Electromagnetic Transmission through Small Resonant apertures

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Abstract

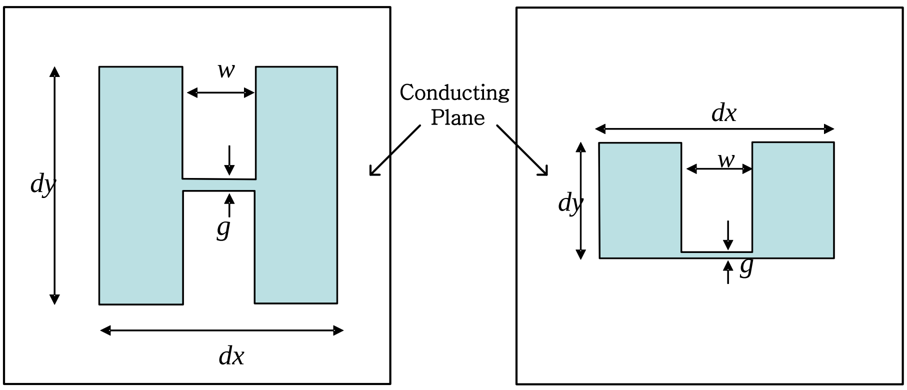
Transmission resonance phenomena were investigated for both H-shaped and C-shaped apertures and compared with that for the circular ridged aperture. It was found that the transmission sections(areas) are the same at resonance for all the three structures.

Keywords: Transmission resonance, H(C)-shaped aperture

1. Introduction

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

Recently many researches have been done on the method for increasing the transmission efficiency of the small aperture in the design area of a nano-scale optical probe, i.e., in the design area of the near field scanning optical microscope(NSOM) probe for near field optical applications such as optical data storage, nano-lithography, and nano-microscopy. In these prior works, H-shaped[2] or C-shaped[3] apertures as shown in Fig. 1 were mainly studied.



(a) H-shaped aperture

(b) C-shaped aperture

Figure 1: H-shaped and C-shaped apertures.

In parallel, as a problem similar to the above H-shaped aperture, the transmission characteristics through the resonant (ridged) aperture as shown in Fig. 2 has been investigated.

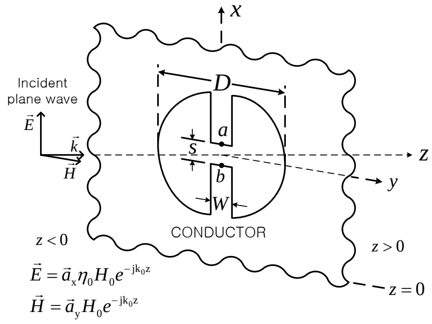


Figure 2: Small circular ridged aperture as a simplified model for the H-shaped aperture

In this problem, the resonant ridged aperture means the one whose geometrical parameters such as diameter D, ridge width w, and ridge gap s are appropriately chosen so that the input impedance between port $a-b$ may become real. This is called "transmission resonance condition". It was found[4][5] that, under this transmission resonance condition, the incident power on the transmission cross section(area) ($=(2G\lambda^2)/(4\pi)\,[\mathrm{m}^2]$, where G means the gain $(=1.5)$ for short magnetic current element) is transmitted through the ridged aperture. In this case the transmitted power P_t through the ridged aperture is given to be the incident power density $[\mathrm{W/m}^2]$ multiplied by the transmission cross section T $\left(=2G\lambda^2/4\pi\ [\mathrm{m}^2],\ G=1.5\right)$ independent of shape and the size of the small aperture. This study aims at investigating whether the transmission cross sections of the small resonant H-shaped and C-shaped aperture at resonance follow the expression $\left(T=3\lambda^2/4\pi\right)$ for that of the ridged aperture.

2. Two types of resonant apertures

Here we are going to deal with two types of resonant apertures, H-shaped and C-shaped apertures which have been widely studied from the viewpoint of transmission power enhancement in the design area of near field probe. For numerical analysis, Rao-Wilton-Glisson(RWG) method was used to obtain the transmission cross sections for the two cases.

2.1 **H-shaped aperture**

For the case that $dx=10\,\mathrm{mm}$, $dy=10\,\mathrm{mm}$, $w=3\,\mathrm{mm}$, and $g=0.5\,\mathrm{mm}$, we calculated the characteristics of transmission cross section T versus frequency from 5 to 8 GHz. In Fig.3, the solid line represents the frequency characteristics of T.

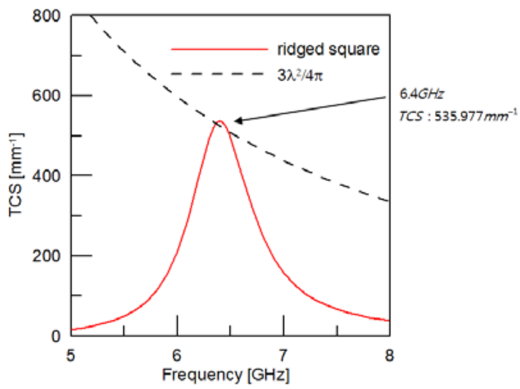


Figure 3: Frequency characteristics of transmission cross section for H-shaped aperture.

The dotted line shows the curve for the transmission cross section T which is given by $T = 3\lambda^2/4\pi = \frac{3}{4\pi}\left(\frac{c}{f}\right)^2$ [m^2] at every transmission resonance frequency f. At 6.4 [GHz], two values $\left(\cong 535.977\,\mathrm{m}^2\right)$ of TCS from two curves are seen to correspond almost to each other.

2.2 **C-shaped aperture**

For the case that $dx = 10\,\mathrm{mm}$, $dy = 5\,\mathrm{mm}$, $w = 3\,\mathrm{mm}$, $g = 0.25\,\mathrm{mm}$ in the C-shaped structure as in Fig.1(b), which has been obtained by bisecting the H-shaped structure in Fig.1(a), we obtained the frequency characteristics of T and compared with the value obtained by use of the curve for $T = \frac{3}{4\pi}\left(\frac{c}{f}\right)^2$ [m^2].

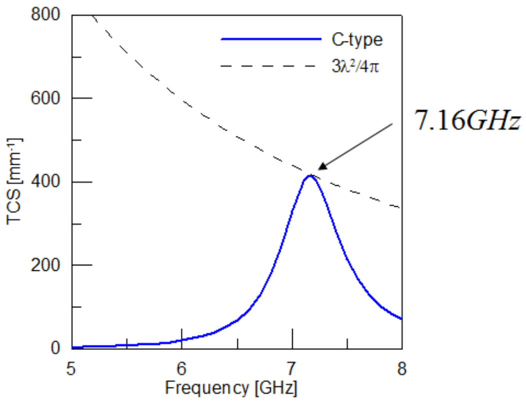


Figure 4: Frequency characteristics of transmission cross section for C-shaped aperture.

Comparison shows good agreement at $7.16GHz$. However frequency shift to higher frequency of $7.16GHz$ is observed. In the C-shaped structure which has been obtained by bisecting the H-shaped structure. But in this case too, by decreasing the gap g somewhat, the transmission resonance frequency can be lowered to the original resonant frequency of $6.4GHz$ in the H-shaped structure. Fig.5 shows the TCS curve for the case that $dx = 10\,\mathrm{mm}$, $dy = 5\,\mathrm{mm}$, $w = 3\,\mathrm{mm}$, and $g = 0.045\,\mathrm{mm}$ in the C-shaped structure.

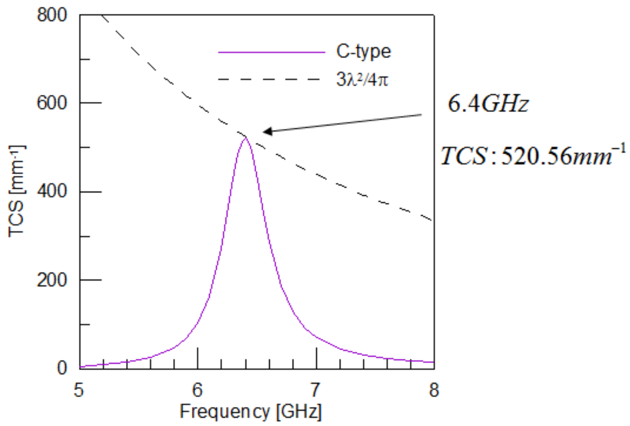


Figure 5 : Frequency characteristics of the TCS in the C-shaped structure for the case that $dx = 10\,\mathrm{mm}$, $dy = 5\,\mathrm{mm}$, $w = 3\,\mathrm{mm}$, and $g = 0.045\,\mathrm{mm}$.

So it can be said that physical size of the aperture can be reduced roughly by half while keeping the TCS constant. This is compatible with the conclusion[4][5] which was drawn from study of the small circular ridged aperture, i.e., TCS is constant at resonance independent of physical shape and size of the small aperture.

3. Concluding remarks

Transmission resonance phenomena have been dealt with for both H-shaped and C-shaped resonant apertures, and compared with that for the small resonant circular ridged aperture. It has been found that the TCS are almost the same at resonance for the above three cases, H-shaped, C-shaped, and small circular ridged apertures.

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