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새로운 금속막대 커패시터를 적용한 감쇄모드 도파관 대역통과 여파기

김병문* · 윤리호* · 이상민** · 홍재표***

Evanescent-mode Waveguide Band-pass Filter Applied by Novel Metal Post Capacitor

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요 약

본 논문에서는 보다 편리한 튜닝을 위해 Evanescent-Mode Rectangle Waveguide(EMRWG)에 삽입된 새로운 작은 직경의 원통형 포스트 커패시터를 제안하였다. EMRWG급전을 위한 제안된 구조는 입력 및 출력 끝에서 도파관과 동일한 너비와 높이를 갖는 단일 리지 직사각형 도파관을 사용하였다. 삽입된 포스트 커패시터는 EMRWG의 넓은 벽체 하부 중앙에 형성된 원형 홈과 상부에 삽입된 동심원기둥 포스트로 구성된다. 먼저 제안된 구조에 대한 등가회로 모델을 제시하였고, EMRWG와 단일 리지 도파관이 결합될 때 이상적인 변압기의 접합 서셉턴스와 권선비는 각각 HFSS(3d fullwave 시뮬레이터, Ansoft Co.)를 사용하여 두 가지 경우에 대해 시뮬레이션하였다. 얻어진 매개변수와 EMRWG의 특성을 이용하여 삽입된 기둥의 서셉턴스 및 공진 특성을 분석하였다. 중심주파수 4.5GHz, 대역폭 170MHz의 2포스트 필터는 WR-90 도파관을 이용하여 설계하였으며, 등가회로 모델에 대한 계산과 HFSS와 CST를 이용한 시뮬레이션 결과가 서로 일치하였다.

ABSTRACT

In this paper, a novel small-diameter cylindrical post capacitor inserted into an evanescent-mode rectangular waveguide (EMRWG) is proposed for easier tuning. In order to feed the EMRWG, the proposed structure uses a single ridge rectangular waveguide with the same width and height as the waveguide at the input and output ends. The inserted post capacitor are made up a circular groove formed in the center of the lower part of the broad wall of the EMRWG, and a concentric cylindrical post inserted into the upper part. First, the equivalent circuit model for the proposed structure is presented. When the EMRWG and the single ridge waveguide are combined, the joint susceptance and the turns ratio of the ideal transformer are calculated by two simulations using HFSS (3d fullwave simulator, Ansoft Co.) respectively. The susceptance and resonance characteristics of the inserted post were analyzed by using the obtained parameters and the characteristics of the EMRWG. A 2-post filter with a center frequency of 4.5 GHz and a bandwidth of 170 MHz was designed using a WR-90 waveguide, and the simulation results by using the HFSS and CST, equivalent circuit model were in good agreement.

키워드

Evanescent Waveguide, Junction Susceptance, Post Capacitor, Circular Groove
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Ⅰ. Introduction

A rectangular waveguide is a basic guiding structure of microwave which is widely used in various systems such as antenna feeding structure and radar systems. Even though planar guiding structures such as strip line or microstrip have surpassed waveguide structure in many techniques like integration and miniaturization of the system, the structure is still inevitable in many applications such as feeding network for large antenna system and high power radar system. Inductive and capacitive post inserted filters and a waveguide limiter are the familiar examples that widely used in radar system [1-3].

It is well known that the size of a waveguide structure is depends on the wavelength of its operational frequency which is usually large. Therefore, miniaturization techniques of a waveguide structure have always attracted interest from the microwave community. One of the methods that has been researched and used is a evanescent mode rectangular waveguide (EMRWG) which operate under the cut-off frequency [4]. A filter using this structure is a well-known example that control is propagation properties though the length of inserted post in the EMRWG. The transition characteristic of a EMRWG and propagation mode rectangular waveguide (PMRWG) has been studied [5, 6] and an admittance measurement technique for an EMRWG, proposed by Carven and Mok [7, 8], used to calculate evanescent mode equivalent admittance for first order filter design. Even though the admittance of the EMWG can be altered through varying the distance between the lower end-plane of the inserted post and bottom surface of the waveguide, a variation of the admittance along the distance between them is too sensitive to adjust them at the exact target point.

In this paper, we demonstrate evanescent-mode band-pass filter using post capacitor with circular groove to lessen a sensitivity of admittance variation along the length of the post. We suggest an equivalent circuit of the filter and analyze it through the comparison with simulation results of commercial full-3D simulators, the one is ANSYS's HFSS and the other is Dassault system's CST studio suite [9, 10].

Ⅱ. Evanescent-mode band-pass filter

The proposed evanescent-mode band-pass filter is shown in Fig. 1. The filter is formed in three sections; ridged waveguide to rectangular waveguide junction, which is marked as A, evanescent-mode waveguide, which is marked as B, and rectangular waveguide to ridged waveguide junction, which is marked as C. In the evanescent-mode waveguide, two post capacitors and circular grooves are inserted to control a transmission characteristic of the band-pass filter more easily. Detailed theories and comparisons of the various analysis are explained in the following sub-sections.

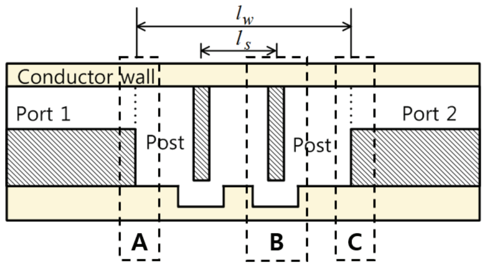

Fig. 1 A longitudinal view of proposed evanescent-mode band-pass filter

2.1 Waveguide junction

Generally, an area of the cross-sectional view of EMWG with rectangular waveguide structure is smaller than an area of the cross-sectional view of PMWG. In case of the ridged waveguide structure, the size of ridge of EMWG is smaller than it with PMWG. Due to theses size difference, a susceptance is occurred at the interface between rectangular waveguide and ridged waveguide. To calculate this junction susceptance, we need design a junction between single-mode PMWG and EMWG [7, 8, 11]. Fig. 2 shows a cross-sectional and side view of the waveguide junction. To minimize an impedance mismatch due to the size mismatch between two types of waveguide, we used a WR-90 for both an EMWG and a PMWG whose cut-off frequency is 6.557 GHz.

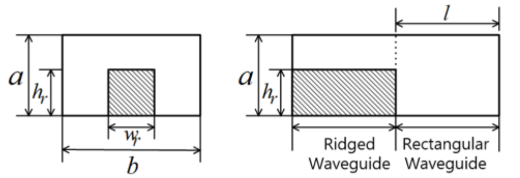

Fig. 2 Cross-sectional view and longitudinal view of the waveguide junction

Then we insert a rectangular ridge to build a PMRWG which maintains a single-mode propagation from 2.972 GHz to 4.5 GHz. An input admittance at the intersection between two waveguides are a function of junction susceptance $Y_J(=1/Z_J)$, turns ratio of a transformer n_H , and load admittance Y_K $(=1/Z_K)$ [12] and can be expressed as an equivalent model like Fig. 3 [13, 14].

$$Y_{in} = \frac{1}{Z_{in}} = \frac{1}{Z_J} + \frac{n^{2_H}}{Z_K} \quad (1)$$

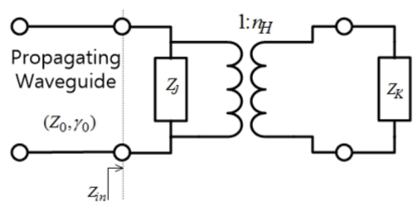

Fig. 3 Equivalent junction model

We extracted junction susceptance Y_J and transformer turn ratio n_H from measured input admittances of two different EMRWG cases, the one for $l=11mm$ and the other for $l=22mm$. S-parameters, characteristic impedance, and propagation constant of the junction was obtained through ANSYS HFSS simulation at the range from 3.0 GHz to 6.0 GHz. Table 1 shows detailed dimensions of waveguide junction.

Table 1. Dimensions of waveguide junction part

Parameters	Values[mm]
a	22.86
b	10.16
w_r	12.00
h_r	8.38
l	11/22

We used WR-90 rectangular waveguide as a reference waveguide for EMWG and PMWG. The transformer turns ratio n_H and junction susceptance Y_J had been calculated through MATLAB and presented in Fig. 4.

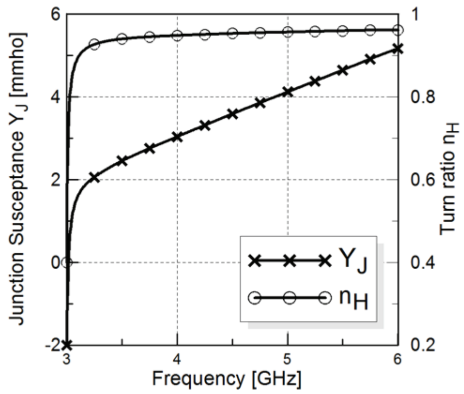

Fig. 4 Junction susceptance and transformer turns ratio

The junction susceptance Y_J and a turn ratio at the center frequency 4.5 GHz are 3.5899 $m℧$ and 0.9530, respectively. Both parameters becomes negative number at the frequency band lower than

3.02 GHz. This seems to be due to an increase of the characteristic impedance of the PMRWG near its cut-off frequency.

2.2 Post capacitors and circular grooves in the EMWG

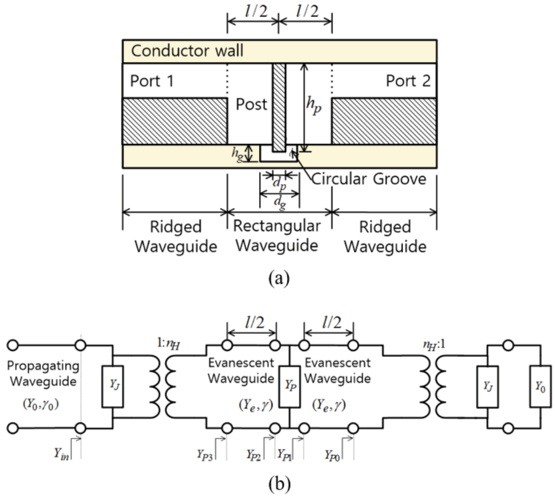

Fig. 5 (a) EMWG with post-inside-grooving capacitor and (b) its equivalent circuit model

Fig. 5 shows longitudinal view of the EMWG which contains post capacitor and circular groove at the bottom of the EMWG. The Susceptance between post and circular groove $Im[Y_p]$ can be calculated through following equations.

$$Y_p = Y_{p2} - Y_{p1} \tag{2}$$

A Susceptance looking from the post to the EMWG Y_{p2} , from the EMWG to the post Y_{p1} , a susceptance of the post, and EMWG can be defined as follows.

$$Y_{p1} = Y_{po}\frac{Y_{po} + Y_e \tanh \gamma l/2}{Y_e + Y_{po} \tanh \gamma l/2} \tag{3}$$

$$Y_{p2} = Y_{po}\frac{Y_{p3} + Y_e \tanh(-\gamma l)/2}{Y_e + Y_{p3} \tanh(-\gamma l)/2} \tag{4}$$

$$Y_{po} = (Y_J + Y_o)/n^{2_H} \tag{5}$$

$$Y_{p3} = (Y_{in} + Y_J)/n^{2_H} \tag{6}$$

$$Y_e = 1/jX_o \tag{7}$$

Table 2. Dimensions of the post and circular groove in EMWG

Parameters	Values[mm]
d_p	2.00
h_p	9.74
d_g	3.00
h_g	1.00
l	31.50

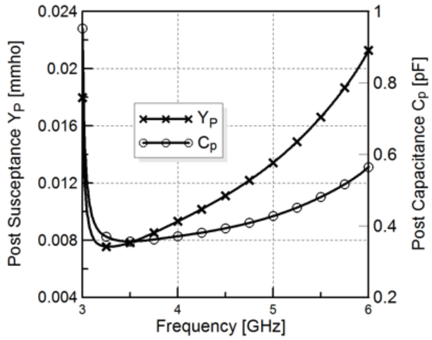

Fig. 6 Post susceptance and capacitance

Fig. 6 is a plot of a susceptance between the post and a circular groove which both are aligned with the center point of the EMWG. Detailed parameters to design the EMWG are in the Table 2. Since the post susceptance maintains a positive number along the frequency band from 3.49 GHz to 6.0 GHz, it acts like capacitance which is in the range of $0.3562\,pF \leqq C_P \leqq 0.5642\,pF$ and is proportional to the operational frequency. This is due to the increase of a fringing field between the bottom surface of the post and the surface of the circular groove [15].

An input admittance of the EMWG is calculated through both an equivalent circuit model and HFSS Full 3-D simulation. A comparison of both methods are shown in Fig. 7 with a good agreement in the range from 3.0 GHz to 6.0 GHz. An input admittance at the center frequency is $Y_o = 19.94 + j0.81\,m℧$ which is also well matched with a characteristic impedance of a single ridge waveguide $Y_o = 20.00\,m℧$. These results tell us that the model we used and a calculation method we did are appropriate for an analysis of the proposed EMWG.

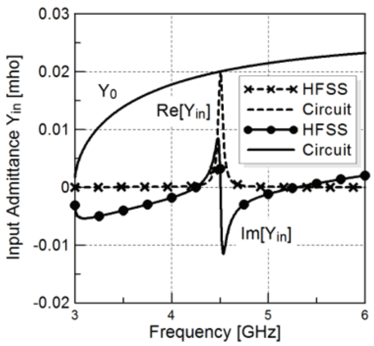

Fig. 7 A comparison of the input admittance using a HFSS simulation and an equivalent circuit model

We compared the post capacitance variations over the post length in the case with a circular groove and without a circular groove (Fig. 8). The comparison had been done at 4.5 GHz. We found that the post capacitance in the case with circular groove changed less rapidly than the case without circular groove. When $h_p = 9.74\,mm$, C_p is 0.3930 pF for the case without a circular groove and 0.5039 pF for the case with a circular groove. Slops for both cases in the point are $0.0391\,pF/mm$ and $2.9090\,pF/mm$.

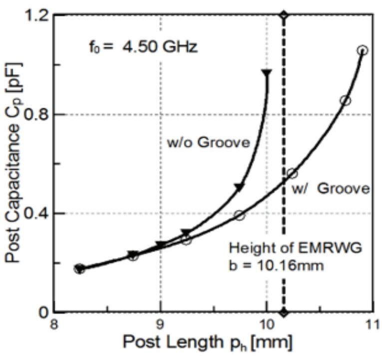

Fig. 8 A comparison of the post capacitance over the post length with/without a circular groove

This means when design a waveguide filter, inserting a circular groove makes the filter less sensitive to the physical length of the post. The post length is a key parameter for matching the filter. In this sense, designer can effectively and more accurately control the center frequency of a designing filter.

2.3 EMWG filter with post-inserted-grooving capacitor

We proceed to design a EMWG filter with two post-inserted-grooving capacitors as depicted in Fig. 1. To design the filter at a center frequency of 4.5GHz and band width of 170 MHz, we calculated a length of the EMWG l_w and a distance between two posts l_s using an equivalent circuit model as illustrated in the previous chapter. Moreover, an optimization through ANSYS HFSS has been done using the calculated parameters as initial values. Input admittances and scattering parameters are plotted in the Figs. 9 and 10.

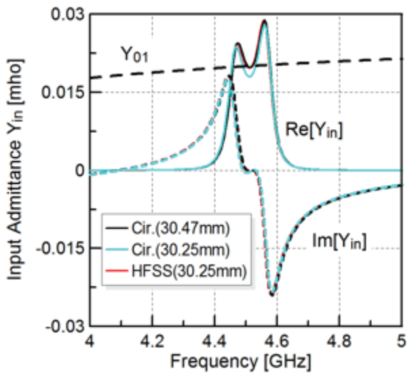

Fig. 9 Input admittance of the EMWG filter

The calculated initial value of l_s is $30.47\,mm$ and the optimized valued through HFSS simulation is $30.25\,mm$, which shows 0.73% difference between them. An input admittance of a circuit model used $l_s = 30.25\,mm$ shows a good agreement with that of HFSS result except a very minor difference at the center frequency.

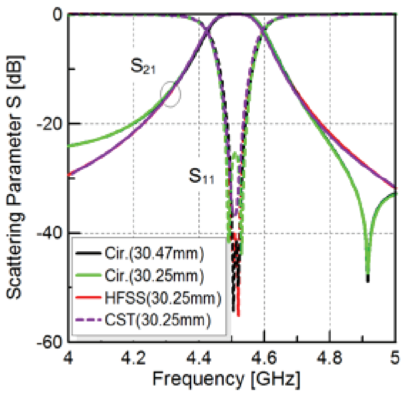

Fig. 10 Scattering parameters of the EMWG filter

Scattering parameters for both cases also well matched except regions blow 4.2 GHz and 4.8 GHz. These minor differences seem to be caused by an absent of a coupling effects between two posts at an equivalent circuit model.

Ⅲ. Conclusion

In this paper, we designed EMWG filter using two-post-grooving capacitor. To analyze each sections of the filter, we build an equivalent circuit model and extracted parameters from its admittance. From that model, we calculated an initial value for key parameters for desired filter characteristic and optimized it through commercial simulation tools.

In the future, we plan to design and manufacture a Near-field scanning microwave microscopy probe with a lower center frequency and narrower band. The probe is intended to be applied for internal inspection of human body and dielectric objects.

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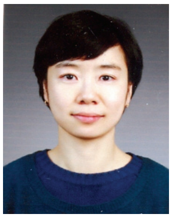

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