Effect of Cylindrical Cavity Enclosure on Resonance Frequency of Annular Ring Microstrip Antenna

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Abstract — The effect of cylindrical metallic enclosure on the resonant frequency of a suspended annular ring microstrip antenna (ARMSA) is investigated using HFSS simulation software and theoretically calculated using modal expansion cavity model and circuit theory concept. Theoretical result shows close agreement with simulated results. Variation in resonant frequency with air gap height and inner patch radius is also studied. The patch miniaturization of about 15% is achieved using cavity backed ARMSA.

Keywords — Microstrip Antenna; Annular Ring Microstrip Antenna; Cavity Backing.

I. Introduction

Microstrip antennas (MSAs) are extensively used in modern communication systems due to their numerous advantages like light weight, ease of fabrication etc. [1]. Among this class of antenna, ARMSA has the broader bandwidth and lower resonance frequency of the same size than the other printed antenna, which leads to substantially miniaturization of antenna [2]. A compact antenna can be realized by increasing dielectric constant of substrate, by using shorting plate/pins, or by cutting slots in the radiating patch or in ground plane [3]. These methods will either distort the patch geometry or degrade the performance of the antenna. One of the suitable choices is Cavity backing, where to place the patch antenna into a metallic cavity, with cavity radius close to the patch radius. It also provides an extra feeding option compared to a conventional microstrip patch antenna. The cavity loading improves the performance of the antenna [4]. The cavity having some characteristic dimensions affects the fringing electric fields surrounding the patch which is responsible for radiation. The resonant fields in the cavity help reducing the size of the antenna without greatly affecting the antenna performance [5]. Thus, cavity backed microstrip antennas have gained significant importance over the last few decades due to their advantages like rigid shape, compact configuration, enhanced gain and bandwidth, improves radiation efficiency, and suppress surface waves in thick substrate [6]-[9]. Cavity backed rectangular microstrip antenna with annular slot antenna was investigated by [10] for dual-band circular polarization. Effect of cylindrical cavity enclosure on the resonance frequency of circular patch and inverted circular patch are analyzed in [11]-[15].

In this paper, we have investigated the effect of cylindrical cavity enclosure on the resonance of the annular ring microstrip antenna (ARMSA) using the commercial simulation software HFSS and theoretically calculated using modal expansion cavity models and circuit theory concept.

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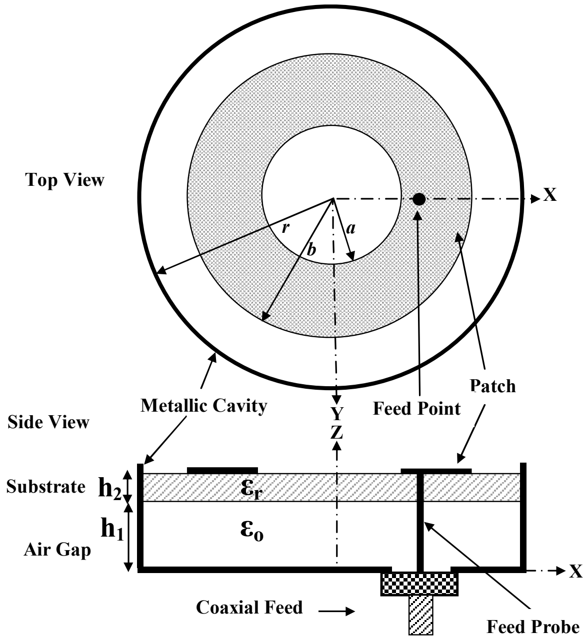

Fig. 1. Geometry of cavity backed coaxial-fed annular ring microstrip antenna.

II. Theoretical Formulation

The cavity backed patch antenna is shown in Fig. 1. The patch is residing in a cylindrical metallic cavity of radius r and height $h_t = h_1 + h_2$, where h_1 is the air gap height and h_2 is the substrate height. The antenna is fed using co-axial probe.

Assuming that only the TM mode exists, the resonant frequency of ARMSA is determined as [16]

$$f_{nm} = \frac{k_{nm} c}{2\pi \sqrt{\varepsilon_{eff}}} \tag{1}$$

where k_{nm} are the roots of the characteristics equation

$$J_n^{'}(CX_{nm})Y_n^{'}(X_{nm}) - J_n^{'}(X_{nm})Y_n^{'}(CX_{nm}) \tag{2}$$

where $C=b/a$ and $X_{nm} = k_{nm} a$. $J_n(x)$ and $Y_n(x)$ are Bessel functions of the first kind of order n, respectively, and the prime denote derivatives with respect to x. Value of k_{nm} for TM_{31} and TM_{21} is 1.9789 and 1.3406 respectively with condition that $C=b/a=2$.

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The effective dielectric constant is defined as [17]

$$\varepsilon_{eff} = \frac{\varepsilon_{re}+1}{2} + \frac{\varepsilon_{re}-1}{2}\left(1+\frac{10h_t}{W}\right)^{-0.5} \quad (3)$$

where $W = b - a$, $h_t = h_1 + h_2$ and ε_{re} is the equivalent dielectric constant of the medium below the patch which comprises of substrate of thickness h_1 and air gap of height h_2 and is given as [18]

$$\varepsilon_{re} = \frac{\varepsilon_r\left(1+\frac{h_1}{h_2}\right)}{\left(1+\frac{\varepsilon_r h_1}{h_2}\right)} \quad (4)$$

where εr is the dielectric constant of the substrate. To account the fringing field effect the effective radii are given as [19]

$$b_{eff} = b\left(1+\frac{2hx}{\pi b\varepsilon_{req}}\right)^{1/2} \quad (5)$$

$$a_{eff} = a\left(1+\frac{2hx'}{\pi a\varepsilon_{req}}\right)^{1/2} \quad (6)$$

where

$$x = \ln\left(\frac{b}{2h}\right) + 1.41\varepsilon_r + 1.77 + \frac{h}{b}\left(0.268\varepsilon_r + 1.65\right) \quad (7)$$

and x' is obtained by replacing b by a in (7).

For given values of a and b, a_{eff} and b_{eff} are calculated. Then the characteristic equation is solved by replacing a and b by a_{eff} and b_{eff}. After solving the characteristic equation for k_{nm}, the resonant frequencies are determined. The antenna design parameters are listed in Table 1.

TABLE I.
ANTENNA DESIGN PARAMETERS

Antenna Parameter	Value
Inner radius of annular ring; (*a)*	30 mm
Outer radius of annular ring; (*b)*	60 mm
Substrate material used	Rogers RT/duroid 5880
Dielectric constant; (ε_r)	2.2
Thickness of Substrate	1.59 mm
Height of Air-Gap; (h_2)	3 mm
Height of patch; (h_1+h_2)	4.59 mm
Height of cavity	4.59 mm
Diameter of Cavity; (2r)	60.5 mm

III. RESULTS AND DISCUSSIONS

Commercial simulation software HFSS is used to study the influence of cavity enclosure on the resonance of the annular ring microstrip antenna. Fig. 2 shows the variation of resonant frequency and air gap height with and without cavity for two values of inner radius, *a* (with condition that *b=2a*).

From the figure 2, it can be observed that the increase of the resonant frequency of the ARMSA without cavity is mainly due to the sharp decline in effective dielectric constant εeff of the air-dielectric interface. On the other hand, for the cavity enclosed patch, resonant frequency increases but not

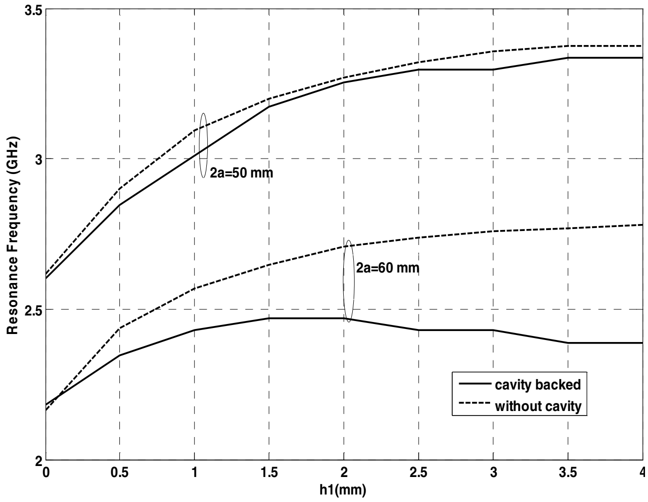

Fig.2. Variation of resonance frequency with air-gap height (h_1) of cavity enclosed and without cavity of the annular ring microstrip antenna. ε_r = 2.2, $2r$ = 60.5 mm, h_2 =1.59 mm.

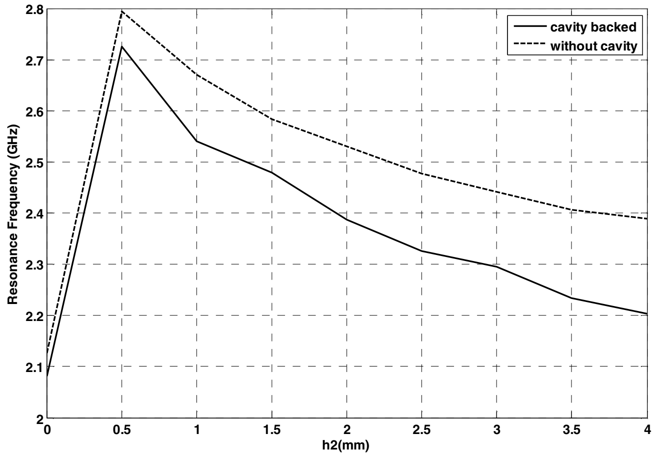

Fig.3. Variation of resonance frequency with substrate height (h2) of cavity enclosed and without cavity of annular ring microstrip antenna. εr=2.2, 2r = 60.5 mm, 2a = 60 mm, h1 = 1 mm.

with the same degree as that of free space case and saturates for larger air gap height. The above facts also verify in the Fig. 3, which show the variation of resonance frequency with substrate height, keeping air gap height constant at 1 mm. It is also observed that the rate of change in resonance frequency is higher for higher side of substrate height and lower in the lower side of substrate height. Variation of resonant frequency with inner radius of annular ring is depicted in Fig. 4. It can be observed that on increasing the radius of inner radius, resonant frequency decreases and it is lower in case of cavity backed ARMSA.Fig. 5 shows the return loss curve of ARMSA with and without cavity. The antenna is excited without cavity in TM_{31} mode at f=2.82 GHz and TM_{21} mode at f=2.21 GHz. And

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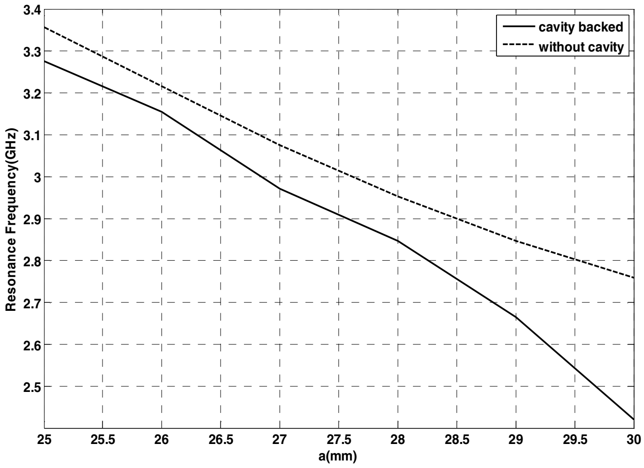

Fig.4. Variation of resonance frequency with radius of annular ring of cavity enclosed and without cavity annular ring microstrip antenna. εr=2.2, 2r=60.5 mm, h1=3 mm,h2=3 mm.

after enclosing the ARMSA with a metallic cylindrical cavity, the above mentioned modes are shifted to *f*=2.4 GHz and *f*=1.72 GHz respectively. From the figure 5, it can be observed that ARMSA with cavity resonates at 0.4 GHz lower frequency than ARMSA without cavity. This is due to the effect of cavity enclosure. A reduction of resonant frequency is about 15% of the conventional patch. This reduction in the size of the patch antenna is due to the patch diameter is inversely proportional to the resonant frequency.

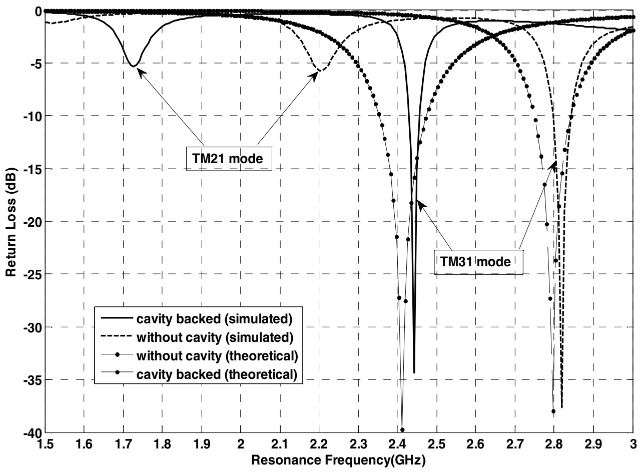

Fig.5. Variation of return loss with air-gap frequency of cavity enclosed and without cavity annular ring microstrip antenna at εr=2.2, 2r=60.5 mm, h1=3 mm, h2=1.59 mm.

IV. Conclusion

In this paper, effect of cylindrical metallic cavity on resonance of ARMSA has been studied using HFSS and theoretical modeling is carried out using cavity model and circuit theory concept. The patch miniaturization in the presence of cavity has been proved. A size reduction of about 15% has been achieved using cavity with a properly chosen radius of 60.5 mm, which is very close to outer patch radius and thus influences the fringing fields associated with the antenna. The proposed antenna can be used for Wi-Fi, Bluetooth, Zig-Bee, and alarm systems etc.

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