A TWO-STEP SYNTHESIS OF BROADBAND RIDGED WAVEGUIDE BANDPASS FILTERS WITH IMPROVED PERFORMANCES

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ABSTRACT

A quarter-wave broadband ridged waveguide bandpass filter with improved stopband attenuation has been designed and realized. A two step design procedure associating Tchebychev's formulas with a rigorous optimization routine is also presented. The predicted filter performances, including the rectangular to ridged waveguide transformer, agree well with the measurements, showing improved stopband attenuation and reduced filter dimension in the Ku band.

INTRODUCTION

The design of evanescent-mode waveguide filters is now an important topic in the synthesis of passive microwave networks [1-4]. Their great attenuation in the upper stopband associated with the superior electrical performances of ridged waveguide[5] provides a convenient way to realize compact broadband bandpass filters with a sharp selectivity for their use in satellite telecommunication systems[6].

A multimodal variational formulation for characterization of waveguide discontinuities is used here due to its numerical advantages[7,8]. The design procedure associates this analysis technique with a direct search optimization routine to obtain the evanescent-mode ridged waveguide bandpass filter with required performances[7-9]. However, the determination of initial length of each waveguide section, that is the starting values of optimization routine, plays an important role and constitues the first step of our work. These values can be obtained by comparing the theoretical coupling coefficient between two waveguide resonators with J- or K-inverter prototypes[4].

Most of the lowpass and bandpass filters presented in the literature are of half-wave resonator type[1-8] which may be rather bulky in the centimeter-wave range and present a second passband located at $2f_0$, the stopband attenuation may be not sufficient for the multiplexer application. The originality of present work resides in *the design and realization of a quarter-wave resonator ridged waveguide bandpass filter*. The measured filter performances are in good agreement with the predicted data, showing improved stopband attenuation, and the total length of the realized filter has been notably reduced compared to the half-wave filters.

CHARACTERIZATION OF A DOUBLE DISCONTINUITY

By considering only the dominant-mode incidence, the multimodal variational formulation leads to a 2x2 scattering matrix[7-9] from which two reciprocal equivalent networks can be derived, as well as their immitance inverter network representation (Fig.1). When considering the equivalent T-network case, we have according to [8]

$$Z_1 = jX_{odd},\ Z_2 = j(X_{even} - X_{odd})$$

with

$$X_g = -N_1^{(1)} . N_1^{(1)*} \left(\overline{\overline{Q}}_g^{\,-1} \right)_{11}, \quad N_1^{(1)} = \left\langle \mathbf{J}_1^{(1)}, \mathbf{E}_1^{(1)} \right\rangle$$

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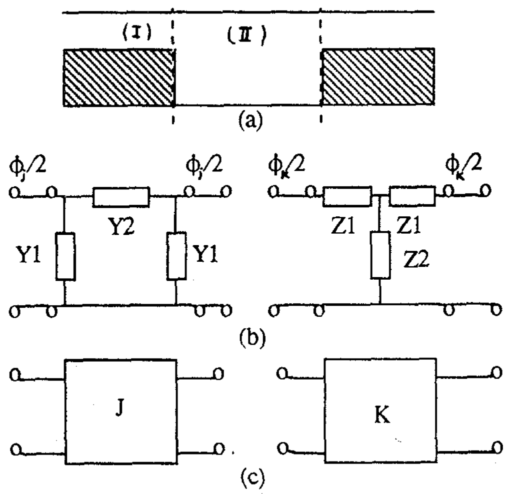

Fig.1(a)Symmetrical double discontinuity;
(b)Two equivalent networks;
(c)Corresponding immitance inverters

$$\left(\bar{Q}_g\right)_{mn} = j\sum_{k=1}^{\infty} y_{gk}\left\langle E_m^{(1)}, J_k^{(2)}\right\rangle\left\langle J_k^{(2)}, E_n^{(1)}\right\rangle, \quad J_k^{(2)} = H_k^{(2)} \times z$$

$$y_{gk} = \begin{cases} -j.\cot(0.5\beta_k^{(2)}L) & g \equiv \text{even} \\ j.\tan(0.5\beta_k^{(2)}L) & g \equiv \text{odd} \end{cases}$$

L being the inserted waveguide length with β_k the phase constant of k^{th} mode; E_k and H_k are the transverse electric and magnetic fields. The corresponding impedance inverter can then be easily deduced[4].

This formulation has been applied to the coupling coefficient of ridged waveguide resonators, showing more accurate results than those obtained by classical variational method[10] (Fig.2).

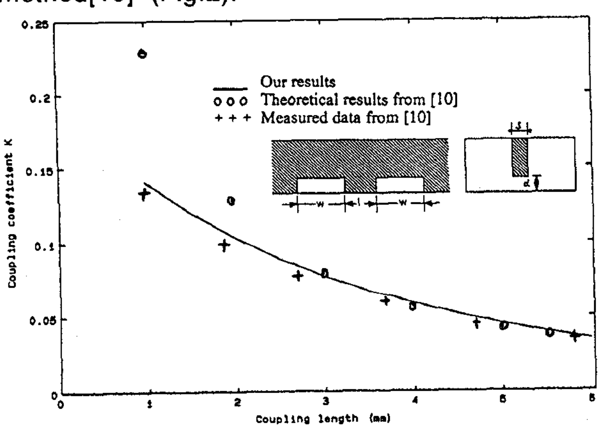

Fig.2 Coupling coefficient of ridged waveguide resonators versus coupling length

We have shown [11] that for the case of a reciprocal and lossless discontinuity, the following relations hold

$$J = K\ ;\ \Phi_j = \Phi_k + \pi$$

These relationships are very interesting since accordingly, both impedance and admittance inverters needed for the quarter-wave resonator filter design[12] can be realized by means of discontinuities of the same type. Furthermore, a quasi-constant coupling coefficient and a linearly-varying phase correction in the considered frequency range are the key points for a successful filter design. Fig.3 shows the convergent admittance inverter parameters versus frequency, obtained by using 25 modes in the propagating waveguide and 50 in the evanescent one.

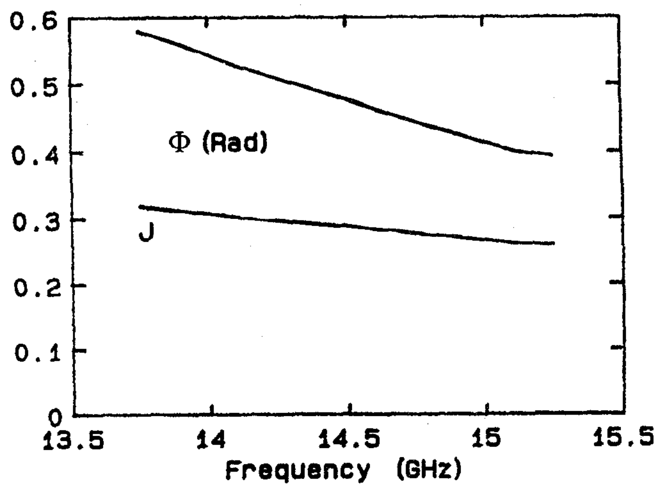

Fig.3 J-Inverter parameters versus frequency

HALF-WAVE AND QUARTER-WAVE RESONATOR FILTERS

Design procedure

Since the success of an optimzation design depends strongly on the initial parameters(the starting point), we propose here a two-step design procedure. A first-order design will be carried out by using the classical Tchebychev's formulas; the waveguide discontinuities are characterized only by their equivalent circuits at the central frequency f_0, the dispersion being neglected. This step allows to determine

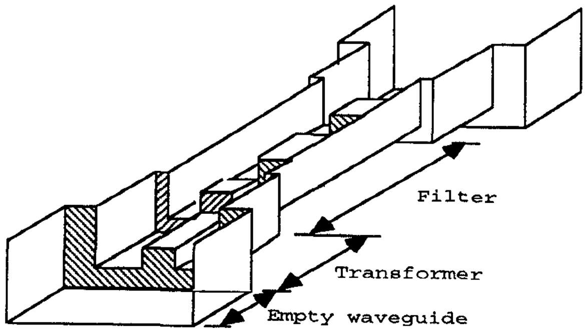

Fig.4 Evanescent-mode ridged waveguide filter

this starting point needed in the second-order design: the optimization procedure, in which all the factors(dispersion, transition, etc.) will be considered.

It will be noted that the distinction between the half-wave resonator and the quarter-wave resonator concepts can only be made by using different initial waveguide lengths. This means that only the first-order design determine the type of the filter.

First-order design

The complete filter structure shown in Fig.4 can be divided into two parts: the ridged waveguide filter and the stepped rectanglar to ridged waveguide transformer. The initial length of each section is determined separately for these two parts through the following procedure:

1)Determine the central frequency f_0, the number of resonators N and the different inversion coefficients $K\rho$ and/or $J\rho$ by using Tchebychev's formulas from the filter specifications;

2)Identify the initial lengths of evanescent waveguide sections which provide the required inversion coefficients at f_0, by using the rigorous discontinuity characterization described above; the values of $\Phi\rho$ can then be deduced;

3)Determine the initial resonator lengths;

4)Determine the number and initial lengths of a stepped quarter-wave rectangular to ridged waveguide transformer in the same way;

Second-order design

This step consists in minimizing the following error function

$$\psi(\overline{L}) = \sum_{i=1}^{N} |S_{11}(\overline{L},f_i)|^2 + \sum_{j=1}^{M} |S_{12}(\overline{L},f_j)|^2$$

f_i, f_j correspond to the sample frequencies within the passband and stopband respectively, and L is the vector containing all the waveguide lengths to be optimized. The overall scattering matrix is obtained by applying the multimodal variational formulation to the overall filter structure, including the stepped rectangular to ridged waveguide transformer. The result of the first order design serves as the starting point in this procedure, allowing more efficient minimum point search in which the final lengths of the complete filter structure will be determined.

Numerical and experimental results

Two ridged waveguide bandpass filters have been designed in the Ku-band, by using respectively the half-wave resonator and quarter-wave resonator prototypes. Eight resonators and two step-transformers have been used for each case, and the optimized reflection and transmission coefficients are given in Fig.5 and Fig.6. Considerable improvement of the stopband attenuation has been observed in the quarter-wave resonator filter case. Furthermore, the overall filter length is 76 mm for the optimized quarter-wave resonator filter, compared to 200 mm for the optimized half-wave resonator one.

A prototype of quarter-wave resonator bandpass filter has been realized by ALCATEL-ESPACE, in Toulouse, according to the optimized data. The measured return losses agree very well with the predicted data as shown Fig.7.

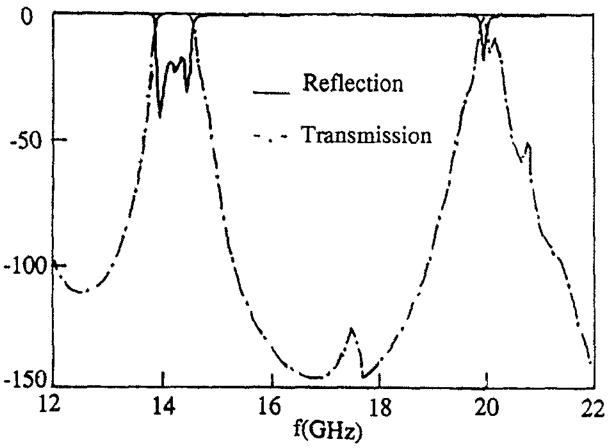

Fig.5 Predicted scattering parameters in dB for an optimized half-wave resonator bandpass filter

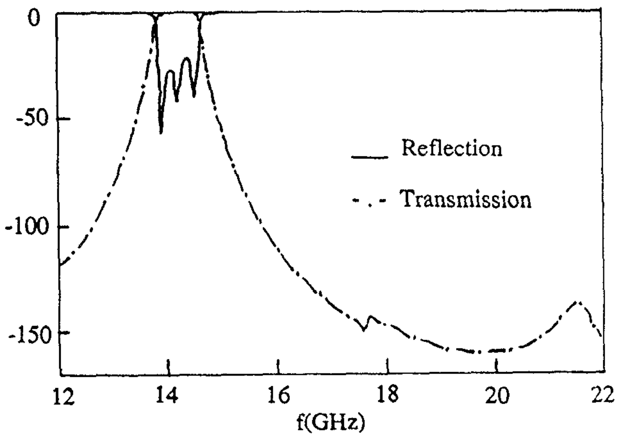

Fig.6 Predicted scattering parameters in dB for an optimized quarter-wave resonator bandpass filter

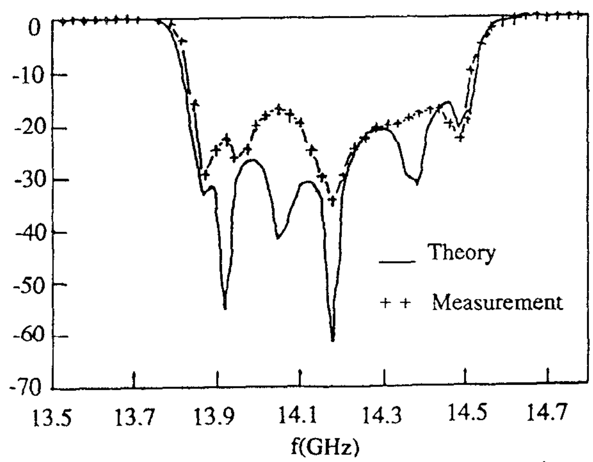

Fig.7 Comparison between predicted and measured return losses of a quarter-wave resonator bandpass filter

CONCLUSION

A quarter-wave bandpass filter with improved stopband attenuation has been designed and realized by using the ridged waveguide technology. A two step design procedure associating Tchebychev's formulas with a rigorous optimization routine is also presented. The predicted filter performances agree well with the measurements.

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REFERENCES

[1]G.F.Craven & C.K.Mok,"The design of evanescent mode waveguide bandpass filters for a prescribed insertion loss characteristic", IEEE-MTT,pp.295-308, Mars 1971

[2]C.K.Mok, "Design of evanescent mode waveguide diplexers",IEEE-MTT, pp.43-48, Jan. 1973

[3]R.V.Snyder,"Broadband waveguide or coaxial filters with wide stopbands, using a stepped-wall evanescent mode approach", Microwave Journal, pp.83-88,Dec. 1983

[4]L.Q.Bui et al.,"Broadband millimeter-wave E-plane bandpass filters", IEEE-MTT, pp.1655-1658, Dec. 1984

[5]S.B.Cohn, "Properties of ridged waveguide", Proc.IRE, Vol.35, Aug. 1947

[6]A.M.K.Saad et al.,"Evanescent-mode-serrated ridged waveguide bandpass harmonic filters", Proc. 16th EuMC, pp.287-291, 1986, Dublin

[7]J.W.Tao & H.Baudrand, "New design procedure for evanescent-mode ridged waveguide filters", Proc. of the 1989 URSI EM Theory Sym., pp.458-460 Stockholm, 1989

[8]J.W.Tao & H.Baudrand, "Multimodal variational analysis of uni-axial waveguide discontinuities", IEEE-MTT, March 1991

[9]P.Couffignal, J.C.Nanan, J.W.Tao, H.Baudrand & B.Theron, "A multimodal variational variational approach for the characterization of waveguide discontinuities for microwave filter design", Proc. 20th EuMC, 1990, Budapest

[10]Y.Konishi, "Planar circuit mounted in waveguide used as downconverter", IEEE-MTT, Sept. 1974

[11]J.C.Nanan, "Synthese des filtres passe-bande", Report Alcatel-Espace N°4, Jan. 1990

[12]G.L.Mathaei, L.Young and E.M.T.Jones,*Microwave filters, impedance matching networks and coupling structures,* Mc-Graw Hill 1964,p.465