ANALYSIS OF POWER HANDLING CAPACITY OF BAND PASS FILTERS

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ABSTRACT

A general analysis method on power handling of the microwave band pass filter is presented. The total stored energy in each resonator of the filter is computed from the normalized general two-port network. By comparing the stored energy to the maximum electric field in the resonator, the power handling capacity of the filter can be accurately determined. The method is general and can be applied to any coupling matrix of the filter and type of the resonator used. An inductive window waveguide filter has been analyzed to verify theory by comparing the results with that obtained by full wave mode matching method and shown to be in excellent agreement.

I. INTRODUCTION

Narrow bandwidth microwave band pass filters have been widely used in satellite and wireless communication systems. As the frequency spectrum becomes more and more crowded, the bandwidth of the filter has tended to be narrower, and the power density has tended to be increasing. Very high close to band rejections are frequently seen in the applications to prevent the interference. Furthermore, the size and mass of the band pass filters have tended to be smaller. As a result, the power handling capability of the transmit filters has become a very important issue for both terrestrial and space communication systems.

The power handling capacity of the band pass filter has been an important topic for years. Cohn and Young studied the power handling and peak internal field of the direct coupled cavity filters in 50's and 60's[1][2]. Nishikawa *et al* analyzed the internal field intensity in a quarter cut TE_{01} mode dielectric image resonator filter [4]. Recently, the stored energy and peak internal voltage inside the resonator of certain types of band pass filters has been studied by various authors [6]-[8]. However, a general analysis method is highly desirable to be able to solve any type of the filter without restriction.

In this paper, a generalized analysis method on power handling capacity of the band pass filters is presented based on the normalized filter prototype and resonator field distribution. The total stored energy in each resonator of the filter is computed from the general two-port network. By comparing the stored energy to the maximum electric field in the resonator, the power handling capacity of the filter can be accurately determined. An inductive window waveguide filter has been analyzed to verify the theory by comparing the results with that obtained by full wave mode matching method and shown to be in excellent agreement.

II. THEORY

Consider the general two-port n-loop band pass filter network with normalized source

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impedance R_1 and terminated with a resistive load R_2, shown in Fig. 1. The circuit consists of N series resonators with resonant frequency ω_i ($i=1,\ldots,N$). A normalized frequency independent coupling M_{ij} can exist between the resonator i and j. Assume the line impedance of each resonator to be normalized to unity characteristic impedance:

$$z_0 = \sqrt{\frac{L_i}{C_i}} = 1 \tag{1}$$

$$L_i = C_i = \frac{1}{w_i}, \qquad w_i^{\,2} = \frac{1}{L_i C_i} \tag{2}$$

The loop equations of the network can be expressed in matrix form as [3][5]:

$$ZI = V \tag{3}$$

$$[R + s + jM][i_1, i_2, \ldots, i_N]^t = [e_1, 0, 0, \ldots, 0]^t \tag{4}$$

where

$$s = \frac{j}{w'}\left(\frac{w}{w_0} - \frac{w_0}{w}\right) \tag{5}$$

$$w' = \frac{BW}{f_0}, \qquad M_{ii} = -l_i \tag{6}$$

λ_i is the normalized resonant frequency of the resonator of the general n-loop prototype network.

The total stored energy in each resonator and output power of the practical filter can be computed from the current of each loop as:

$$W_i = \frac{1}{4}L_i i_i^{\,2} + \frac{1}{4}C_i v_{c_i}^{\,2} = \frac{1}{2}L_i i_i^{\,2} = \frac{i_i^{\,2}}{2w_0} \tag{7}$$

$$P_0 = \frac{1}{2}R_2 w' i_N^2 \tag{8}$$

Equation (7) and (8) imply two important properties of the microwave band pass filters: (1) The stored energy of the resonator in a band pass filter will be scaled down by ω_0 from its unity resonant frequency network. (2) The stored energy to output power ratio of the filter will be scaled up by fractional bandwidth of the filter from its unity fractional bandwidth prototype.

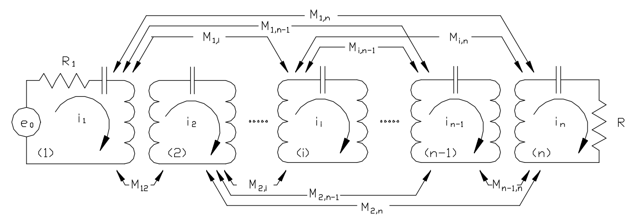

Fig. 1 General multi-coupled resonator band pass filter

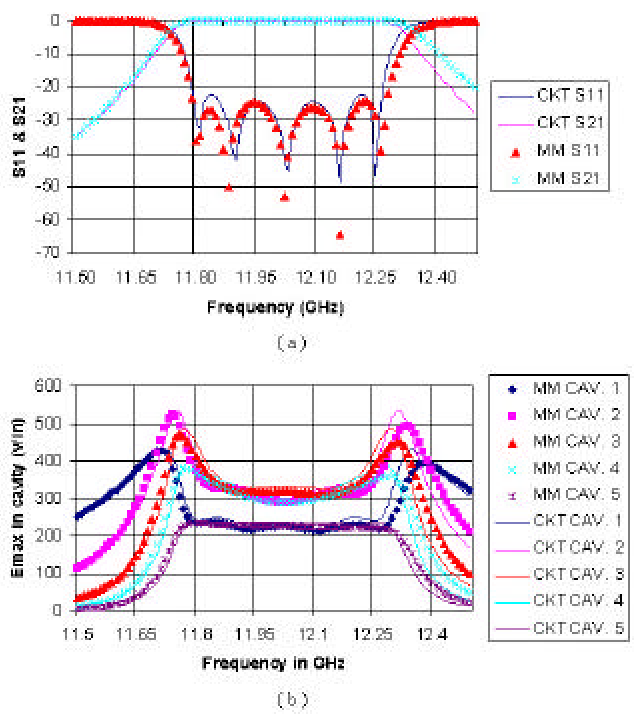

Fig. 2 Computed frequency responses and maximum electric fields in the cavities of the 5-pole waveguide filter with 1 Watt input power.

After obtaining the stored energy within each resonator of the filter, the peak internal electric field intensity within the resonator can be determined from the relationship of the field distribution and stored energy of the type of resonator used [4]. Assuming the stored energy of the resonator is proportional to the peak electric field strength square of the resonator:

$$W \propto E_0^2 \qquad (9)$$

The maximum power handling capacity of the filter can therefore be determined by setting the maximum field intensity within the resonator to be the breakdown threshold value, and compute the maximum input/output power. The breakdown electric field strength of the air is 2600 V/mm at 1 Atm pressure [6].

III. NUMERICAL RESULTS

To verify the theory, a 5-pole H-plane inductive window waveguide filter presented in [8] has been used to compute the power handling of the filter by both the proposed method and full-wave mode matching method. The filter has center frequency of 12.026 GHz and 470 MHz bandwidth with coupling matrix of R_1=R_2=1.178, M_{12}=M_{45}=0.928, M_{23}=M_{34}= 0.662. The filter is using WR75 waveguide with cavity length 0.523”, 0.589”, 0.597”, 0.589”, 0.523”, and iris width 0.383”, 0.252”, 0.223”, 0.223”, 0.252”, 0.383” of 0.050” thickness, respectively. Fig. 2 present the computed frequency responses and maximum electric field in the cavities when 1 Watt of power is input into the filter using both the presented method and the full wave mode matching method. The computed results by the proposed method are in excellent agreement with that by full wave mode matching method. The maximum power handling capacity of the waveguide filter can be easily determined from Fig. 2 to be about 15,000 Watts.

In the above computation, the following equations are used to compute the power through a rectangular waveguide operating in TE_{10} mode and the stored energy of a TE_{101} mode rectangular cavity:

$$P = \frac{ab}{4}\frac{b}{wm}E_0^2 \qquad (10)$$

$$W = \frac{abl}{8}eE_0^2 \qquad (11)$$

For most of the regular shaped waveguides and cavities, the power flowing through the waveguide and the stored energy in the resonator can be obtained analytically.

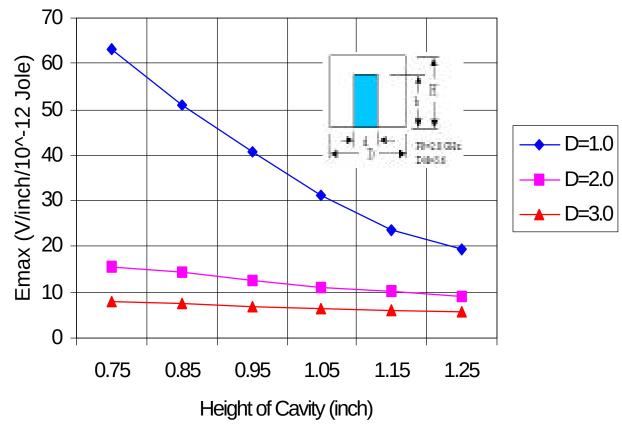

Fig. 3 Maximum electric field of a PCS band combline resonator with 10^{-12} Jole stored energy versus height and diameter of the resonator.

Numerical techniques have to be used to obtain the stored energy and field distribution of the resonator for more complicated structures. Fig. 3 presents the computed maximum electric field in a PCS band combline resonator with 10^{-12} Jole stored energy versus height and diameter of the resonator. It is shown that a shorter resonator with smaller diameter has larger peak internal electric field, therefore it has lower power handling capability.

Transmission zeros close to pass band can greatly affect the stored energy distribution in the resonators of the filters. Fig. 4 shows the computed frequency responses and stored energy of the resonators of a 5-pole filter with three transmission zeros at lower pass band side versus frequency. The filter has center frequency of 1910 MHz and 12 MHz bandwidth. The coupling matrix of the filter is given as [9]:

$$R_1 = R_2 = 1.300$$

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$$M = \begin{bmatrix} 0.02167 & 1.012 & 0.000 & 0.000 & -0.1093 \\ 1.012 & 0.0228 & 0.3328 & -0.4933 & 0.4608 \\ 0.000 & 0.3328 & 1.07421 & 0.2042 & 0.000 \\ 0.000 & -0.4933 & 0.2042 & 0.5286 & 0.9011 \\ -0.1093 & 0.4608 & 0.000 & 0.9011 & 0.0280 \end{bmatrix}$$

It is seen that the stored energy of the 3rd resonator is about 27 times higher than that of the 5th resonator at the band edge. The 3rd cavity determines the power handling capacity of the 5-pole filter.

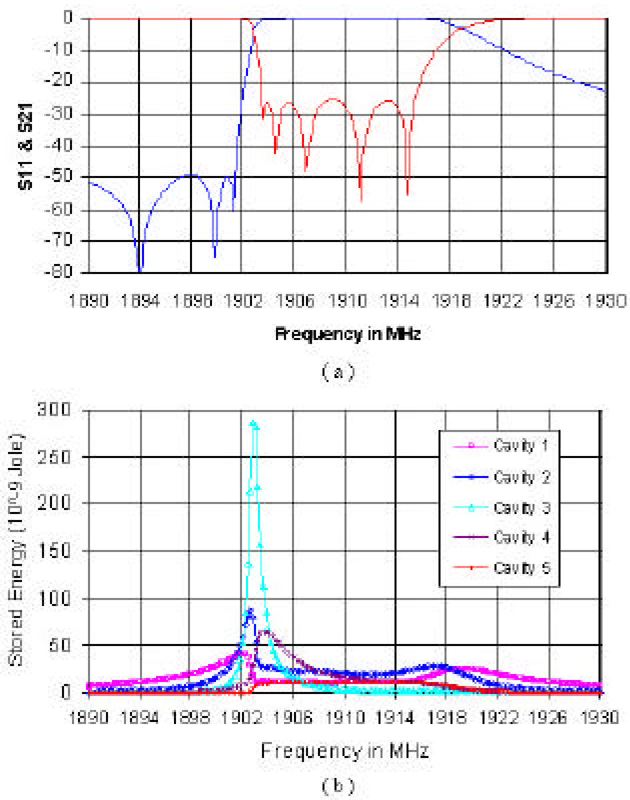

Fig. 4 Computed frequency responses and stored energy in the resonators of the 5-pole PCS band filter with 1 Watt input power.

CONCLUSIONS

A generalized method on analyzing the power handling of the microwave band pass filter has been presented. The total stored energy in each resonator of the filter is computed from the normalized general two-port network. By comparing the stored energy to the maximum electric field in the resonator, the power handling capacity of the filter can be accurately determined. No restriction applies to the coupling matrix of the filter and type of the resonator used. The computed results have been compared with that obtained from the full wave numerical method and shown to be in excellent agreement.

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