated values of VSWR are due to fabrication tolerances. A measured insertion loss within stop-band of filter are greater than 34 dB.

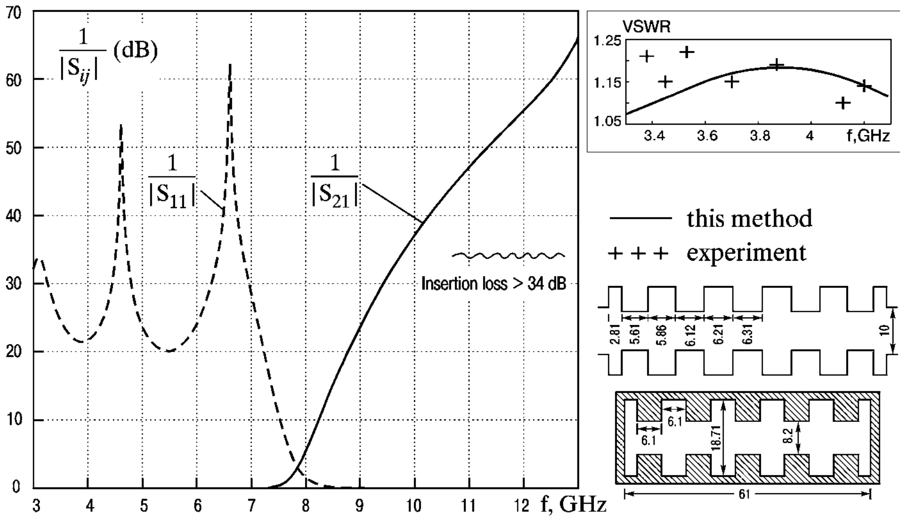
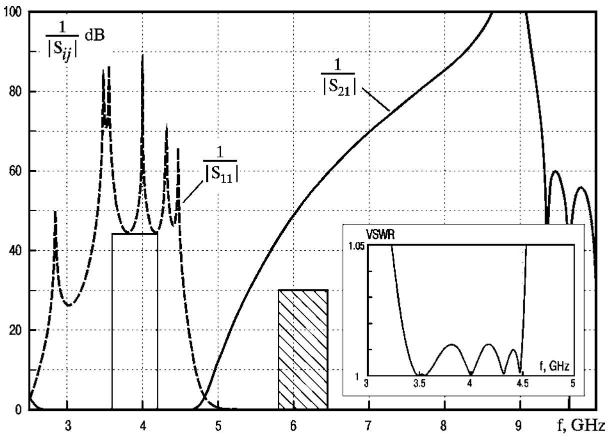
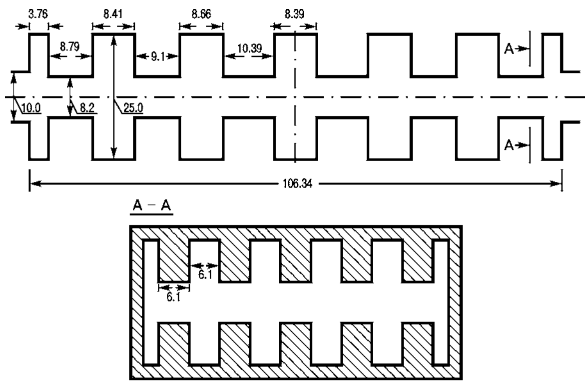


Fig. 4. Scattering parameters of waffle-iron filter with 5 multi-ridged sections (dimensions in mm).



(a)



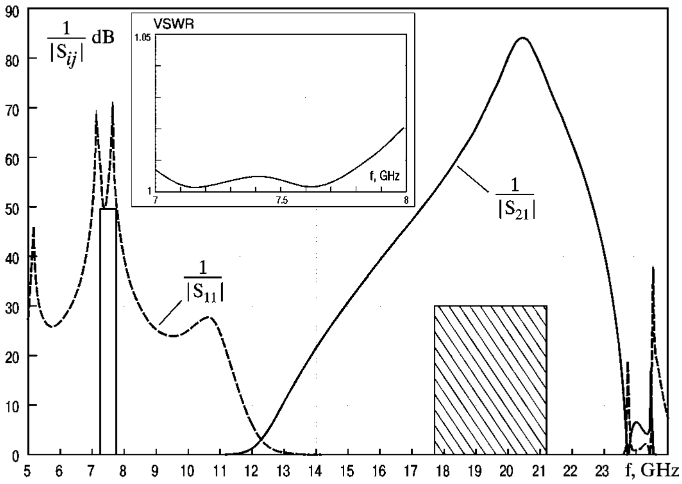
(b)

Fig. 5. Scattering parameters of waffle-iron filter with 6 multi-ridged sections. (Input waveguide dimensions: 61×10 mm).

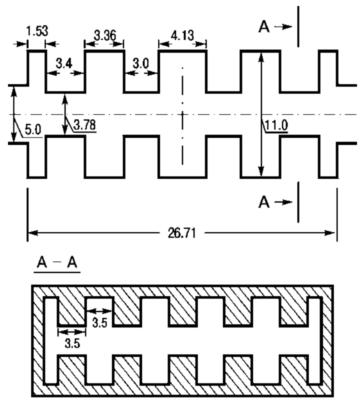
A number of waffle-iron filters for multiband feeders of reflector antennas operating in S, C, X, Ku bands has been designed. The design specifications for low-pass waffle-iron filters are formulated as follows. Typically, the filter has pass-band and one or two stop-bands. The key requirement is a low insertion loss within pass-band, therefore, VSWR of the filter has to be minimized (VSWR < 1.05). Insertion loss within stop-band should be usually greater than 30 dB. Generally, any response of the filter out of the pass-band and stop-bands is acceptable. Some design examples are plotted in Fig. 5, 6. The blank rectangle corresponds to specified pass-band of the filter and the filled rectangle shows stop-band with required insertion loss. The calculated VSWR of the both filters within the operating pass-band is about 1.01.

4. Conclusions

Accurate field theory CAD of waffle-iron filters is presented. The full wave analysis is based on combined Generalized Scattering Matrix Method/Galerkin's Method. The presented theory is in good agreement with the experimental and theoretical results of the references and with own experimental results. A number of low-loss waffle-iron filters for multiband feeders of reflector antennas has been designed.



(a)



(b)

Fig. 6. Scattering parameters of waffle-iron filter with 4 multi-ridged sections. (Input waveguide dimensions: 35×5 mm).

REFERENCES

[1]. G.L. Matthaei, L. Young, and E. M.T. Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures. New York: McGraw-Hill Book Co, 1964.

[2]. E.D. Sharp, "A High-Power Wide-Band Waffle-iron Filter", IEEE Trans. Microwave Theory Tech., vol. MTT-11, pp. 111-116, March 1963.

[3]. R. Bunger, F. Arndt, "GSM/Moment method CAD of waffle-Iron-Filters with Round Teeth", IEEE MTT-S Digest, 1999, pp.1691-1694.

[4]. F. Arndt, J. Brandt, V. Catina, J. Ritter, I. Rullhusen, J. Dauelsberg, U. Hilgefort, W. Wessel, "Fast CAD and Optimization of Waveguide Components and Aperture Antennas by Hybrid MM/FE/MoM/FD Methods – State –of-the –Art and Recent Advances", IEEE Trans. Microwave Theory Tech., vol. MTT-52, N. 1, January 2004, pp. 292-305.

[5]. F. Arndt, J. Brandt, "Direct EM based optimization of advanced waffle-iron and rectangular combline filters", in MTT-S Int. Microwave Symp. Digest, Seattle, pp. 2053 - 2056, June 2002.

[6]. G. Zargano et all, "Waveguides with complicated cross sections", Moscow: Radio i Svyaz, 1986 (in Russian).

[7]. V.P. Lyapin, M.B. Manuilov, G.P. Sinyavsky, "Quasi-analytical method for analysis of multisection waveguide structures with step discontinuities", Radio Science, Nov.-Dec. 1996, vol.31, N.6, pp. 1761-1772.

[8]. J. Bornemann, F. Arndt, "Transverse Resonance, Standing Wave, and Resonator Formulations of the Ridge Waveguide Eigenvalue Problem and Its Application to the Design of E-plane Finned Waveguide Filters", IEEE Trans. Microwave Theory Tech., vol. MTT-38, N.8, August 1990, pp.1104-1113.

[9]. V.P. Lyapin, V.S. Mikhalevskii, G.P. Sinyavskii, "Solution of problems of diffraction by plane resonant obstacles in a rectangular waveguide taking into account the edge features of the field behavior" // Radioelectronics and Communications Systems Vol. 25, 1982, No.8, pp. 7-11. (Translated from "Izvestiya VUZ. Radioelektronika").

[10]. Y. Tikhov, J.H. Ko, Y.K. Cho, "Field theory based design and comparison of two kinds of quasi-planar band-pass filters", IEE Proc. Microwav. Antennas Propag., vol.145, N. 6, December 1998, pp. 441-448.