

Waveguide Bandpass Filter Using Artificial Magnetic Conductor

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1. Introduction

Since then precursors of the electromagnetic bandgap structure opened a new sphere of the electromagnetic material field, it is certain that the electromagnetic bandgap structures have extensively donated their own merits to many parts of microwave application [1]-[3]. And the enormous research has been made in order to make the most use of the electromagnetic bandgap structures.

The electromagnetic bandgap structure has an attribute of diminishing surface wave so it has been used to the microwave components which require a prevention of the surface wave resulted from system. And the electromagnetic bandgap structure also exhibits a characteristic that they do not make reflected phase of an electromagnetic wave inversed, namely phase reversal [2]. Such a feature has been often compared to that of the perfect magnetic conductor, so the electromagnetic bandgap structure is usually referred as AMC, artificial magnetic conductor, and many researchers have taken notice of its good property to overcome several shortcoming points of the microwave components. Moreover, the artificial magnetic conductor can be easily manufactured by etching method of high frequency laminate with simple photolithography process so it has peculation to other parts of the electronics. And many researchers have also added a variety of approaches toward the artificial magnetic conductor – dynamic modeling, equivalence behavior theory, genetic synthesis method and so on [4]-[5].

In this paper, we suggest a new application of the artificial magnetic conductor for rectangular waveguide bandpass filter. Proposed bandpass filter exploits a nature of artificial magnetic conductor and rectangular waveguide. Besides, the artificial magnetic conductor used in the filter has been synthesized by the genetic algorithm for satisfying desired properties and conditions.

We will show the simple concept of proposed filter in section II and explain the detailed design procedures in section III. Experimental measurement and discussion are described in section IV, and section V for conclusion follows.

2. Basic Concept

The proposed E-plane bandpass filter consists of X-band rectangular waveguide and two substrate of artificial magnetic conductor substrates which form a vertical septum, as simply depicted in Fig. 1. Proposed waveguide bandpass filter holds the artificial magnetic conductors in its interior along the E-plane so that the inner part of the waveguide section would be halved into two parallel square waveguide

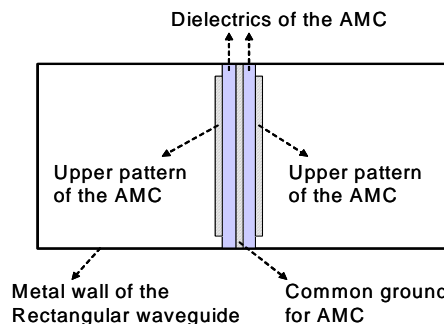


Fig. 1. Cross sectional view of the proposed E-plane rectangular waveguide bandpass filter.

paths which induce increasing cut-off frequency of the fundamental waveguide mode. Therefore, in other frequency band which is not in operation band of the artificial magnetic conductor, the lowest band of the waveguide does not make transmission and the stopband can be shown because the artificial magnetic conductors exhibit a characteristic of the perfect electric conductor and then, they are nothing but metal. But in certain frequency range, the artificial magnetic conductor inserted in waveguide interior makes reflection phase of the incident electromagnetic wave vicinity of zero, the square waveguide can support the passband due to boundary condition caused by artificial magnetic conductor and allow the fundamental modes to propagate. So we can ensure the stopband in other frequency region below the second higher mode because of the cut-off phenomenon of waveguide, and permit the pass-band in the specific frequency range owing to embedded artificial magnetic conductor.

### 3. Design Process

#### A. Motivation of the Operation Band

The very first step of designing bandpass filter is a forecast of the operation bands through the use of simple but fundamental electromagnetic theory of waveguide.

Let us assume the rectangular waveguide of broadside length  $a$  and vertical length  $b=a/2$  which is filled with a homogenous medium  $\epsilon, \mu$ . It is evident that the cut-off frequency,  $f_{cut}$  of fundamental mode in the given waveguide is calculated as equation (1).

$$f_{cut} = \frac{\sqrt{\mu\epsilon}}{2a} \text{ [Hz]} \quad (1)$$

If the broadside wall is shortened so that the waveguide would have a square dimension of aperture, the starting frequency  $f'_{cut}$  where the lowest mode can propagate will be doubled as equation (2).

$$f'_{cut} = 2f_{cut} = \frac{\sqrt{\mu\epsilon}}{a} \text{ [Hz]} \quad (2)$$

So in the case of the waveguide that has two parallel square cross sections like Fig. 2, the lowest mode that is able to travel through this waveguide starts from  $f'_{cut}$  and no power can get through waveguide below  $f'_{cut}$  because inserted isolation metal wall makes the cut-off frequency of the fundamental mode doubled. Assume that we place two perfect magnetic conductors as the isolation wall just like E-plane septum in Fig. 3, one can easily obtain the cut-off frequency of the lowest propagation mode from boundary condition that the magnetic field diminishes on perfect magnetic conductor so it can be confirmed that obtained cut-off frequency is identical to  $f_{cut}$  by nature. At this point, we suggest an artificial magnetic conductor which has the operation band  $\Delta f$  ( $f_{cut} < \Delta f < f'_{cut}$ ) instead of the perfect magnetic conductor in Fig. 3. The artificial magnetic conductor resembles perfect magnetic conductor in a certain frequency band, i.e.  $\Delta f$ , so the passband can be presented below cut-off frequency  $f'_{cut}$  and we are able to promise the stopband in other frequency range in  $f_{cut} \sim f'_{cut}$ .

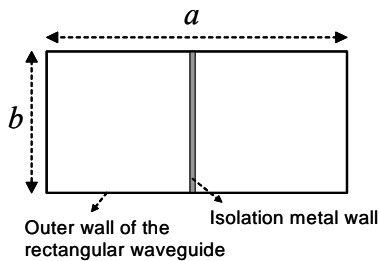


Fig. 2. A circumstance that the rectangular waveguide is halved into two square waveguide by vertical isolation metal wall

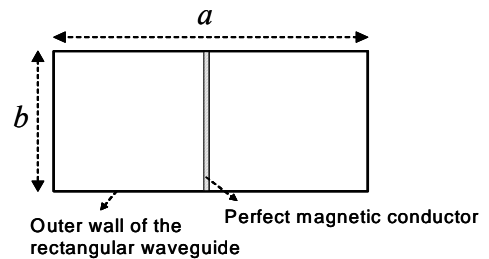


Fig. 3. Waveguide embedding a perfect magnetic conductor as vertical isolation wall

Such interesting features can be interpreted as an equivalence of filter and we have exploited it in order to make the waveguide bandpass filter.

### B. Synthesis of the Embedded Artificial Magnetic Conductor

We have checked an availability of the artificial magnetic conductor for use of E-plane waveguide bandpass filter. The next step for designing filter is how we can choose passband and construct the structure which acts as perfect magnetic conductor in the desired band. In this paper, a synthetic method using genetic algorithm has been used for optimizing artificial magnetic conductor for the proposed waveguide bandpass filter. The genetic algorithm is simple but powerful method for optimization and widely used in many fields of science and engineering owing to its general purpose concept, simple calculation process, robustness of evolution process [5]-[6]. We have used the genetic algorithm for obtaining artificial magnetic conductor which is satisfying desired conditions such as center frequency, unit cell size, specific substrate and required bandwidth. As shown in Fig. 4, the upper conductor of the artificial magnetic conductor is divided into smaller cells, and they are converted into binary encoded digit array like '0000000111...', namely chromosome. And additional information describing other factors such as substrate properties and metallic via is attached to chromosome of pattern and we can apply genetic algorithm by using the obtained chromosome.

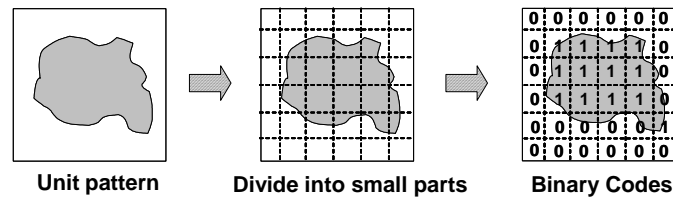


Fig. 4. Discrete representation of the upper pattern to be etched by photolithography process for the artificial magnetic conductor

### C. Arrangement of the Overall Structure

After the artificial magnetic conductor for the waveguide bandpass filter is obtained, it is possible to combine the rectangular waveguide and the synthesized substrates. Two identical artificial magnetic conductors are placed in the X-band waveguide and adjusted so that two substrates would be leaning against each other. Inserted artificial magnetic conductor has the periodicity along the traveling axis and repeats itself as Fig. 5. Embedded artificial magnetic conductor divides the rectangular waveguide into two parallel square waveguide, so they impede propagation below cut-off frequency and allow pass-band if the inserted substrate plays an important role as the artificial magnetic conductor in a certain frequency range. And their periodicity may increase the steepness of the filter since it is apparent that more cells get unwanted band to be rejected significantly. By using all of discussed factors, we performed the full-wave simulation of whole structure in the aid of MWS (CST MicroWave Studio v5.0), and Fig. 6 gives the simulated result.

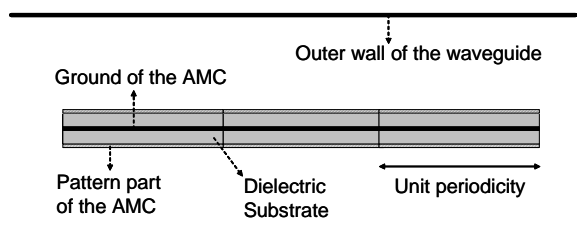


Fig. 5. Horizontal (H-plane) cross section of the filter

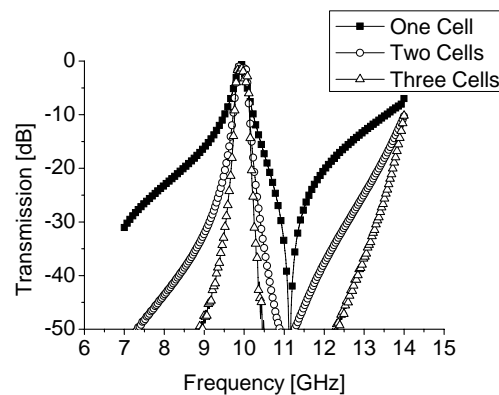


Fig. 6. Simulated transmission of the proposed filter as augmentation of inserted cells

#### 4. Measurement and Discussion

We fabricated the waveguide which are fitted with standard flanges of rectangular waveguide for X-band, and appearance of the manufactured waveguide bandpass filter can be seen in Fig. 7. Overall dimension including two flanges is about 41.4 x 41.4 x 110 [mm<sup>3</sup>] (width, height, length). And it is measured with the vector network analyzer (VNA) HP8510 via standard waveguide measurement flanges. Measured performance acquired from the experiment of the proposed waveguide bandpass filter can be verified in Fig. 8.

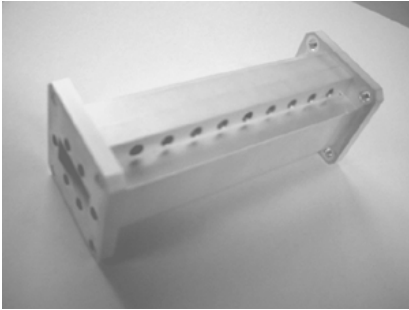


Fig. 7. Photography of the proposed waveguide bandpass filter

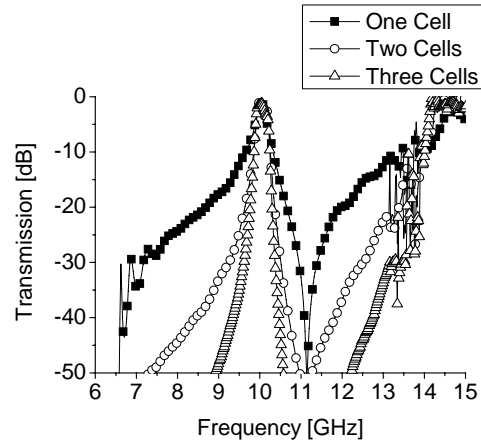


Fig. 8. Measured result of the proposed filter with respect to the number of embedded artificial magnetic conductor cells

#### 5. Conclusion

A waveguide bandpass filter which firstly utilizes the artificial magnetic conductor as an E-plane septum has been suggested and evaluated. Proposed filter embeds the substrates that act a role of the artificial magnetic conductor in the waveguide and operates as bandpass filter because of the cut-off phenomenon and AMC operation of inserted cells. Design processes that have been used to the suggested filter are described with theories of waveguide and artificial magnetic conductor. The filter accomplishes the suppression of the spurious passband in the higher band with simply designed isolation walls and shows high selectivity in the passband of the waveguide. It is certain that the proposed structure can be manufactured with low cost and simple process, so this filter is expected to be used widely in the microwave passive component applications.

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