

Tunable Waveguide Filter Design using Topology optimization based on the ON/OFF method

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In this study, we propose a two-dimensional (2D) metallic waveguide filter to achieve the bandpass operation in microwave band. This waveguide device can select the operation frequency according to tuning the gap of the metallic barriers in the device. The waveguide device is designed using a systematic design approach based on the topology optimization combined with the On/Off method. The design objective is defined as maximizing the integration of the transmitted electric field intensity at the target frequency. The configuration of the derived optimal structure is modified using parametric studies assuring the frequency selectivity. We confirmed the performance of the proposed waveguide device at X-band using numerical simulations.

Index Terms— Design optimization, electromagnetic analysis, electromagnetic devices, waveguide junctions

I. INTRODUCTION

RECENTLY, microwave applications have been rapidly recognized that the performance of the microwave devices is sensitive to select the operation frequency so that it could require accurate frequency selection within the operating bandwidth. Several types of waveguide filters have been widely used to select the operation frequency of the device and it is repeatedly proposed using theoretical and experimental approaches [1]. In microwave band, conventional methods such as the simulation program with integrated circuit emphasis (SPICE) lead to the serious error of the circuit analysis [2]. In this study, we propose a 2D metallic waveguide filter to control the operation frequency using the topology optimization based on the On/Off method. The topology optimization is the systematic design method for the design of microwave applications on the contrary to the conventional method. The topology optimization is generally regarded as one of the gradient based method that suffers from sharp variation of the design sensitivity by using a conductive material in the microwave band [3]. In topology optimization based on the On/Off method, the design sensitivity is defined using the finite difference approximation (FDA) based on the On/Off algorithm [4]. The proposed design process is unaffected from the unstable sensitivity analysis and the greyscale problem.

In this study, we propose a simple shaped waveguide filter tuning the operation frequency in microwave band. Fig. 1 shows a schematic diagram for the concept of this study where the incident wave pass through the waveguide filter at the operation frequency while it is blocked at the cut-off frequency. The performance of the proposed device is verified using numerical simulations.

II. NUMERICAL ANALYSIS

The EM wave in TE₁₀ dominant mode is excited at the input port with the port power of 1.0 W. The incident EM wave

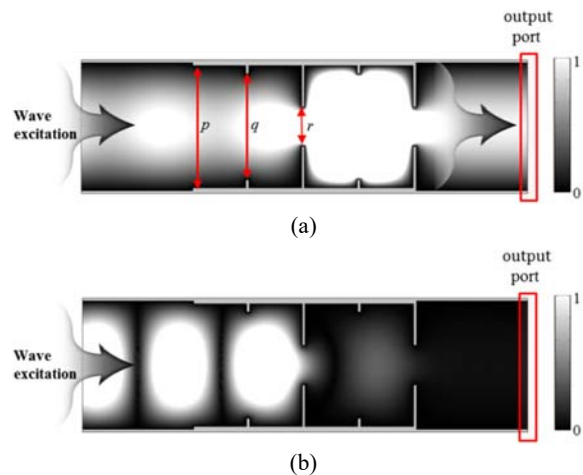


Fig. 1. Schematic diagram for the concept of this study. (a) Electric field transmission at the operation frequency and (b) the field blocking at the cut-off frequency.

propagates to the output port in Fig. 1. The TE wave propagation in rectangular waveguide is analyzed by solving the time harmonic Helmholtz equation as the following equation:

$$\nabla_{xy}^2 H_z + (\gamma^2 + k^2) H_z = 0 \quad (1)$$

where γ is the propagation constant and k is the wavenumber which is defined to the relative permittivity and permeability with the speed of light. H_z is a longitudinal component of magnetic field toward the direction of the energy flow. In this study, the waveguide filter is composed of the non-magnetic conductive material such as aluminum and copper.

III. DESIGN PROCESS

The On/Off method defines the status of each element in the design domain as the density value of 1 (On) or 0 (Off). The element status ‘On’ and ‘Off’ represents the solid material as a good conductive material and the void material as an air. The On/Off method is applied to the boundary element of the

structure with the close and open filtering scheme [5]. Therefore, the proposed method guarantees a clear boundary shape. The objective function is defined as the following equation:

$$\text{Maximize } F = \frac{\sum |S_{21}|_{f=f_R} + |S_{11}|_{f=f_T}}{\sum |S_{21}|_{f=f_T} + \sum |S_{11}|_{f=f_R}} \quad (2)$$

where $\begin{cases} f = 10\text{GHz} & \text{if } f = f_T \\ f < 9.5 \text{ and } f > 10.5\text{GHz} & \text{and } f \neq 10\text{GHz} \text{ if } f = f_R \end{cases}$

where f_T is a target frequency of 10GHz and f_R is the other frequencies except the target one in the X-band between 9.5 GHz and 10.5 GHz. Setting the f_R range as in Equation (2) guarantees single bandpass with the sharp skirt property. We carried out the design sensitivity analysis using the FDA based on the On/Off method as the following equation [4]:

$$\frac{\Delta F}{\Delta \varphi} = \frac{F(\varphi(\rho_{On})) - F(\varphi(\rho_{Off}))}{\varphi(\rho_{On}) - \varphi(\rho_{Off})} = F(\varphi(\rho_{On})) - F(\varphi(\rho_{Off})) \quad (3)$$

where $\varphi(\rho) = \begin{cases} 1 & \text{if } \rho = \rho_{On} \text{ (status of element 'On')} \\ 0 & \text{if } \rho = \rho_{Off} \text{ (status of element 'Off')} \end{cases}$

where φ is the characteristic function and F is the design objective function.

IV. NUMERICAL RESULT

Fig. 2 shows the S-parameter plot of the derived optimal model for target frequency of 10GHz. The derived model provides the good skirt property with the insertion loss of -33.10 (dB) which converts to a transmitted rate of 99.50%. The derived model is composed of the planar shaped metallic barriers with $\lambda/4$ period in the waveguide. We performed additional parametric studies to design the tunable bandpass filter dealing with the operating frequency. The center frequency of the device is changed by variation of the principle parameters p , q , r which are derived from the gap of the metallic barriers in Fig 1(a). The parameter p was fixed and orthogonal distances of the gap of the metallic barriers such as parameters q , r were determined from the parametric studies. Table I represents the results of the parametric studies tuning the operating bands.

V. CONCLUSION

We proposed a tunable waveguide bandpass filter for X-band using a systematic design approach based on topology optimization combined with the On/Off method. The values of the principle parameters derived from the optimal model are selected from the additional parametric studies. The proposed device can select the operating bandwidth varying the principle parameters. We confirmed the performance of the proposed device using numerical simulations. Proposed design approach in this study may be useful for design of microwave applications.

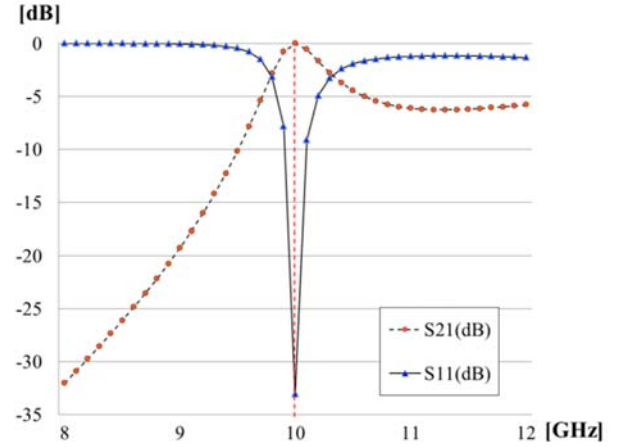


Fig. 2. S-parameter plots of the derived optimal model for target frequency of 10 GHz.

TABLE I
TRANSMITTED RATE FOR TARGET FREQUENCY ACCORDING TO PRINCIPLE PARAMETER VARIATIONS

| Target frequency (GHz) | 9.1 | 9.3 | 9.7 | 10.0 | 10.5 | 11.0 | 11.3 | 12 |
|------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
| q (mm) | 22 | 21 | 17 | 15 | 16 | 13 | 12 | 10 |
| r (mm) | 11 | 10 | 10 | 10 | 9 | 8 | 8 | 8 |
| Transmitted rate (%) | 99.53 | 99.89 | 99.72 | 88.50 | 94.99 | 99.00 | 99.63 | 99.32 |

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