Bandwidth Enhancement of Cavity-Backed Slot Antenna Using a Via-Hole Above the Slot

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***Abstract*—A novel technique for the bandwidth enhancement of a cavity-backed slot antenna is presented. A via-hole located above the slot creates an additional resonance at a higher frequency by shortening the effective length of the slot. The location of the via-hole can be changed to determine the second resonance frequency of the antenna. With proper placement of the via-hole, the bandwidth of cavity-backed slot antenna can be increased. The fabricated antenna has a 60% wider bandwidth than a cavity-backed slot antenna without a via-hole. The proposed antenna maintains high radiation efficiency and gain, which are characteristics of a conventional cavity-backed slot antenna. The proposed technique is especially useful for enhancing the bandwidth of a cavity-backed slot antenna in a limited area.**

***Index Terms*—Cavity-backed, dual resonance, slot antenna, substrate integrated waveguide (SIW), wideband.**

I. Introduction

IN MANY applications such as wireless body area network (WBAN) applications, there are strong needs for a low-profile antenna. Slot antennas that have attractive features like a planar surface and low profile are very suitable candidates for these applications. On the lossy medium, however, a slot antenna has poor radiation efficiency because of its bidirectional radiation. A cavity-backed slot antenna eliminates the backside radiation using a quarter-wavelength cavity behind the slot. It takes advantage of planar structures and maintains high radiation efficiency on the lossy mediums.

A quarter-wavelength cavity under the slot may not be suitable in many applications because the cavity increases the height of the antenna. Therefore, a quarter-wavelength cavity is usually bent into the parallel direction with slot to lower the height of the antenna [1]. According to the waveguide theory, the guided wavelength of the rectangular waveguide does not depend on the cavity height. Therefore, the cavity under the slot can maintain its electrical length without reference to the height of the cavity.

However, there are some inherent drawbacks in using a low-height substrate in a cavity-backed slot antenna. The height of the substrate affects the Q of the slot and the rectangular cavity. A thin substrate increases the Q of the antenna, which causes a narrow bandwidth [2]. Overcoming a narrow bandwidth is an important issue in designing a low-profile cavity-backed slot antenna.

Various techniques have been proposed to overcome the narrow bandwidth of a cavity-backed slot antenna. References [3]–[7] make use of a dual resonance to achieve the wideband characteristic. In [3]–[5], two slots are used to create a dual resonance. This technique gives dual-band or wideband characteristics to the antenna depending on the dimensions of the slots. These antennas show uniform gain over the operating frequency. However, these techniques may increase the size of the cavity to place the two slots on the surface of the cavity. In [5], the fictitious resonant microstrip feed, which is a proposed concept in [6], is used for the wideband resonator-backed slot antenna. The location or the length of the microstrip feed line can be adjusted for the second fictitious resonant frequency. However, a microstrip-fed cavity-backed slot antenna requires a substrate for the microstrip feed line, which increases the minimum thickness of a cavity-backed slot antenna. In [7], a varactor-tuned cavity-backed slot antenna with a 1.9:1 tuning range is proposed. At low frequency, however, the efficiency may be low because of large losses in the varactor.

In this letter, a new technique for the bandwidth enhancement of a cavity-backed slot antenna is presented. The proposed antenna only has a via-hole above the slot to create the second resonance. The proposed antenna shows dual resonance without using two slots on the surface of the cavity or special feeding techniques. By adjusting the location of the via-hole, the second resonance can be moved to enhance the bandwidth of main resonance. The fabricated antenna showed uniform gain and antenna efficiency over the operating frequency.

II. Principles of Operation

A. Antenna Configuration

Fig. 1 shows the geometry of the proposed antenna. It has a similar geometry to that of a conventional cavity-backed slot antenna except for the single via located above the slot. By using simple rectangular waveguide theory, the dimensions of the cavity are calculated to have a quarter-wavelength in both directions perpendicular to the slot. Instead of the solid conductor cavity, substrate integrated waveguide (SIW) with via conditions $(D/S = 0.67, D/\lambda_0 = 0.0065)$ is used to fabricate the antenna using a standard printed circuit board process [8].

The slot is located on the center surface of the cavity. An I-shaped slot is used for an inductive loading of the slot to decrease the slot length. The slot length is approximately a half wavelength at the operating frequency. The via-hole is placed above the slot for the dual resonance. The proposed antenna is

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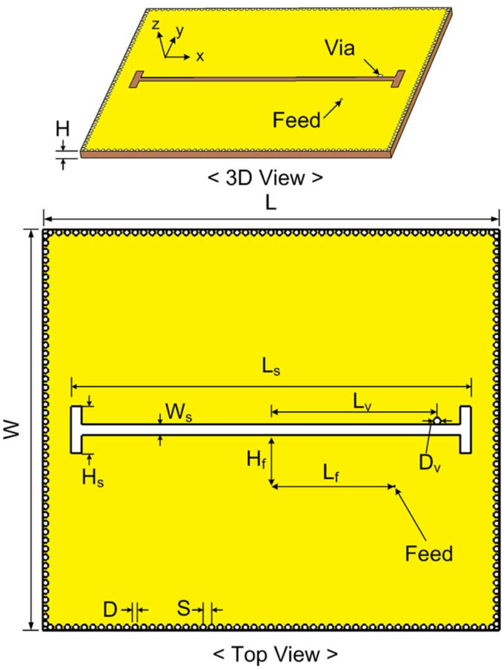
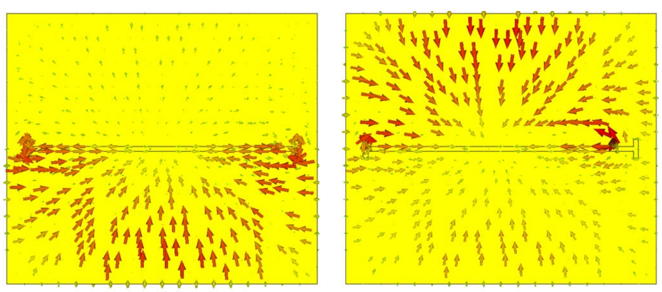


Fig. 1. Structure of wideband cavity-backed slot antenna. ($W = 55.8, L = 63.8, H = 1.57, L_s = 55.75, H_s = 6.6, W_s = 1.5, L_v = 23.5, D_v = 1, H_f = 7.25, L_f = 17.5, D = 0.8, S = 1.2$, all in the unit of millimeters).



(a) (b)

Fig. 2. Current distribution of proposed structure at each resonance. (a) At first resonance and (b) at higher frequency when second resonance occurs.

fed by a coaxial cable at the bottom of the cavity. At the feeding point, the center pin and outer conductor of the coaxial cable are connected to the surface and bottom of the cavity, respectively, through the small hole using an SMA connector. The simulation is conducted using CST Microwave Studio.

B. Current Distribution

Fig. 2 illustrates the current distribution when a normal slot resonance (first resonance) and a higher frequency resonance (second resonance) occur. In a conventional cavity-backed slot antenna, the resonance occurs when the slot has a half wavelength at the operating frequency. The frequency of resonance is mainly determined by the cavity size and the slot length. At first resonance, the minimum current flows to the center of the slot and the maximum current flows to the two edges of the slot in same direction, which is the typical current distribution of a cavity-backed slot antenna.

At second resonance, however, the location where the minimum current flows is slightly moved to the opposite side of the via-hole, and maximum current only flows to the left edge of the slot. The via-hole, which connects the top surface and the bottom surface of the cavity, creates another route for the current. It shortens the effective length of the slot at a higher resonance frequency.

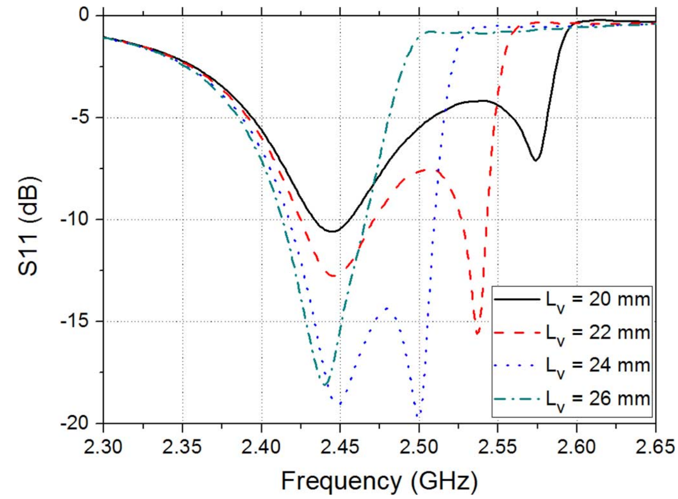


Fig. 3. Effect of via location on the reflection coefficient. All other parameters are kept as described in Fig. 1.

The second resonance frequency can be changed to a lower or higher frequency by moving the location of the via-hole. Fig. 3 shows the simulated input reflection coefficients of the antenna according to the location of the via-hole (L_v). As the via-hole moves to the center of the slot, the second resonance frequency increases. The location of the via-hole does not have a significant effect on the first resonance frequency. By selecting the proper location for the via-hole, wideband operation can be achieved without significantly changing the first resonance.

A single via-hole is enough to achieve the second resonance; in fact, two via-holes facing each other across the slot may shorten the current flowing to the slot edge. In this case, the first resonance is also affected by the via-hole. Therefore, only a single resonance occurs according to the location of two via-holes.

The proposed structure creates the second resonance without using double slots or special feeding techniques. A single via-hole located above the slot is enough to create a double resonance. This technique is especially useful for enhancing the bandwidth of a cavity-backed slot antenna in a limited area.

III. Measured Results

For the demonstration of the proposed technique, 2.45 GHz was selected as the operating frequency. Cavity size and slot length and width values were determined for the resonance at 2.45 GHz. The parameters H_f, L_f, which relate to the location of the feeding point, were tuned to match the antenna input impedance at 50 Ω. The E-field in z-direction has a maximum value at the center of the cavity and decreases as the observation point moves to the edge of the cavity. As a result, the antenna impedance is higher at the center of the cavity and lower at the edge. By moving the feeding location, a 50-Ω antenna impedance can be achieved. After determining the antenna geometry, the via-hole location and the diameter are optimized for

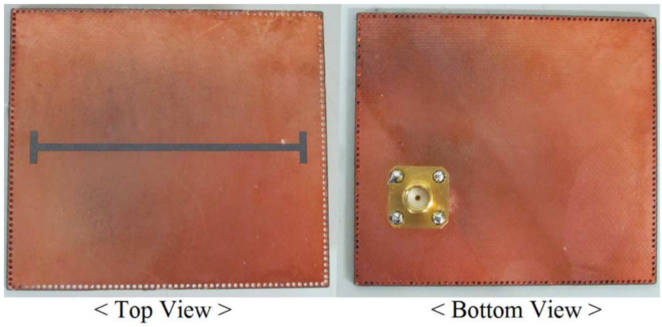


Fig. 4. Fabricated wideband cavity-backed slot antenna.

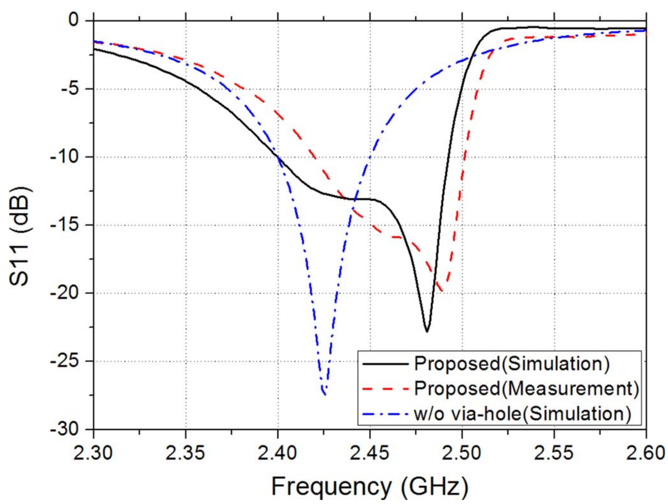


Fig. 5. Comparison of the reflection coefficient of the proposed antenna and a conventional cavity-backed slot antenna without via-hole.

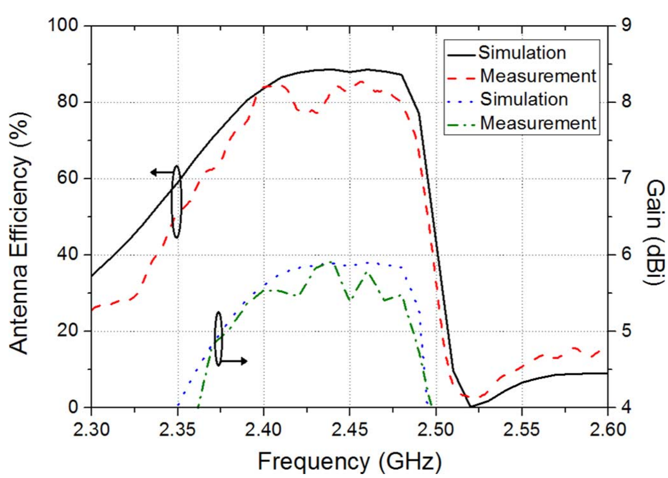
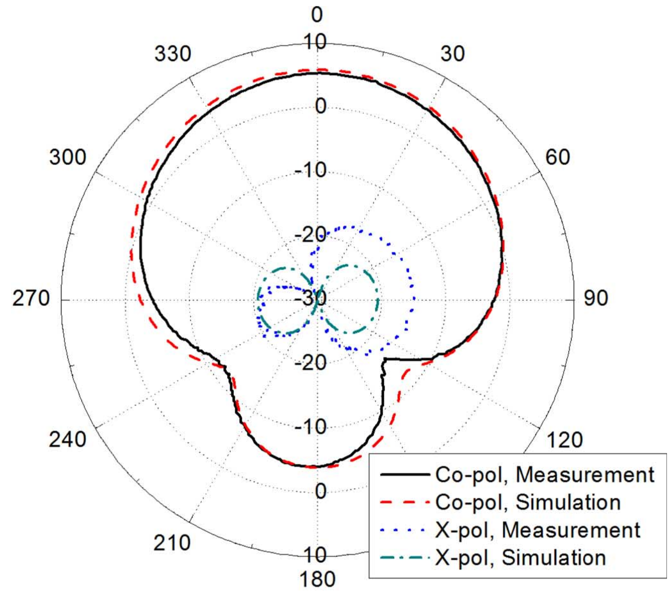


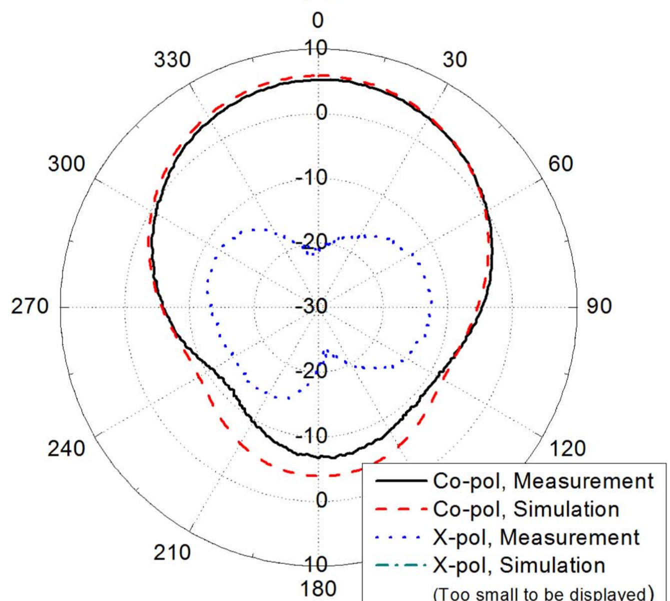
Fig. 6. Comparison of measured and simulated total efficiency and antenna gain of the proposed antenna.

the maximum bandwidth of the antenna. All optimized antenna parameter values are described in Fig. 1. The designed antenna was fabricated on the substrate with a 1.57-mm-height Duroid 5880 that had a relative permittivity of 2.2 and a loss tangent of 0.0009 using a standard printed circuit board process. The fabricated antenna is shown in Fig. 4. For measurement, an SMA connector is connected at the bottom of the cavity.

Fig. 5 shows the simulated and measured reflection coefficients of the antenna. Regarding measurement, the -10-dB



(a)



(b)

Fig. 7. Radiation patterns of the proposed antenna. (a) E-plane (yz-plane) and (b) H-plane (xz-plane) at 2.45 GHz.

bandwidth of the proposed antenna is measured to be 82 MHz, which is a similar result to the simulated bandwidth of 91 MHz. The small difference between the two results may have been caused by the fabrication errors in the via-holes. The bandwidth of the proposed structure is very sensitive to the location of the via-hole as displayed in Fig. 3.

In the simulation, a conventional cavity-backed slot antenna with the same dimensions has a 50-MHz -10-dB bandwidth in the given operating frequency. Compared to this result, an approximately 60% wider bandwidth was achieved with the proposed technique.

The antenna efficiency measured in the Bluetest Reverberation Test System chamber is shown in Fig. 6. Similar results were obtained with regard to the measured and simulated antenna efficiency. An approximately 80% antenna efficiency was measured in the -10-dB impedance bandwidth. The differences between the two values may have been caused by errors in measurement.

The antenna efficiency drops very rapidly after the second resonance. A quarter-wavelength cavity is connected in series with slot antennas in a probe-fed cavity-backed slot antenna. After the dual parallel resonances of the slot, a parallel resonance occurs in the cavity. At the parallel resonance frequency of the cavity, the impedance of the cavity is much higher than that of the slot impedance. Therefore, most energy is consumed in the cavity. This antenna efficiency drop is an inherent characteristic of a coaxial-fed cavity-backed slot antenna.

Measured and simulated antenna gain are also compared in Fig. 6. Although the wider-band characteristic, a flat gain higher than 5 dBi is maintained over the -10-dB bandwidth.

The radiation pattern was measured in an anechoic chamber as shown in Fig. 7. Measured radiation patterns were compared to simulated radiation patterns in the E-plane (yz-plane) and H-plane (xz-plane) at 2.45 GHz. The radiation patterns of the proposed antenna were very similar to those of a conventional cavity-backed slot antenna. In the boresight direction, the maximum radiation was measured in both cut-planes. The proposed antenna also showed the very low cross-polarization levels in the two cut-planes. In the simulation, cross polarization in the H-plane was too small to be displayed on the graph. The measured cross polarization in the H-plane may have been caused by the feeding cable behind the antenna. The front-to-back ratio (FTBR) of the proposed antenna is 12.28 dB at 2.45 GHz. The measured result shows that the proposed antenna keeps its large FTBR.

Although the proposed antenna has a similar gain and radiation patterns to those of a conventional cavity-backed slot antenna, it exhibits a wider-band characteristic that is highly favorable in designing a low-profile cavity-backed antenna.

IV. Conclusion

A technique for enhancing the bandwidth of a cavity-backed slot antenna is proposed and demonstrated. By shortening the effective length of the slot at the higher frequency using a single via-hole above the slot, a second resonance is achieved. By moving the second resonance frequency, the bandwidth of a cavity-backed slot antenna can be increased.

Although the fabricated antenna has a 60% wider bandwidth than a conventional antenna, it maintains the high gain and high antenna efficiency over the -10-dB bandwidth. It is a useful method for enhancing the bandwidth of a cavity-backed slot antenna in a limited area.

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