2005

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Published in Lee, B., Harackiewicz, F.J., Jung, B., & Park, M.J., (2005). Cavity-backed slot antenna array for the repeater system of a satellite digital multimedia broadcasting service. *IEEE Antennas and Wireless Propagation Letters, 4*, 389 - 392. doi: 10.1109/LAWP.2005.857967

Cavity-Backed Slot Antenna Array for the Repeater System of a Satellite Digital Multimedia Broadcasting Service

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***Abstract*—For the repeater system of the satellite digital multimedia broadcasting (DMB) service (2630∼2655 MHz) requiring a high-gain antenna and enough isolation between antennas, a cavity-backed slot antenna array (CBSAA) fed by a single waveguide is proposed to suppress side lobe level (SLL) and to increase front-to-back ratio (FBR). The SLL and FBR are enhanced with an optimized magnitude ratio of the electric field at each slot and an additional vertical reflector. The measured SLLs in the H- and E-planes are under −33.24 and −35.78 dB, respectively. An FBR over 37.84 dB and a peak gain over 17 dBi are measured. The proposed CBSAA consists of 2 × 4 slot elements backed by a single cavity and has the characteristics of high power handling capability, high radiation efficiency, low feed line loss, and simple feed network.**

***Index Terms*—Cavity-backed slot antenna array, digital multimedia broadcasting, front-to-back ratio, isolation, side lobe level.**

I. Introduction

IN CONJUNCTION with recent progress and rapid growth in mobile communications, the service of mobile terminals has advanced to be not limited to digital audio but to be extended to a variety of multimedia data services as well as mobile TV service. A nationwide digital multimedia broadcasting (DMB) service in Korea was launched in 2004. DMB is the next generation digital broadcasting service to provide high quality digital audio, video, and data broadcasting to fixed, portable, and mobile receivers with a nation-wide coverage. There are two types of DMB systems, satellite and terrestrial. The satellite DMB system transmits multimedia contents such as audio, video and data to receivers in various mobile and portable environments from satellite. Satellite DMB in Korea mainly focuses on mobile TV service and its reception in harsh conditions such as in-building out of satellite line of sight (LOS), underground and in a region shaded by high buildings. This means that a repeater system (gap-filler) is required to receive signals in such an environment. An antenna for this repeater system must have enough isolation to reduce interference between systems, and

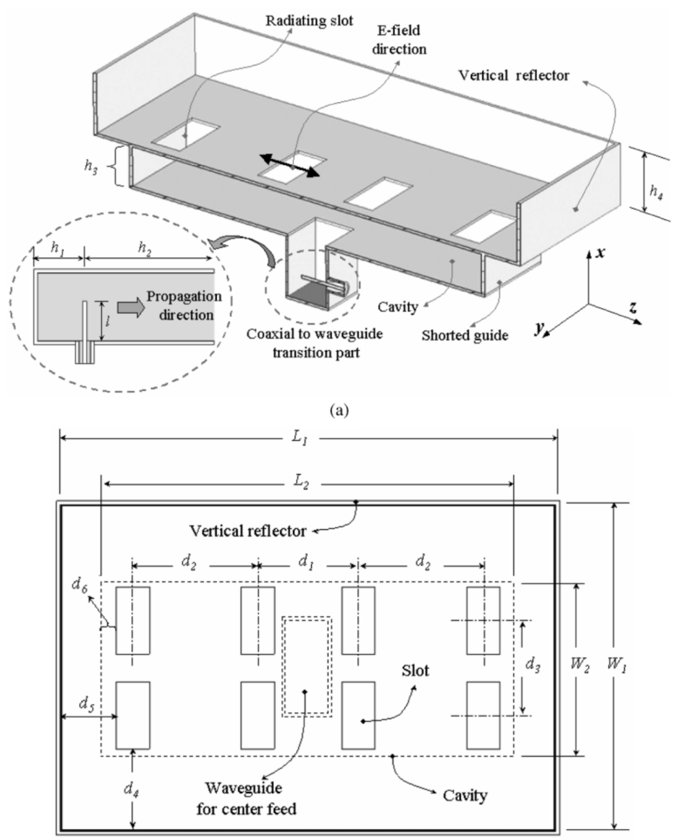

Fig. 1. Structure of the proposed antenna. (a) Three-dimensional cross sectional view. (b) Top view.

high gain [1]. Slot antenna arrays have been used widely because they are relatively simple to build and analyze [2], [3]. Slot antenna arrays where each slot element is backed by an individual cavity have been used for satellite-communication systems and direct-broadcast satellite applications because of their high efficiency. However, as the number of elements becomes large it may be impractical to back each slot by its individual cavity, and the feed network will be complicated. In this work, a 2 × 4 slot antenna array backed by a single cavity and fed by a waveguide is proposed for the repeater system of the satellite DMB (2630∼2655 MHz) service. Since all of the slot elements are backed by a single cavity, the feed line can be simple, and its loss can be minimized. In addition, a low suppress side lobe level (SLL) and high front-to-back ratio (FBR) are achieved by using an optimized magnitude ratio of electric field at each slot and vertical reflector. This letter presents experimental results

Manuscript received July 22, 2005; revised August 23, 2005. This work was supported by Grants from Kwangwoon University and also the Brain Korea 21 Project.

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Digital Object Identifier 10.1109/LAWP.2005.857967

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TABLE I
DESIGN PARAMETERS OF THE PROPOSED ANTENNA

Design parameters			
h_1	25.0 mm	d_1	80.8 mm
h_2	70.0 mm	d_2	100.0 mm
h_3	33.4 mm	d_3	74.5 mm
h_4	50.0 mm	d_4	63.5 mm
l	21.0 mm	d_5	43.2 mm
L_1	394.0 mm	d_6	10.0 mm
L_2	327.6 mm	-	-

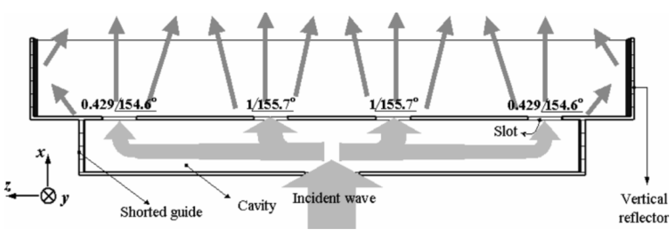


Fig. 2. Approximated field distribution within CBSAA by Ansoft's HFSS software.

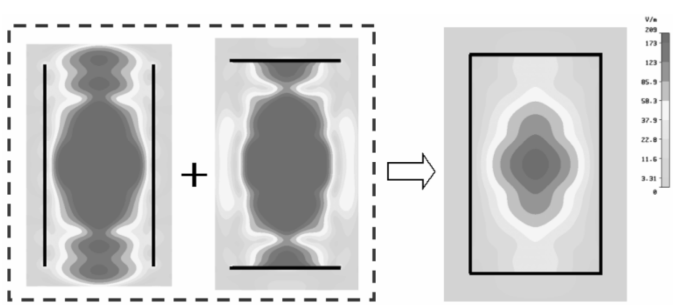


Fig. 3. Electric field distribution in the near field with the vertical reflector.

as well as simulation results by Ansoft's high-frequency structure simulator (HFSS) software for impedance bandwidth and radiation characteristics.

II. ANTENNA DESIGN AND STRUCTURE

Fig. 1 represents the structure of the proposed antenna whose design parameters are shown in Table I. The antenna consists of a coaxial to waveguide transition part, a rectangular cavity, eight radiation slots in a 2 × 4 array, and a vertical reflector. The total dimension of the antenna is $260 \times 400 \times 85.4\ [\mathrm{mm}^3]$. Slots and a feeding waveguide are placed on top and bottom side of the cavity, respectively. The dimension of the feeding waveguide is $72.12 \times 36.06\ [\mathrm{mm}^2]$, and its cutoff frequency is 2070 MHz which is sufficiently lower than the satellite DMB frequency band (2630∼2655 MHz). The input energy from the coaxial to waveguide transition is transmitted to each slot. A conventional open slot antenna is free to radiate on both sides.

Using a cavity, a slot antenna can radiate into one side or have a unidirectional beam. A cavity with an appropriate height (h_3) and a vertical reflector (h_4) are added to enhance the directivity and reduce the front-to- back ratio in this work. In the proposed antenna, the height (h_3) of a cavity is about $0.3\lambda_0$ so as to reduce the susceptances between slot and cavity and maximize the slot conductance [4]. Since all eight radiation slots are the same in size the most important factor to obtain the required radiation performance is the element spacing between the slots. If the spacing (d_6) between the slot at the edge and the shorted guide of the cavity set to be $0.25\lambda_{\mathrm{g}}$, the field inside cavity becomes a standing wave. Then, each slot has the same phase with the element spacing of λ_{g} which corresponds to $1.6\lambda_0$. This distance is enough to generate grating lobes. In this work, by decreasing the gap (d_6) from the shorted guide to edge of the slot by $0.08\lambda_{\mathrm{g}}$ for increasing the cutoff wavelength and setting the element spacings (d_1 and d_2) to be $0.8\lambda_0$, the field inside cavity becomes a travelling wave which results in the phase differences at each slot. To correct these phase differences, the element spacings, d_1, d_2 are set to be $0.71\lambda_0$ and $0.88\lambda_0$, respectively. Consequently, the slots are arranged in its amplitude ratio of 0.429: 1.0: 1.0: 0.429, and the phases are almost identical with 154.6°: 155.7°: 155.7°:154.6° from left to right slot.

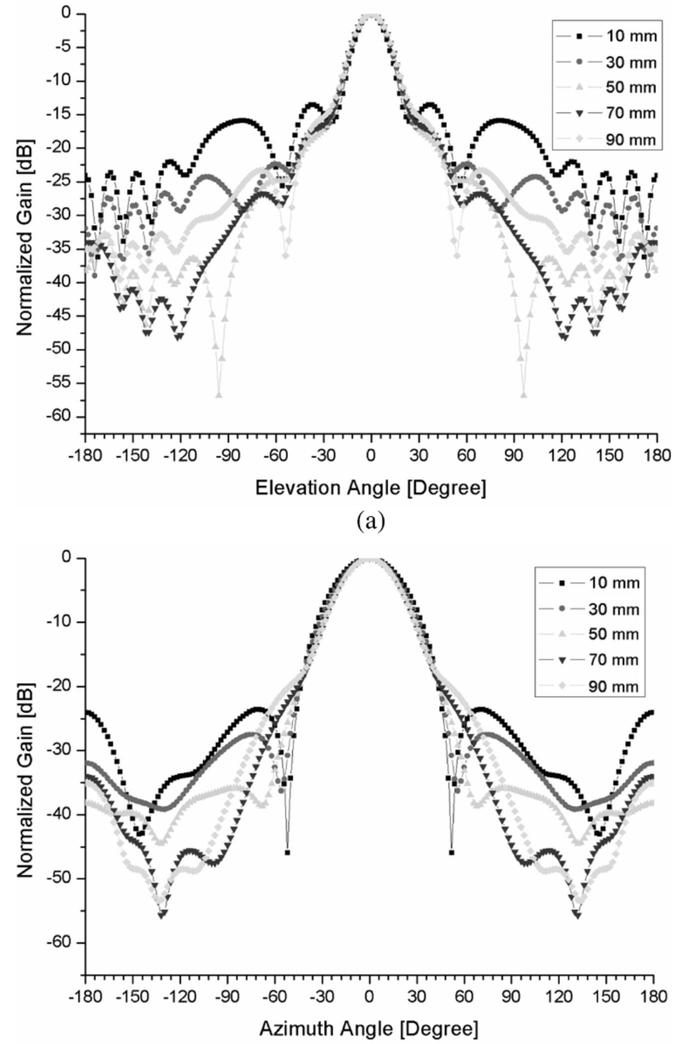
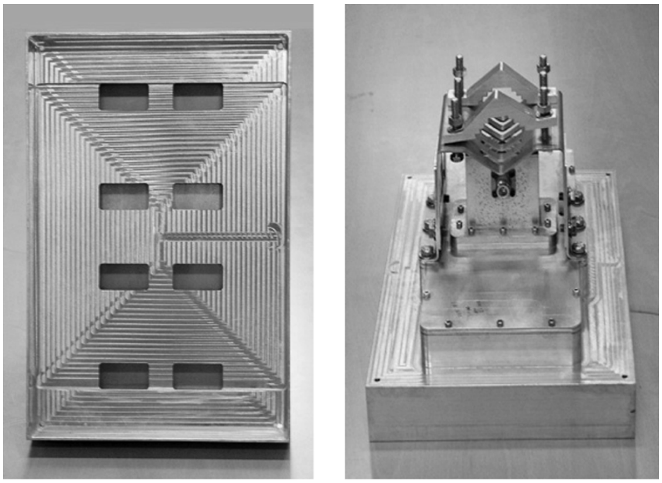


Fig. 4. Calculated gain pattern at 2642 MHz with varying the height (h_4) of the vertical reflector. (a) Elevation pattern. (b) Azimuth pattern.

Fig. 2 shows an approximated field distribution inside the proposed CBSAA. However, for a four point-sources array with element spacing of 0.8λ and an unequal magnitude, the side lobe



(a) (b)

Fig. 5. Photo of the developed antenna. (a) Front view. (b) Rear view.

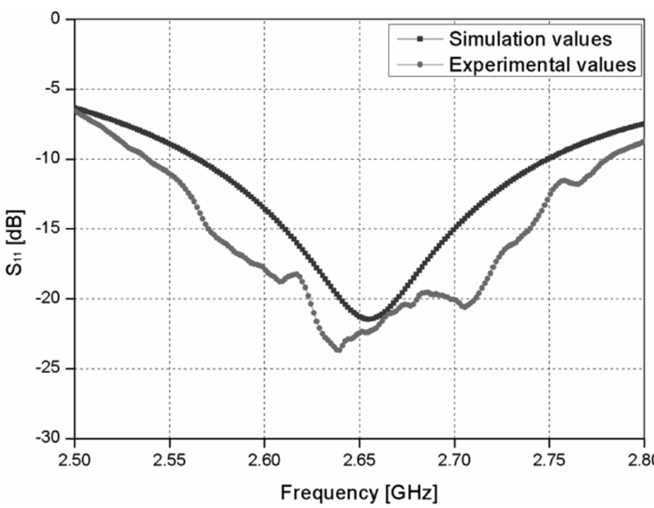
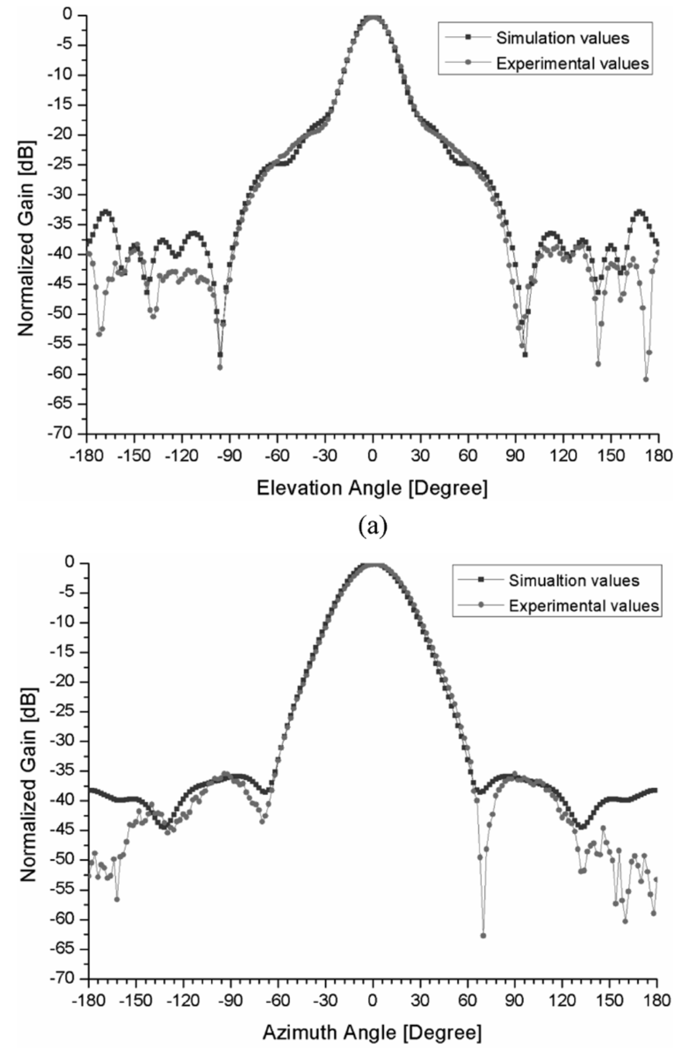


Fig. 6. Simulated and experimental return losses.



(a)

(b)

Fig. 7. Simulated and experimental radiation patterns at 2642 MHz. (a) Elevation pattern. (b) Azimuth pattern.

is, in general, increased at $\pm 90^\circ$ directions from the broadside direction. Since the diffraction at edge of the ground of the proposed antenna affects to degrade not only the SLL but also the FBR [5], [6], the vertical reflector with an optimized height (h_4) set apart an appropriate distance (d_4, d_5) from the radiating slot is added to reduce the side lobe and back lobe levels. Fig. 3 shows the calculated electric filed distribution in the near field with the added vertical reflector. It is noticed that the vertical reflector can reduce the leakage current leading to diffraction at the edge of the proposed antenna ground. Since the rim of the vertical reflector also acts as the part of radiator of the antenna, the optimized height of the vertical reflector has to be found in order to synthesize both fields generated from the slots and the rim of the vertical reflector [7], [8]. Fig. 4 represents the calculated radiation patterns of the antenna with varying height (h_4) of the vertical reflector. It is shown that when the height (h_4) of the vertical reflector is 50 mm and the distances, d_4, d_5, from the edge of the slot are about $0.56\lambda_0$ and $0.38\lambda_0$, respectively, the best performance of the antenna is obtained with the gain at 17.3 dBi, the side lobe levels at -36.5 dB, and the front-back ratio at 41.6 dB.

TABLE II
MEASURED PERFORMANCE OF THE PROPOSED ANTENNA

	Frequency [MHz]	Gain [dBi]	HPBW [Deg.]	SLL [dB]	FBR [dB]
H-plane	2630	17.92	31.32	-34.44	41.33
	2642	18.00	31.45	-34.24	40.08
	2655	18.04	31.26	-33.32	40.64
E-plane	2630	17.75	20.30	-37.50	39.73
	2642	17.78	20.19	-39.03	39.52
	2655	17.88	20.02	-35.78	37.84

III. MEASUREMENT RESULTS

A photograph of the proposed antenna is shown in Fig. 5. The measured magnitude of S_{11} by an Agilent E5071B network analyzer is in comparison with the simulated result in Fig. 6. The measured impedance bandwidth $(\mathrm{VSWR1} < 1.5)$ is 170 MHz (2570~2740 MHz), and it meets the bandwidth requirement for a satellite DMB. Fig. 7 displays the measured radiation patterns in the H and E planes. The measured gains and other results are listed in Table II. From Fig. 7 and Table II, it can be known that the developed antenna has SLLs under 33.32 dB and FBR over 40 dB. Also, it has high gain over 17 dBi, and the half power beamwidths are around 31° in the H plane and 20° in the E plane.

IV. Conclusion

A planar slot-array antenna, composed of a single waveguide feed and 2×4 slot elements backed by a single cavity, has been proposed and developed for the gap-filler repeater system of the satellite DMB service (2630∼2655 MHz) in Korea. High efficiency, low side lobe level, and high front-to-back ratio, which is demanded for the gap filler to eliminate interferences between systems, are achieved by adjusting the slot spacing and by using an additional vertical reflector. Moreover, the proposed cavity-backed slot antenna array (CBSAA) can be easily realized by the waveguide feed, cavity, and radiating slots, and vertical reflector with the feature of high aperture efficiency, high heat-resistance, and compact size.

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