MODELING OF COUPLINGS BETWEEN DOUBLE RIDGE WAVEGUIDE AND DIELECTRIC LOADED RESONATOR

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ABSTRACT

Full wave modeling of the coupling structure between a double ridge waveguide and dielectric resonator in a rectangular cavity through an iris is presented. Eigen modes of the double ridge waveguide, and the discontinuities of the structures are obtained by rigorous mode matching method. By applying the cascading procedure, the reflection coefficients of the coupling structure can be obtained. From the phase variation of the reflection coefficient and circuit theory, resonant frequency, input/output coupling of the structure are accurately determined. An equivalent circuit model of the resonant structure is established. The computed results are compared with those obtained by other method and shown in good agreement, which verifies the theory.

I. INTRODUCTION

Dielectric loaded resonator filters are widely used in communication systems and other microwave applications, because of their excellent characteristics, such as small size, low loss and high temperature stability. If empty rectangular waveguide is used as the input/output transmission medium, the size of the structure becomes too bulky. Ridge waveguide has lower cutoff frequency and wider bandwidth, therefore it can be used to significantly reduce the size of the input/output waveguide and in wide band applications [1]-[3].

Accurate computation of the input/output coupling and its loading effect on the resonant frequency of the first/last stage resonator is very important for the design of the high performance cavity filters. In addition, an equivalent circuit of the structure helps to understand and predict the performance of the microwave filters. Since the enclosure of the resonator is usually beyond cut off at the filters pass band, conventional theory can not be applied to obtain the coupling coefficients from the transmission parameters of the two port network. The input/output couplings are usually determined by experiment or by an approximate method [6][9] which is usually not efficient, or accurate enough for the filter design. Accurate modeling of the coupling structure is therefore essential for the determination of the input/output coupling, loaded resonant frequency and equivalent circuit of the DR structure.

In this paper, full wave mode matching method is used to model the coupling structure between the double ridge waveguide and dielectric loaded cavity. Eigen modes of the double ridge waveguide are obtained. The generalized scattering matrices of the double ridge waveguide junction to rectangular waveguide, and the dielectric resonator in rectangular waveguide discontinu-

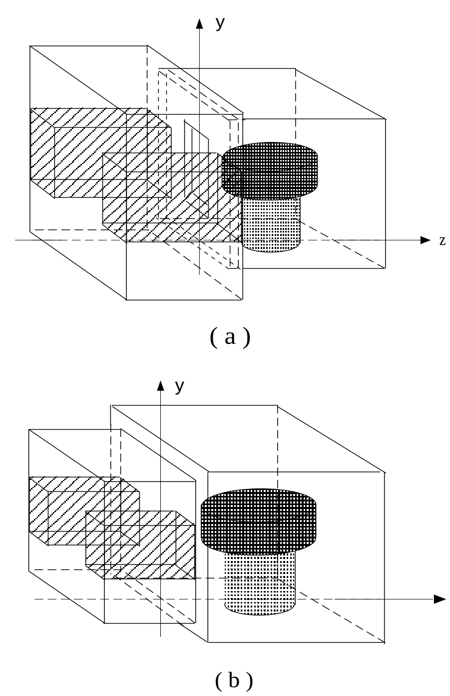

Fig. 1. Configuration of a coupling system from a double ridge waveguide to dielectric resonator, (a) Coupled through an iris; (b) Coupled through space

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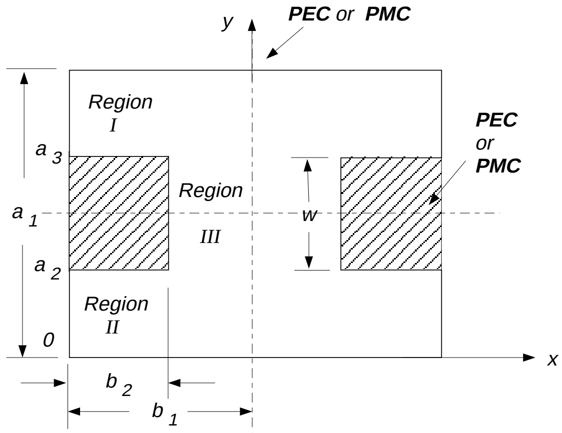

Fig. 2. Cross-section of the double ridge waveguide

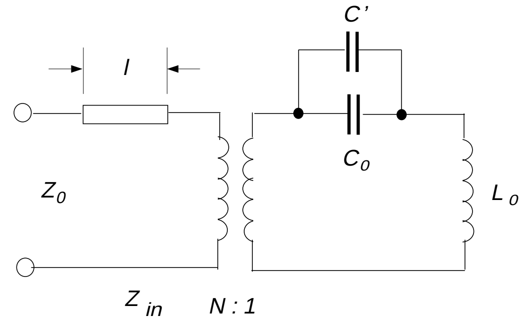

Fig. 3. Equivalent circuit of the waveguide to resonator cavity coupling structure

ities are obtained by rigorous mode matching method. Equivalent circuit of the coupling structure is established. All the parameters of the equivalent circuit are determined from the reflection coefficient of the structure. The computed results are compared with results from the finite element method, and are shown to be in good agreement.

II. CONFIGURATION AND ANALYSIS

The configurations of the coupling structure between double ridge waveguide and dielectric loaded resonator under consideration are shown in Fig. 1, where in Fig. 1-(a) the coupling through a slot; and in Fig. 1-(b) the coupling is achieved through the direct connection between the double ridge waveguide and the resonator's enclosure. To be able to effectively couple the ridge waveguide to the DR by the y-component of the magnetic field, the ridges of the double ridge waveguide have to be at the sides of the DR cavity as shown, and all the discontinuities of the coupling structures must to be characterized in order to obtain the S-parameters of the whole structure.

A. Eigen Modes of the Double Ridge Waveguide

The configuration of the double ridge waveguide is illustrated in Fig. 2. The the double ridge waveguide height is a_1 , width $2b_1$, with ridges of width w and thickness b_2. The plane at $x = 0$ at the middle of the ridge waveguide is a symmetry plane. By putting a perfect electric conductor (PEC) or a perfect magnetic conductor (PMC) at this symmetrical plane, only half the structure needs to be considered. When the ridge waveguide is also symmetrical about $y = a_1/2$ plane, even and odd modes can be determined separately by putting PEC and PMC at that symmetry plane.

A half double ridge waveguide is divided into three regions, region I, II and III, as shown in Fig. 2. The longitudinal (z directed) fields of the ridge waveguide eigenmodes are expanded in normal TE and TM modes in each region. The transverse electromagnetic fields are then expressed from the longitudinal field components. Applying the boundary conditions at the interface of the regions, and taking proper inner product, a characteristic equation for the cutoff wave number of the ridge waveguide can be obtained. Searching for the zero determinant of the equation, the cutoff wave number k_c of the double ridge waveguide can be obtained. All the field coefficients of the eigen modes can then be obtained by solving the equation.

B. Modeling of the Coupling Structure Between Double Ridge Waveguide and DR Cavity

Having found the eigenmodes and their field distributions of the double ridge waveguide, a full wave mode-matching technique can be used to obtain the generalized scattering matrices of the double ridge waveguide to iris (small rectangular waveguide), and to the resonator cavity (larger rectangular waveguide) discontinuities. The modeling procedure described in [8] is used to obtain the generalized scattering matrices of the dielectric loaded resonator in a rectangular waveguide.

Knowing the generalized scattering matrices of all the discontinuities, the whole structure can be analyzed by cascading the scattering matrices of the double ridge waveguide to rectangular waveguide discontinuity with that of the dielectric loaded waveguide shorted at its end [4][5]. From the phase variation of the reflection coefficient, one can obtain the input/output coupling and the loaded resonant frequency of the DR cavity.

C. Equivalent Circuit of the Coupling Structure

From the refection coefficients of the coupling structure, an equivalent circuit can be derived to help in the design. Since the dielectric enclosure is usually a waveguide below cut-off, it is convenient to represent the DR cavity by a resonant LC circuit, as shown in

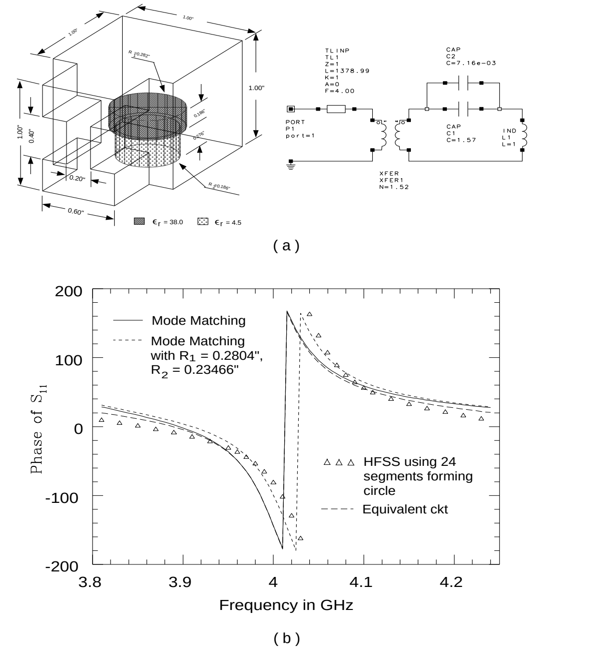

Fig. 4. (a) Configuration and the equivalent circuit of the double ridge waveguide coupled with DR cavity via space; (b) Computed phase of the reflection coefficients

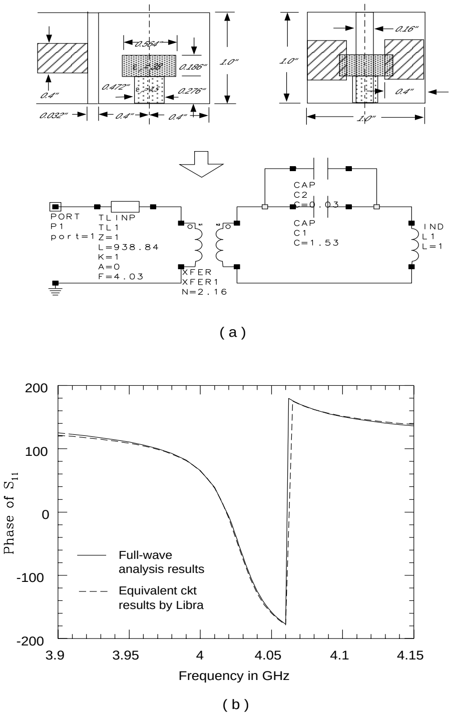

Fig. 5. (a) Configuration and the equivalent circuit of the double ridge waveguide coupled with DR cavity via iris; (b) Computed phase of the reflection coefficients

Fig. 3. L_0 and C_0 have the same resonant frequency of the unloaded DR cavity. C' represents the effect of the loading and discontinuities on the resonant frequency of the DR cavity. Thus the parallel combination L_0 and $C_0 + C'$ have the same resonant frequency of the whole structure. The transformer characterizes the coupling coefficient of the ridge waveguide to DR cavity. A length of transmission line l represents the phase offset introduced by the discontinuities.

It can be shown from the equivalent circuit that the input/output coupling coefficient R of the resonant structure is related to the phase change θ of the reflection coefficient at frequency f and to the loaded resonant frequency f_l as:

$$R = 2(f - f_l)\frac{1 - cos\theta}{sin\theta} \tag{1}$$

$$N = \sqrt{\frac{Z_o}{2\pi R}}, \qquad Q_e = \frac{f_l}{R} \tag{2}$$

by letting

$$L_o = 1.0 \ \ nH \tag{3}$$

The loaded resonant frequency can be obtained by searching for the frequency for which the variation of θ with frequency f is maximum.

III. NUMERICAL RESULTS

A computer program has been developed to implement the presented modeling method for computing the unloaded resonant frequency of the DR cavity, loaded resonant frequency of the double ridge waveguide to dielectric loaded resonator in rectangular enclosure, input/output coupling coefficient R and the parameters of the equivalent circuit of the structure.

Fig. 4 shows the computed reflection coefficients of a double ridge waveguide coupled to a dielectric loaded resonator cavity by both mode matching method and finite element method. It is seen that there is about 20 MHz difference between the resonant frequencies computed by the two methods. This is believed to be due to the method used by HFSS to approximate the circle of the structure by small segments (polygon). In the computation, 24 segments are used to form each circle with segment's ends on the circle. Thus HFSS decreases the volume of the cylindrical dielectric resonator and support, thus results in an increase of the resonant frequency of the computed structure. When the radius of the dielectric resonator and support is decreased to 0.9943 of the original value, of which the circle has the same area as the polygon approximating the circle by HFSS, the two methods give the same resonant frequency, and the results by the two methods are in good agreement. The figure also shows that

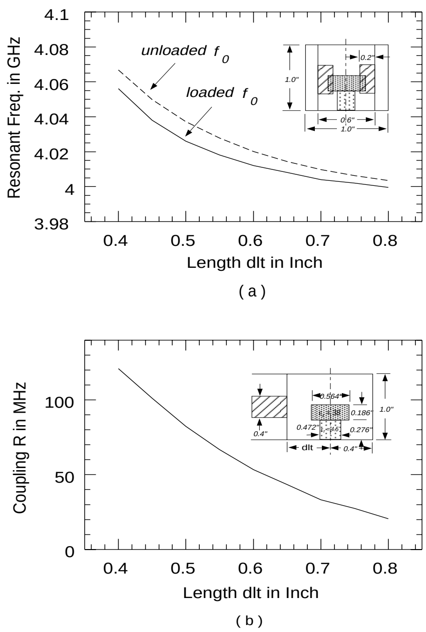

Fig. 6. (a) Unloaded and loaded resonant frequency versus the distance between ridge waveguide and DR; (b) Input/output coupling versus the distance between ridge waveguide and DR

the results obtained by the equivalent circuit are in excellent agreement with the rigorous full-wave analysis ones.

Fig. 5 gives the computed results of the coupling structure of a double ridge waveguide to a dielectric loaded resonator cavity via an iris of 1.0" in length and 0.16" in width by both full-wave analysis and the obtained equivalent circuit. Excellent agreement between the rigorous full-wave analysis and the equivalent circuit results has been obtained, and verifies the correctness of the equivalent circuit model and its parameter computation.

Fig. 6 gives the resonant frequencies and the input/output coupling of the ridge waveguide to DR cavity versus the distance between the ridge waveguide and center of the dielectric resonator. Large input/output coupling range can be obtained by space coupled ridge waveguide and the dielectric loaded resonator cavity. The coupling increases significantly when the waveguide is closer to the DR, and the loaded resonant frequency decreases only slightly. This is because the unloaded resonant frequency of the cavity increases and it cancels the effect of the loading on the loaded resonant frequency.

IV. CONCLUSIONS

Full wave modeling of the coupling structure of the double ridge waveguide to dielectric resonator in a rectangular waveguide through iris and space is presented. Eigen modes of the double ridge waveguide with the ridges at the left and right side of the waveguide, and the generalized scattering matrices of all the discontinuities in the structures are obtained. By using the cascading procedure, the reflection coefficients of the coupling structure are obtained. From the phase variation of the reflection coefficient and the circuit theory, loaded resonant frequency, input/output coupling of the structure including the effect of both waveguide discontinuities and dielectric loaded resonator are accurately determined. Equivalent circuit model of the coupling structure considering all the discontinuities is established. The good agreement between the results by present method and that by finite element method verifies the theory.

REFERENCE

[1] S. B. Cohn, "Properties of ridge wave guide," *Proceedings of I.R.E.*, vol. 35, pp. 783-789, Aug. 1947.

[2] S. Hopfer, "The design of ridged waveguide," *IRE Trans. on Microwave Theory and Techniques*, vol. MTT-3, pp. 20-29, Oct. 1955.

[3] J. P. Montgomery, "On the complete eigenvalue solution of ridged waveguide," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-19, pp. 547-555, June 1971.

[4] R. Mittra and J. R. Pace, "A new technique for solving a class of boundary value problems, " *IEEE Trans. on Antennas and Propagation*, vol. AP-11, pp. 617, Sept. 1963.

[5] A. S. Omar and K. Schünemann, "Transmission matrix representation of finline discontinuities," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-33, pp.765-770, Sept. 1985.

[6] A. E. Atia and A. E. William, "Measurements of intercavity coupling," *IEEE Trans. on Microwave Theory and Techniques*, vol. MTT-23, pp. 519-522, June 1975.

[7] S.-W. Chen and K. A. Zaki, "Dielectric ring resonators loaded in waveguide and on substrate," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-39, pp. 2069-2076, Dec. 1991.

[8] X. P. Liang and K. A. Zaki, "Modeling of cylindrical dielectric resonators in rectangular waveguides and cavities," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-41, pp. 2174-2181, Dec. 1993.

[9] G. L. Matthaei, L. Young, and E. M. T. Jones, " Microwave Filters, Impedance-Matching Networks and Coupling Structure," *New York: McGraw-Hill*, 1984.