A Cylindrical Reentrant Cavity with a Circumferential Slot as an Antenna

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내부에 두 개의 융기부를 가지고 표면에 방사슬롯을 갖는 원통형 안테나

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Abstract A simulation investigation on the circular cylindrical reentrant cavity with axial ridges and a cylindrical circumferential slot is presented. This study indicates that by properly adjusting the dimensions of the ridge sand the slot, the size of the cavity can be miniaturized to around $0.3\lambda_0$. The simulation results using CST MWS show good agreement with past theoretical predictions and provide useful insight into fundamental concerns associated with electrically small antennas.

요 약 본 논문에서는 원통 실린더 내부의 아래와 윗면에 융기부가 있고 원통의 가운데 면을 따라 슬롯이 있는 구조에 대한 모사 연구이다. 이 연구는 두 융기부나 슬롯의 크기를 조절하여 원통의 크기를 0.3파장으로 줄일 수 있음을 보여주고 있다. CST MWS를 이용한 모사 결과는 이론적인 예측과 비슷한 결과를 보여주고 전기적으로 작은 안테나의 연구에 중요한 역할을 할 것으로 사료된다.

1. Introduction

A ridged waveguide is generally used in various broadband microwave systems [1]. In particular, the reentrant cylindrical cavity is widely employed in the design of microwave and solid-state devices, such as Klystron and Gunn diode oscillator [2]-[4]. This sort of geometry seems the best fitted for miniaturization of resonant cavities. Indeed, a few works on the reentrant cylindrical cavity are presented and the theoretical calculation and experimental results are compared [5]-[7]. However, little or no work has been dedicated to this sort of structure as an antenna, nor has a complete investigation using simulation software. There has been considerable interest to develop small and compact size antennas for various applications and also there has been newly interest in the sort of structure presented here to achieve miniaturization of an antenna [8]-[9]. In this study, we present a simulation investigation on the circular cylindrical reentrant cavity with axial ridges and a cylindrical circumferential slot and utilize a simulation model obtained by using CST MWS. This type of structure seemingly has several features, which may be exploit over previously introduced various types of small antennas. For instance, lower quality factor and higher radiation efficiency can be obtained by changes in cavity geometries. We note that this work is a fundamental verification of the past theoretical predictions on the certain geometry. The next section describes the antenna structure and the simulation results, which are surely utilized to our further study on small antennas.

2. Antenna structure and analysis

A typical cylindrical cavity is presented in figure 1. The dimensions of the cavity presented here are radius (a) ≈ 30mm and height (h) = 60mm. With these dimensions, the resonance frequency of dominant mode is 3.85GHz (λ_0

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= 77.9 mm) as given by (1) and (2). Note that for $h/a < 2$ and $x_{np} = 2.405$ the TM010 mode is dominant, while for $h/a \geq 2$ the TE111 mode with $x'_{np} = 1.84$ is dominant [10].

$$(f_r)^{TM}_{npq} = \frac{1}{2\pi a \sqrt{\mu}} \sqrt{(x_{np})^2 + \left(\frac{q\pi a}{h}\right)^2} \qquad (1)$$

$$(f_r)^{TE}_{npq} = \frac{1}{2\pi a \sqrt{\mu}} \sqrt{(x'_{np})^2 + \left(\frac{q\pi a}{h}\right)^2} \qquad (2)$$
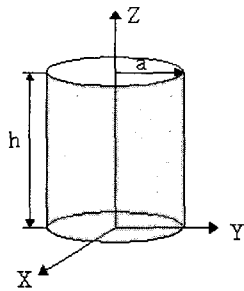

Fig 1. A typical circular cylindrical cavity.

Figure 2 shows a circular cylindrical cavity with single ridge and the equivalent LC circuit. C_0 is occurred by the gap between the ridge and cavity. C_1 and L is due to the cavity height and diameter, respectively. R is caused by the surface resistance. The values mentioned above is calculated by the followings.

$$L = \mu_0 \frac{h}{2\pi} \ln \frac{a}{b} \cong 1.6nH \qquad (3)$$

$$C_0 = \varepsilon_0 \frac{\pi b^2}{g} \cong 8.4pF \qquad (4)$$

$$C_1 = 4\varepsilon_0 b \ln \frac{e\sqrt{(a-b)^2 + h^2}}{2 \times g} \cong 2.58pF \qquad (5)$$

$$f_r = \frac{1}{2\pi \sqrt{L(C_0 + C_1)}} \cong 1.2GHz \qquad (6)$$

The cavity with single ridge resonates in about 1.2GHz as shown in (6). The geometry considered in this study is a circular cylindrical reentrant cavity with a circumferential slot as shown in figure 3. As shown in fig. 3(b), the structure basically can be expressed as an equivalent LC circuit that the inductive load(L_{cavity}) is generated due to the cavity and the capacitive loads (C_{gap}, C_{slot}) are caused by the gap between the ridges and the circumferential slot, respectively. Two axial ridges are put inside the typical cylindrical cavity whose radius (b) and

gap (g) between them will be adjusted for optimum impedance matching. A cylindrical circumferential slot as a radiating aperture is placed along the surface of the cylinder and the width (t) of the slot is also optimized. The structure basically can be expressed as a LC resonator circuit that the inductance is due to the length of the cavity and ridges and the capacitance is caused by the gap between the ridges. By properly adjusting the ridge radius and gap one can adjust the resonant frequency of the resultant structure.
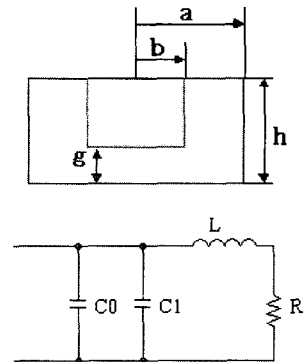

Fig 2. A circular cylindrical cavity with a single ridge
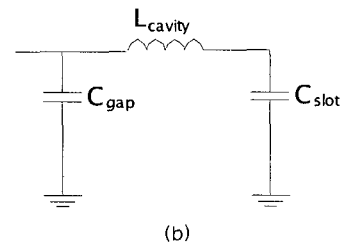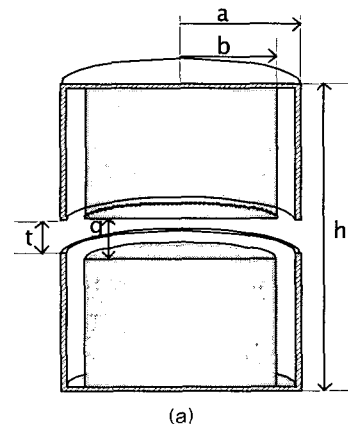

(b)

Fig 3. A circular cylindrical reentrant cavity with a circumferential slot.

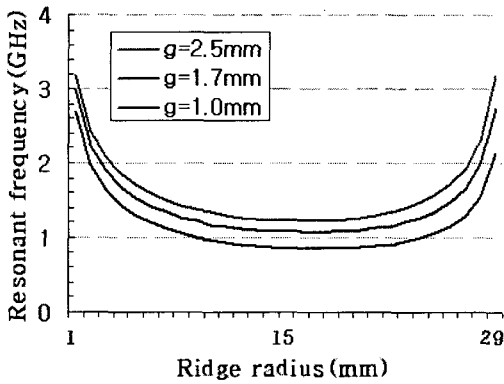Fig 4. Variation of resonant frequency as a function of ridge radius b for various values of ridge gap (g).

Fig 5. Variation of resonant frequency as a function of b/a for various values of ridge gap (g), t=4mm.

The maximum dimension(60mm) for the conventional circular cylindrical cavity is $0.77\lambda_0$. Figure 4 shows the variation of resonant frequency as a function of ridge radius b for various values of ridge gap (g). As we predicted, the resonant frequency is about 1.2GHz with proper ridge radius. Fig. 5 shows the variation of resonant frequency as a function of b/a for various values of ridge gap, other parameters being held constant as shown. For a fixed ridge gap, the resonant frequency increases as b/a becomes larger as a consequence of increase in the capacitance, while it decreases as the capacitance getting bigger in the conventional LC resonator. This result indicates that the inductance affects more significantly in the presented structure. Therefore, we believe that introduced geometry here will be more effective in the applications of the small antenna design. Fig. 6 shows the variation of resonant frequency as a function of ridge gap for various values of ridge radius. As would be expected, with increase the ridge gap, the resonant frequency increases due to decrease the capacitance. The increase in the resonant frequency is more prominent than that observed for variation of slot width as shown in fig. 6. This implies that the capacitance caused by the ridges is much bigger than that of the cavity walls. Fig. 7 shows the variation of resonant frequency as a function of slot width for various values of ridge radius. The resonant frequency is observed to increase with increase in slot width, though it is not a decisive factor. Fig. 8 shows the return loss (S11) with frequency for the optimum values.
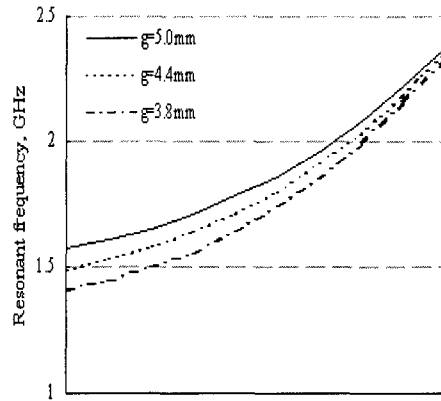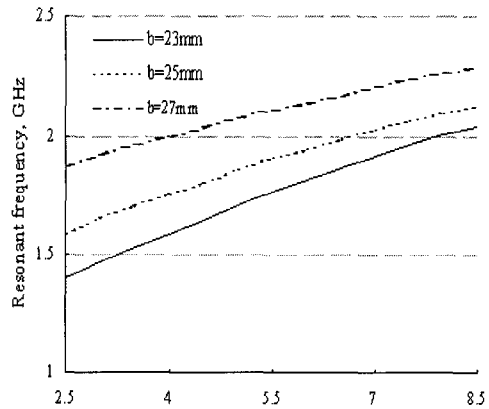

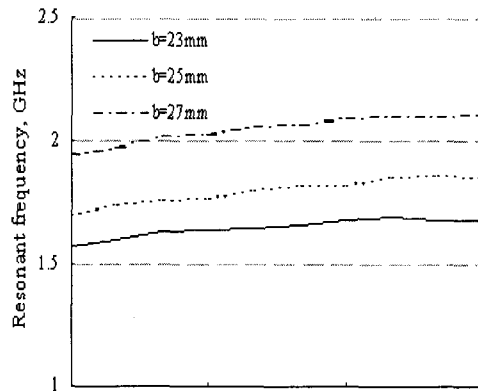Fig 6. Variation of resonant frequency as a function of ridge gap (g) for various values of ridge radius (b), t=4mm.

Fig 7. Variation of resonant frequency as a function of slot width (t) for various values of ridge radius (b), g=4.4mm.

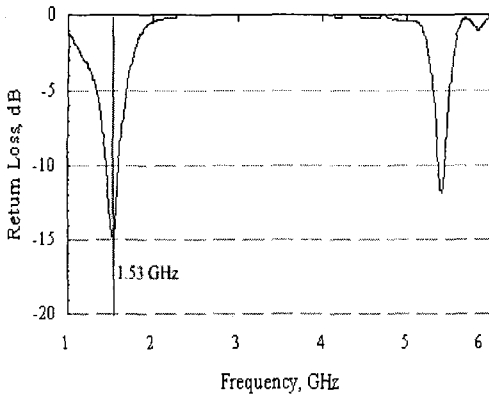**Fig 8.** Return loss (S11) with frequency for the optimum values : b=23mm, g=3.5mm, t=4mm.

The optimized parameters obtained from the simulation results presented above. In this case dual resonance characteristics is observed, which is attributed to the slot width and ridge radius. It is seen that good impedance matching is obtained at the lower resonance frequency at 1.53GHz, which is much lower than that of the cavity without ridges or slot. The dimensions of the cavity in terms of the wavelength corresponding to this frequency are $0.3\lambda_0$. The resonant frequency we calculated above is 1.2GHz with single ridge. The reason why we have a relatively high resonant frequency in our own geometry is due to the slot around the surface. The slot changes the capacitance in the cavity. Further investigation is carried out to obtain more conclusive results, which well agree with our study on small antennas. The dielectric material ($\varepsilon_r = 2$) is filled in the gap and the whole cavity resulting in varying the capacitance between them. The influence of the increasing capacitance can, of course, make decreasing the resonant frequency to 1.35GHz and 1.2GHz, respectively. Figure 9 presents the return loss plots for each case. The dimension of the cavity in terms of the wavelength corresponding to the lowest frequency ($\sim$1.2GHz) is $0.24\lambda_0$. This implies that the presented cavity structure is well suitable for miniaturization in electrically small antennas. Finally, the figure 10 shows the radiation characteristics for presented slot antenna. We will extend our study to a practical antenna design for utilizing the results presented here.
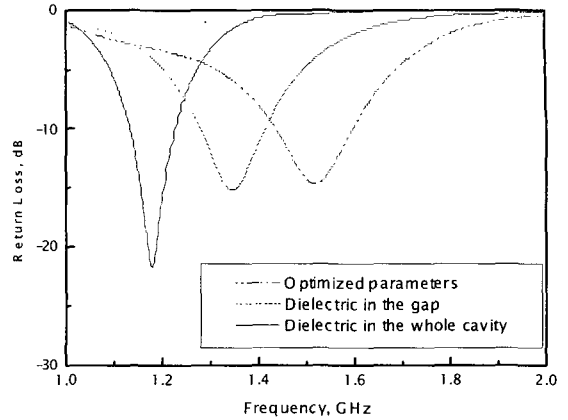

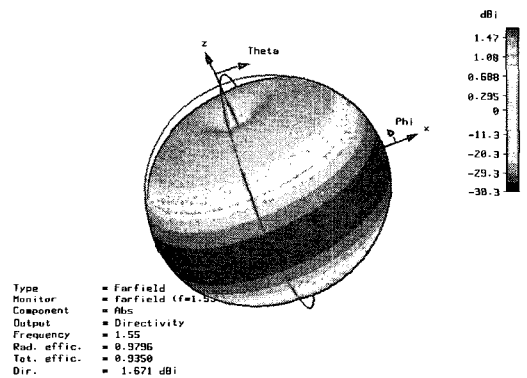**Fig 9.** Return loss (S11) with frequency with filling dielectric material in the gap and the cavity

Fig 10. Radiation field for the cylindrical cavity with slot.

3. Conclusions

A ridged circular cylindrical cavity with a cylindrical circumferential slot is considered for miniaturization of an antenna. An important contribution of this work is that we verified the past theoretical predictions on suggested structure using simulation software. It is shown that by properly adjusting the dimensions of the ridge and the slot, considerable miniaturization of an antenna is accomplished. In addition, the results provide further perception into fundamental studies on electrically small antennas. Future work in this direction to miniaturize the structure further is in progress with using a more complicated model.

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