A New Vertical Half Disc-Loaded Ultra-Wideband Monopole Antenna (VHDMA) With a Horizontally Top-Loaded Small Disc

Jae W. Lee, *Member, IEEE*, Choon Sik Cho, *Member, IEEE*, and Jaeheung Kim, *Member, IEEE*

***Abstract*—In this paper, a new vertical half disc-loaded monopole antenna (VHDMA) with a horizontally top-loaded small disc is investigated. This antenna provides a similar radiation pattern compared to that of the simple monopole antenna, a wide input impedance bandwidth, and a very small size. The radiation pattern of the proposed VHDMA in the azimuthal direction is almost omnidirectional, which is usually required for the design of conventional monopole antennas. In addition, the simulation and measured results show that the return loss characteristic of the VHDMA provides a considerably large bandwidth even with a small radiating area. Comparing the measured results of a circular and a half-circular disc-loaded monopole antenna with a small disc mounted on the top, it is found that the half-circular disc-loaded monopole antenna with a mounted disc is comparable to the circular disc-loaded monopole antenna with respect to size and electrical performance. Surface wave and dielectric loss are often caused by the printed antenna with a high dielectric constant, whereas they are not generated by metallic planar antennas by realizing a good impedance matching and avoiding lossy matching units. This implies that antenna return loss is directly related to antenna radiation efficiency.**

***Index Terms*—Filtering characteristic, half disc, monopole, ultra-wideband.**

I. Introduction

RECENTLY, much effort to overcome the technical difficulties in the ultra-wideband (UWB) system has been expended by researchers and industry that delivered the regulation of spectrum mask and mitigated the interferences with other communication systems. The UWB system is now arising as a candidate for the home network system with millimeter-wave regime. Particularly, the dispersion and distortion characteristics of the wave transmitted by a standard wideband conical antenna have been investigated by using the analytical method [2] and the time-domain analysis method [7]–[9].

There are general factors determining the antenna performance of the UWB system. Those are input matching representing VSWR and antenna efficiency, radiation pattern determining the available beam angle for distortionless wave received from the transmitter, frequency-independent main lobe, group delay, gain flatness described by the antenna transfer function, and so on. Numerous methods to increase the radiating area for monopole antennas by changing the antenna shape have been widely discussed in [3]–[6] and [10].

The spectrum allocated for the UWB system is categorized into two parts. The one is an extremely wide band from 3.1 to 10.6 GHz with negligible interference to the existing communication systems by employing a notch filtering characteristic around 5 GHz. The other one is a multiband, which is divided

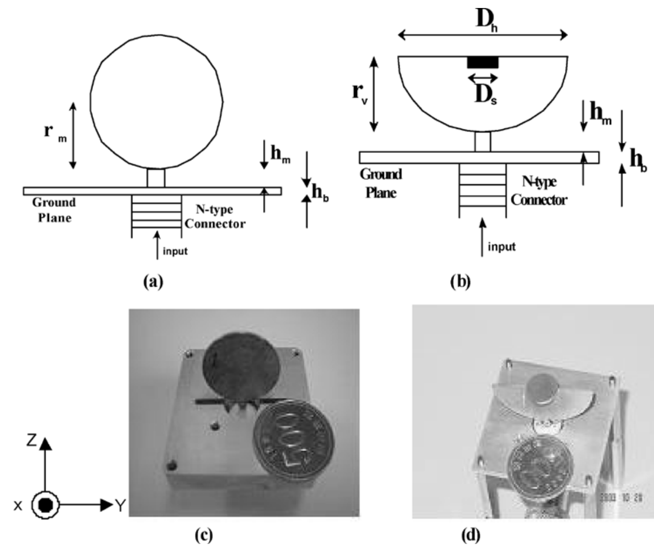

Fig. 1. Disc-loaded monopole antennas. (a) Circular/elliptical disc-loaded monopole antenna. (b) VHDMA with a horizontally top-loaded small disc. (c) Photograph of the fabricated circular disc-loaded monopole antenna. (d) Photograph of the fabricated VHDMA with a horizontally top-loaded small disc. Diameter of the coin is 26 mm.

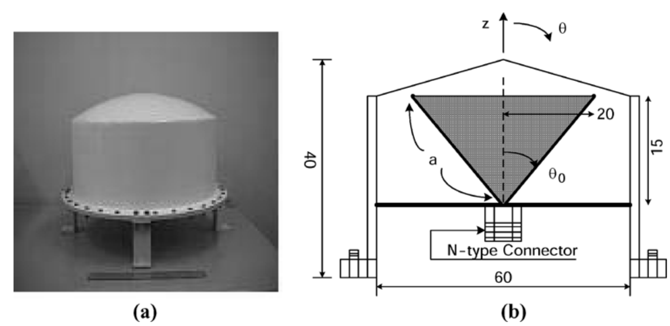

Fig. 2. A standard conical antenna for the transmitter with radome and inside sketch, unit [cm].

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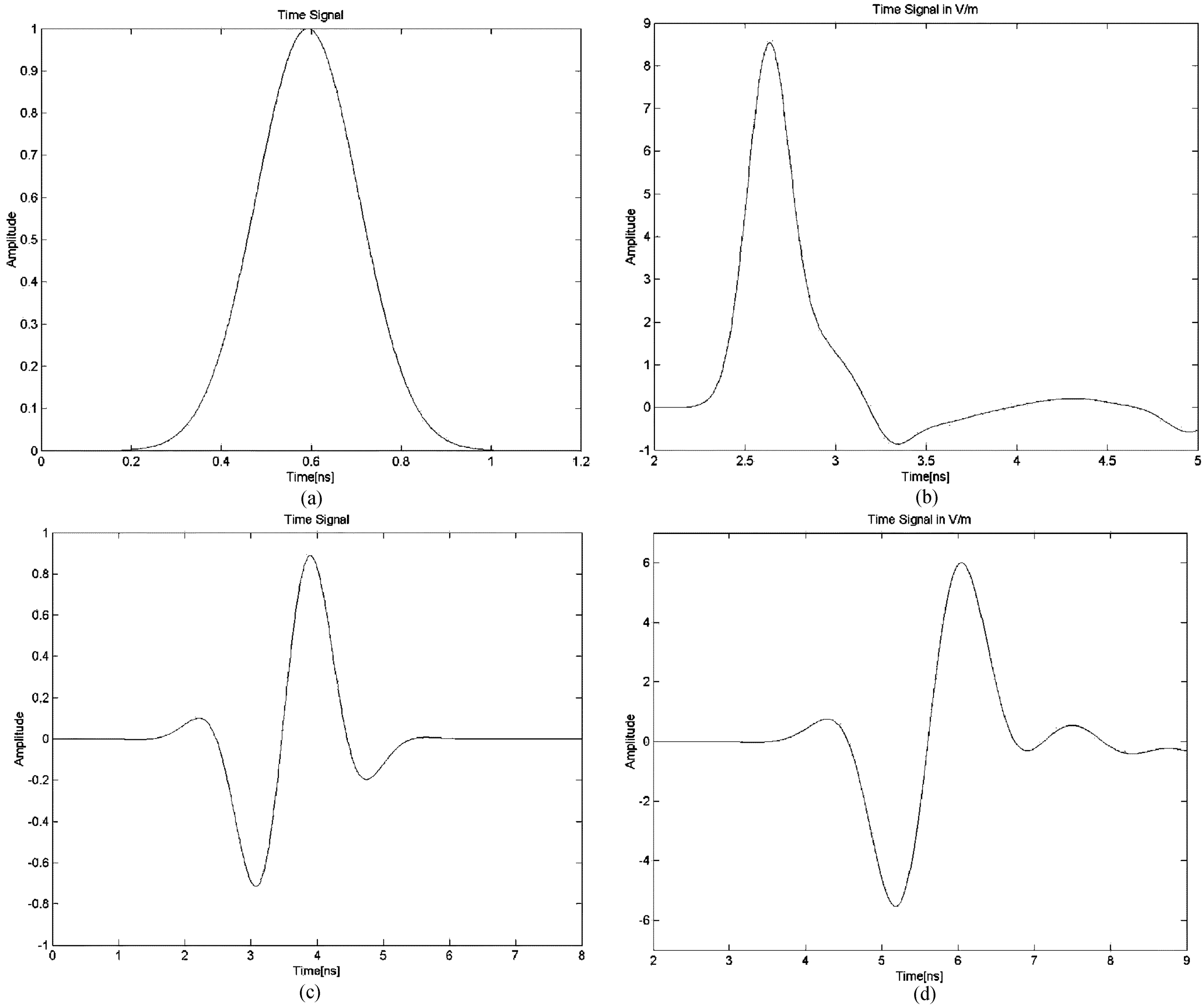


Fig. 3. Signal transfer characteristics (simulated waveform distortions) of a standard conical antenna. (a) Gaussian pulse at the antenna input port. (b) Response of Gaussian pulse at the probing point, $\theta = \pi/2$. (c) Differentiated Gaussian pulse at the antenna input port. (d) Response of differentiated Gaussian pulse at the probing point, $\theta = \pi/2$.

into several bands between 3.1 and 10.6 GHz, according to the modulation scheme.

In this paper, we examine the waves received at the probing points located 10 cm away from a disc-loaded monopole antenna. The height and the outer radius of the top circle of a standard conical antenna are set to be 15 and 20 cm for fabrication, respectively. Furthermore, the investigation of the wave transmitted from a standard conical antenna gives us a physical insight into distorted amount of the wave transmitted from the proposed antenna. The disc-loaded plate antenna with an ellipticity ratio, 13/12 and a length of the major axis, $r_m = 26$ mm shown in Fig. 1(a) provides an input impedance bandwidth more than 3 GHz for $S_{11} \leq -6.5\ dB$. In addition, the compact monopole antenna with a horizontal circular disc [vertical half disc-loaded monopole antenna (VHDMA)] shown in Fig. 1(b) gives a better performance for $S_{11} \leq -7.2\ dB$ and a smaller size than simple circular plate antennas maintaining the return loss characteristics. The thickness, t of the disc-loaded monopole antennas shown in Fig. 1, is set to be 1 mm for simulation and measurement.

In Section II, transfer functions of a standard conical antenna and the proposed antenna are described by applying the ratio between the electric field strength, $E^{\mathrm{rad}}(f)$ in the spectral domain at arbitrary detecting points and the input waveform, $V_g(f)$ at the input terminal of the transmitter antenna. In addition, signal transfer characteristics of two antennas operating at the UWB band are given in Section II. In Section III, the simulation and measurement of a vertical half disc-loaded UWB antenna with a horizontally top-loaded small disc are carried out. Conclusion in Section IV describes a brief summary of this work.

II. Transfer Characteristics of the Transmitter Antenna

A. Transfer Function of a Standard Conical Antenna

In a standard conical antenna shown in Fig. 2, the driving-point impedance at the input port can be defined as the ratio of

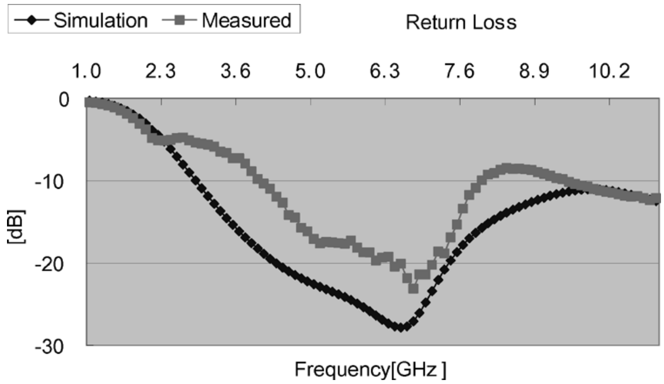


Fig. 4. Simulated and measured results of the VHDMA.

the voltage applied to the input terminal to the current flowing into the input terminal [2], i.e.,

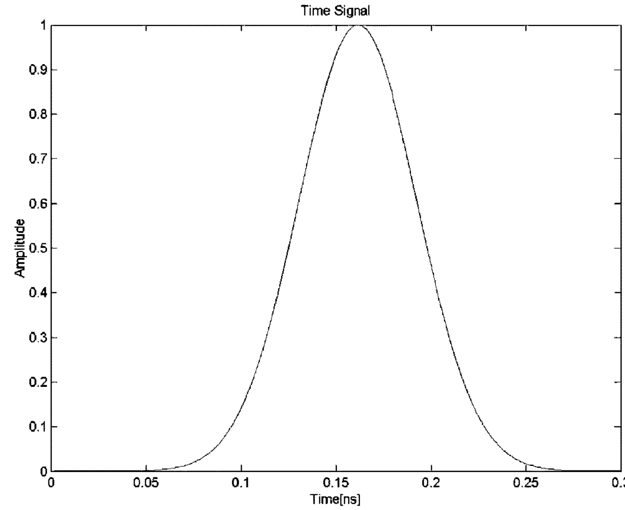
$$Z_0(f) \equiv \frac{V_0(f)}{I_0(f)} = Z_c(f)\frac{1-\frac{\beta}{\alpha}}{1+\frac{\beta}{\alpha}}$$

where $Z_c(f)$, α and β are defined in [2].

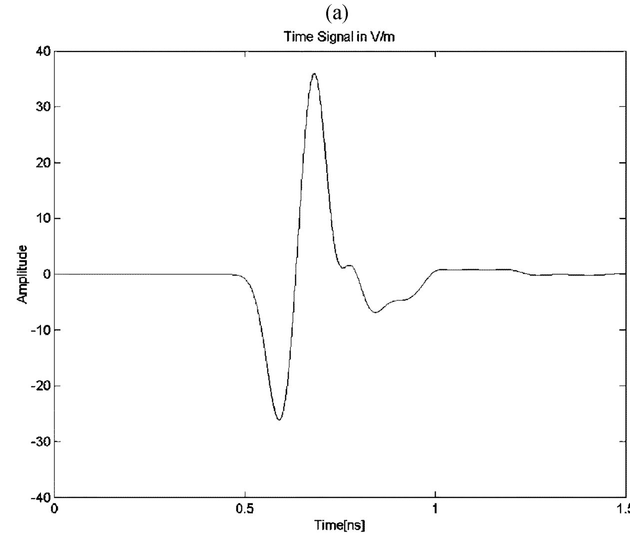
Like conventional conical antennas, the driving-point impedance can be approximated to the characteristic impedance which is determined by the flare angle, θ_0 and is not dependent on the frequency because β/α is approximated to zero as radial distance approaches infinity and the operating frequency increases. A purpose of loading an elliptical or a circular disc on the monopole with a cavity or an additional top-loading disc is to increase the input impedance bandwidth and to move the resonant frequency to a lower band maintaining the same overall antenna height. As introduced in [2], a time-domain radiation field at the probing points can be obtained from the known transfer function and the known source voltage by using inverse Fourier transform of the product of two known functions. From the transfer function for transmission represented by a relation between the radiated field at an arbitrary distance and the source voltage, we can see that the amplitude of the transfer function is independent of the frequency and the antenna height to maintain the pulse shape of source without distortion. The amplitude of the transfer function, defined as $T(f) = E^{rad}(f)/V_g(f)$, approaches $|T(f)| \propto (j2\pi f)^2 F(a, \theta_0)$ which depends on frequency, antenna length, and flare angle when the overall antenna length is very small. Meanwhile, it is proportional to a constant value C when the overall antenna length approaches infinity. From Fig. 3, it is shown that the signal transmitted from a standard conical antenna is distorted by a delayed time at a probing point.

B. Transfer Function of the UWB VHDMA

A basic structure of the various monopole antennas shown in Fig. 1 has been originated by modifying the $\lambda/4$-wire monopole antenna to increase the radiating area. From Fig. 4, the VHDMA proposed in Fig. 1(b) shows a wide impedance bandwidth by not using a matching module. It maintains high radiation efficiency and satisfies gain flatness over the entire system frequencies. In order to investigate the transfer characteristics of the VHDMA proposed in this paper, the Gaussian pulse is excited into the antenna port. The transmitted wave at an arbitrary point with $\theta = \pi/2$ is the differentiated Gaussian pulse as shown in Fig. 5 because of spectral filtering characteristics caused by physical miniaturization of the UWB antenna.



(a)



(b)

Fig. 5. Signal transfer characteristics of the VHDMA in Fig. 1(d). (a) Gaussian pulse at the antenna input port. (b) Response of Gaussian pulse at the probing point, $\theta = \pi/2$.

III. Experimental Results and Simulation

In Fig. 3, distortion of the transmitted wave according to different input waveforms (input sources) is described. The lesser the input pulse occupies in the low frequency band, the wider the available beam angle without distortion of wave. A modified circular disc-loaded antenna and a half disc-loaded monopole antenna with a cavity or an additional disc mounted on the top are described in Fig. 1. Using a commercial software package CST MW Studio version 5.0 based on the finite difference time domain (FDTD) method for various ellipticity ratios, the simulation results (return loss and distorted waveforms of transmitted pulses) were obtained. Fig. 4 shows a wideband characteristic of the proposed VHDMA in terms of the return loss with a good agreement between simulation and experiment. There is a discrepancy between the measured data and the simulated results

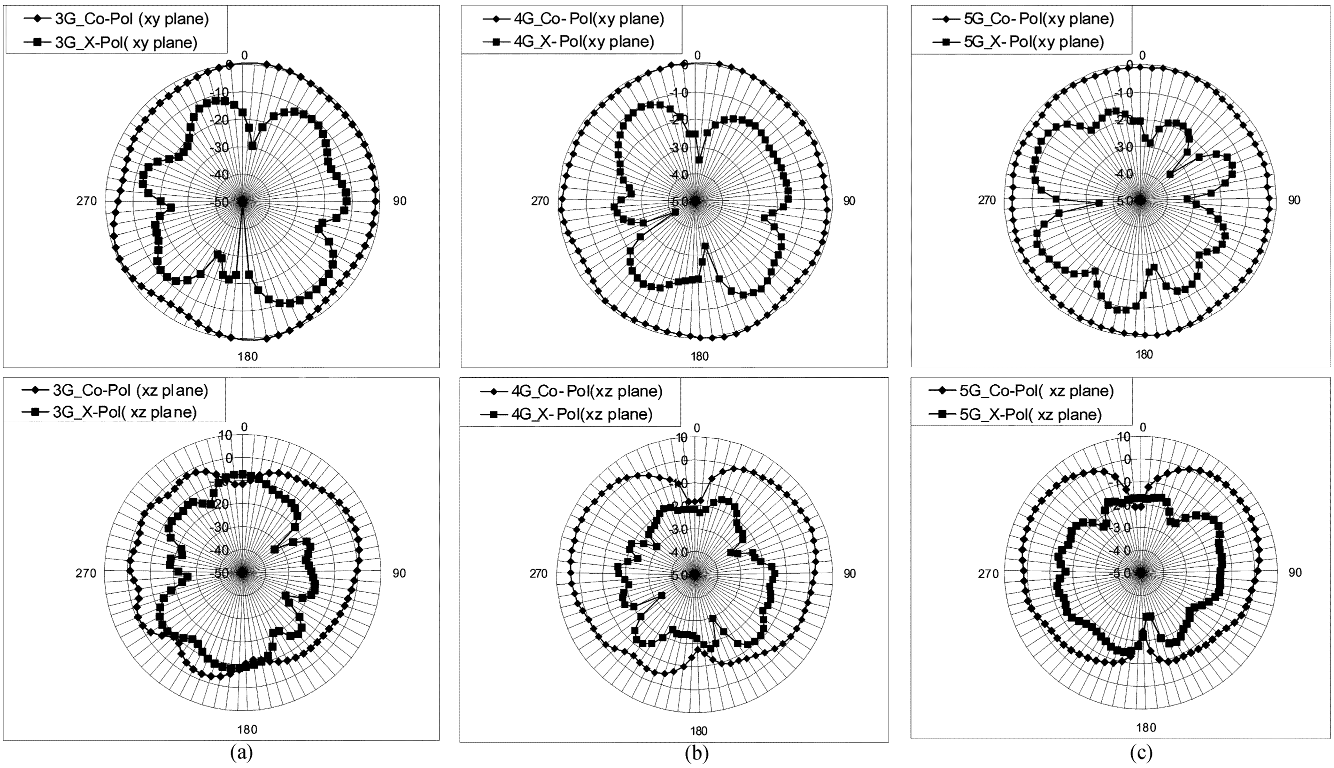


Fig. 6. Measured azimuth and elevation patterns of the VHDMA at (a) 3 GHz, (b) 4 GHz, and (c) 5 GHz.

TABLE I
ANTENNA GAIN OF THE VHDMA, UNIT[dB]

Freq. & Cutting plane	3GHz	4GHz	5GHz	6GHz	7GHz	8GHz	9GHz	10GHz
xy-plane	0.77	0.71	-0.17	-0.30	-0.21	2.2	1.4	1.6
xz-plane	2.5	4.95	4.0	3.2	2.7	2.6	1.9	2.9

TABLE II
VARIOUS TYPES OF DISC-LOADED MONOPOLE ANTENNAS

Types	$D_h = 2r_v[mm]$	$D_s[mm]$	*Common Parameters*
(i)	25	0 in Fig. 1(b)	$h_m = 1[mm]$ and $h_b = 10[mm]$
(ii)	25	12.5	
(iii)	30	12.5	
(iv)	34	12.5	
(v)	34	13:11	

in Fig. 4. This is caused by a small cavity existing between the loaded disc and the inner core at the input port, and a misalignment between the center point of the horizontal small disc and the loading point of the main half disc as shown in Fig. 1(c). The measured data of Fig. 4 were obtained in a laboratory. The measured pattern in Fig. 6 is comparable to that of simple monopole antennas as expected. From Table I, it is seen that the gain variations in xy – plane and xz – plane are within $0.77 \sim 2.2$ dBi and $1.9 \sim 4.95$ dBi, respectively, from 3 to 10 GHz. Table II describes the dimensions of the various types of disc-loaded monopole antennas including the proposed VHDMA.

IV. CONCLUSION

The waveform distortion of plate antenna loaded with a circular/elliptical disc has been studied using a simulation tool based on the FDTD method employing several Gaussian pulses, and this was validated by experiment. It is found from measurement that the factors affecting signal distortion are impedance bandwidth, gain-flatness, and pattern uniformity in the given frequencies. In addition, availability of the VHDMA with a horizontally top-loaded small disc to the UWB application has been investigated in terms of return loss, VSWR, pattern uniformity, and compactness compared with conventional monopole antennas. The reason for improved performance of the proposed antenna (VHMDA) is considered to be a structural similarity to a standard conical antenna.

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