Transmission Characteristics of a FSS Resonator for Rectangular Waveguide Filter

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Abstract

Transmission characteristics of a new FSS structure for waveguide filter is investigated. The structure for designing waveguide filter consists of circular ridged aperture and four armed conducting patch. This structure has a pass-band between two adjacent stop-bands, for which the equivalent circuit representation is considered.

Keywords: waveguide filter, resonant ridged aperture, series and parallel resonance

1. Introduction

According to the Bethe's theory of diffraction by small holes[1], the transmission cross section T [m^2] of the small circular aperture whose diameter l is much smaller than wavelength λ is proportional to $(l/\lambda_0)^4 \cdot l^2$ [m^2]. So the transmitted power P_t through the small aperture is given by $P_t = P_i \times (T \text{ [m}^2\text{]})$, which is very small. Here P_i means an incident power density.

Recently lots of researches have been done on the method for increasing the transmission efficiency of the small apertures in the design area of the near filed scanning optical microscope (NSOM) probe. As aperture structures which have been widely studied, representative are H-shaped, C-shaped apertures[2][3], and circular ridged aperture[4][5]. Through these previous works, it has been found that the transmission cross section (TCS), as a criterion for the transmission efficiency, are almost the same under the transmission resonance condition for the above three structures. The TCS is given by $(3\lambda^2)/(4\pi)$ [m^2] for the above three cases independent of the small aperture size and shape.

This work aims at examining the usability of the above transmission resonant structure as a filter ingredient structure. So we are going to investigate the transmission characteristics of the waveguide band-pass filter which comprise variation of iris with a small circular ridged aperture.

2. Transmission characteristic of a new FSS structure

Here we are going to propose a new FSS structure composed of circular ridged aperture and four armed patch reported as in [6]. This structure has a pass-band between two adjacent stop-bands, for which the equivalent circuit representation is considered.

2.1 Circular ridged aperture in waveguide

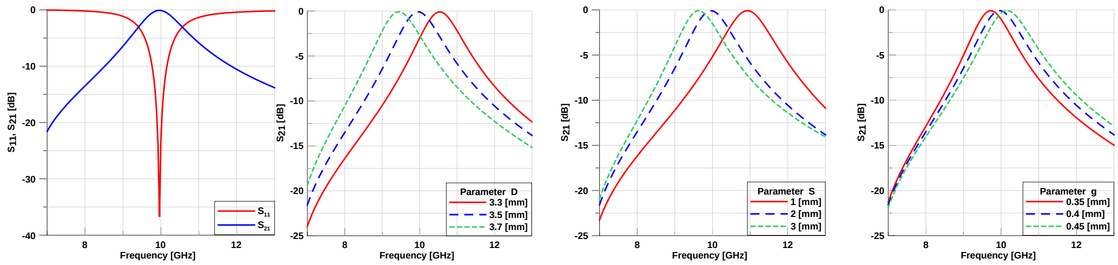
To begin with, circular ridged aperture structure in Fig. 1(a) is dealt with for understanding the resonant behaviour of the proposed FSS structure in Fig. 1(b). In the waveguide problem, an original circular aperture whose diameter is much smaller than the wavelength behaves like inductive element. But by loading the circular aperture with capacitive element such as two ridges, the parallel resonance condition is satisfied so that pass-band characteristics appears as shown in

Fig. 2(a). Therefore the equivalent circuit of the circular ridged aperture structure is thought of a parallel combination of an inductive element and a capacitive element in Fig. 3(b).

(a) (b)

Figure 1: Circular ridged aperture structure and new FSS structure with four armed patch.

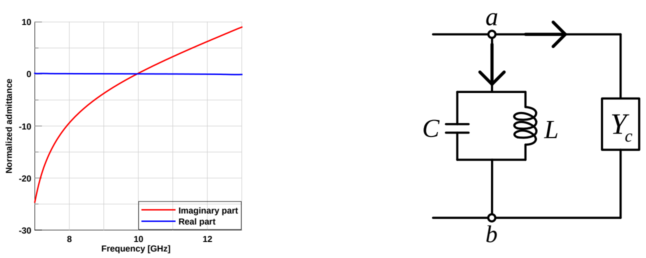
The center frequency of the pass-band can be changed by changing the geometrical parameters such as D (diameter), S (ridge width), g (ridge gap) as shown in Fig. 2(b) - (d) respectively.



(a) (b) (c) (d)

Figure 2: Transmission property of circular ridged aperture structure and its variation versus D, S, and g

If we combine four armed conducting patch reported in [6] and the above circular ridged aperture structure, we have a new FSS structure having a pass-band and two stop-bands as shown in Fig. 6(a). To understand clearly why the FSS structure shows this pass-band and rejection-band characteristics in the waveguide, it is useful to plot normalized admittance ($\overline{Y_a} = Y_a / Y_c$, where Y_c is characteristic admittance of the rectangular waveguide) versus frequency at the transverse plane only for the circular ridged aperture case in Fig. 1(a) by use of calculated values S_{11} and relation $\overline{Y_a} = 2S_{11}/(1+S_{11})$ between $\overline{Y_a}$ and S_{11}. Fig. 3(a) shows a plot of normalized admittance ($\overline{Y_a}$) versus frequency.



(a) (b)

Figure 3: Normalized admittance and equivalent circuit of circular ridged aperture structure.

As seen in Fig. 3, the imaginary part of $\overline{Y_a}$ is changed from inductive component below the resonant frequency to the capacitive component above the resonant frequency. This corresponds to the parallel LC circuit in Fig. 3(b). For reference, the normalized admittance is zero at resonance so that the port a-b in Fig. 3(b) is open for the circular ridged aperture structure case. Therefore total transmission occurs at the pass-band frequency and this is known as parallel resonance mechanism.

2.2 Four armed conducting patch in the waveguide

To obtain the equivalent circuit of the four armed conducting patch structure in Fig. 4(b), normalized admittances of both a simple rectangular patch and a four armed patch versus frequency are plotted respectively in Fig. 5(a) and (c). Note that the simple rectangular patch behaves like simply capacitive element in all frequency range. For the four armed patch structure case, the normalized admittance undergoes very rapid change near the resonant frequency, which is typical to the series LC resonant circuit. So the equivalent circuit of the four armed patch is thought of a series combination of an inductive element and a capacitive element in Fig. 5(d).

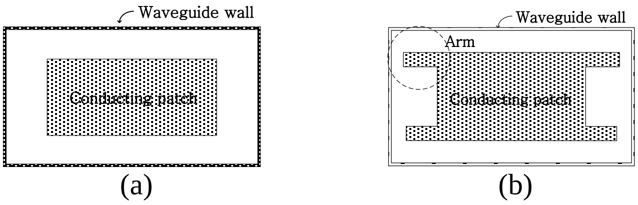


Figure 4: (a) Simple rectangular patch structure and (b) four armed patch structure

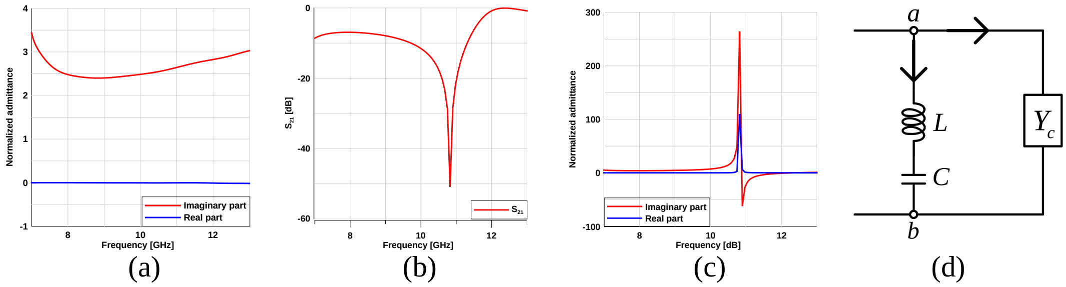


Figure 5: (a) Normalized admittance for the single patch, (b) S21 the four armed patch, (c) Normalized admittance for the four armed patch, and (d) equivalent circuit for four armed patch.

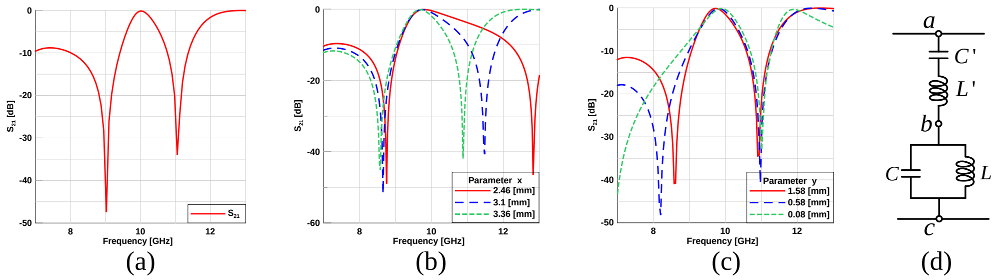


Figure 6: Transmission properties of the new FSS structure.

2.3 New FSS structure with four armed patch in the waveguide

Fig. 6(a) shows a typical transmission characteristics of the present structure in Fig. 1(b) in the rectangular waveguide. The center frequency of the pass-band is determined by the parallel LC circuit of the circular ridged aperture structure itself as mentioned above. The overall equivalent circuit for the present strcuture is represented as in Fig. 6(d). The equivalent circuit for the structure is represented as in Fig. 6(d). Below the transmission resonant frequency of the ridged aperture, the input impedance at port b-c becomes inductive as shown in Fig 3(a). So the total inductive component ($L + L'$) is combined with the capacitive component (C') to form the series LC resonant circuit at port a-c, which produces the lower frequency band rejection.

On the other hand, above the transmission resonance frequency of the circular ridged aperture, the circular ridged aperture becomes capacitive (C). This capacitive component is combined with the capacitive element (C'). In this case the four arms at the 4 corners seem to play important role of providing the desired inductive component of L' for the upper band rejection frequency. So the total capacitive component ($CC'/C+C'$) is combined with the inductive component (L') to form the series LC resonant circuit at port a-c, which produces the higher frequency band rejection.

It has been observed that the center frequency of the pass-band is never changed as shown in Fig. 6(b) and (c) even if the gap x and the arm length y are varied. The equivalent circuit can give an answer for this question. As seen, this is because the center frequency of the pass-band is determined only by the resonance frequency of the parallel LC resonant circuit for the ridged aperture.

3. Conclusion

Transmission characteristics of a FSS element, which consists of resonant ridged aperture in the four armed conducting patch, is investigated for application to waveguide filter. This structure is thought to be useful because the pass-band and stop-band can be almost independently controlled by varying the shapes of ridged aperture and armed patch respectively

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