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A Conical-Cylindrical Monopole Antenna

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Abstract

In this paper, a monopole antenna of conical-cylindrical compound shape is presented. The conventional circular conical monopole antenna is modified by placing a cylinder at the top of the inverted cone. The cylindrical portion is useful in the wideband impedance matching, in adjusting the antenna gain in the horizontal direction, and in reducing the cone diameter. The dependence of the antenna performance on various geometric parameters is investigated using a commercial electromagnetic simulation software, from which an optimum design of the antenna is derived. The diameter of the circular ground plane is minimized to 1/5 wavelength at the lowest operating frequency. The antenna proposed in this study shows a reflection coefficient less than −10 dB and a 1~6 dBi gain over 3~20 GHz frequencies. The antenna shows a circular-symmetric radiation pattern in the horizontal plane and a null-free pattern in the vertical direction over the whole operating frequency range.

Key words : Monopole Antenna, Ultrawideband Antenna, Antenna Design.

Ⅰ. Introduction

There have been active research efforts all over the world in the area of ultra-wideband antennas. As new applications in communications and sensor technology are constantly emerging, there are growing demands for antennas covering a very wide bandwidth[1]~[3]. The conical monopole antenna is derived from the classical biconical antenna[4]~[8] by placing an inverted cone on the ground plane and feeding the base with a coaxial cable. The wideband plate monopoles[9]~[13] that have received much interests in recent years can be viewed as a planar form of the conical monopole with shape modification. The dual conical monopole[14]~[17] is a back-to-back connection of two cones.

The primary merit of the conical monopole antenna is its ultra-wideband impedance and pattern characteristics. The antenna's VSWR can be made less than 2.5 over more than a decade bandwidth without using any impedance matching circuit. The conical monopole has a uniform circular radiation pattern in the horizontal plane and a vertical pattern free of deep nulls over its entire operating frequency range. The plate monopole can be impedance-matched over a very wide bandwidth, but its radiation pattern is non-uniform in the horizontal plane and has some deep nulls in the vertical direction.

The conical monopole may be constructed using a solid metal if it is small enough. When the monopole is physically large, it is usually realized in a wire skeleton form[18]~[20] as can be seen in many commercial products operating at the 2~30 MHz band[21],[22].

The theoretical analyses of the conical monopole are presented in [23]~[25], while [26] deals with the experimental study and [27]~[29] describe antenna design aspects. The transient response of the conical monopole are investigated in [30]~[32]. The application of the conical monopole antenna as a device for high-power pulse radiation is described in [33].

In this paper, we present a conical-cylindrical monopole antenna, which is a modification of the standard conical monopole. A circular cylinder is placed at the top side of the inverted cone. The cylinder offers an additional design parameter that can be used in controlling the input impedance and the gain in the horizontal plane. Furthermore the cylindrical section is useful in reducing the antenna volume since the cone diameter is not increased beyond that of the cylinder.

We first present results of a parametric study, from which an optimum design of the conical-cylindrical monopole antenna is derived. The antenna is in a solid metal form and operates over 3~20 GHz frequency range. A thorough parametric study on the conical and conical-cylindrical monopole has not yet been published in the open literature. Microwave Studio(MWS)® by Computer Simulation Technologies, a widely-known commercial electromagnetic software, is used for the simulation of the antenna performance. The designed antenna is fabricated and its performance is measured and com-

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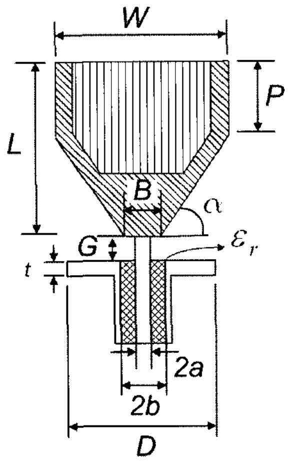
pared with the computer simulation.

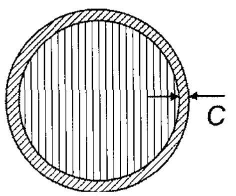
Ⅱ. Parametric Analysis and the Antenna Design

2-1 Antenna Structure

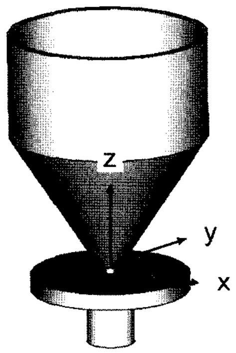
Fig. 1 shows the structure of the conical-cylindrical monopole. Also denoted are antenna design parameters such as cylinder diameter W, monopole height L, cone base diameter B, feed gap G, cone angle α, ground plane diameter D, cylinder height F, ground plane thickness t, and cylinder's metal thickness C. Parameters that have the most sensitive influence on the impedance property of the antenna are cone angle, feed gap and cone base diameter.



(a) Side view



(b) Top view



(c) 3D view

Fig. 1. Structure and design parameters of the conical-cylindrical monopole.

First, a detailed parametric study has been carried out. Initial values of design parameters are obtained using results in the existing literature. They are W=30 mm, L=30 mm, D=20 mm, B=3 mm, G=1.5 mm, α=50°, P=13 mm, C=2 mm, t=3 mm. The coaxial cable feeding the monopole has the characteristic impedance of 50 ohms with $2a$=1.3 mm, $2b$=4.1 mm, ε_r=2.1.

With a suitably chosen set of initial parameter values, antenna characteristics are analyzed as each parameter value is changed one by one. When the antenna shows the best performance, the parameter value is set to an interim optimum value. This process is repeated for the next parameter. At the end of the individual parameter sweep, one easily gets the knowledge of each parameter's effect on the antenna performance.

In the next step, we carry out a selective parameter study, where we change only those parameters that most sensitively affect the antenna input impedance and the radiation pattern. With the selective parameter study, we finally obtain the optimum set of parameter values.

2-2 Parametric Study

Fig. 2 shows the antenna reflection coefficient for various values of the cylinder diameter W. The cylinder length P is changed for each value of W so that the conditions L=30 mm and α=50° are satisfied. The design goal is to make the reflection coefficient less than −10 dB over 3~20 GHz. From Fig. 2, we observe that the cylinder diameter in 20~30 mm range is a good choice. With the cylinder diameter less than 20 mm, the reflection coefficient is greater than −10 dB over the desired frequency range. The cylinder diameter greater than 30 mm leads to a too bulky antenna with little improvement in the antenna performance.

Next we change the cone base diameter B and observe

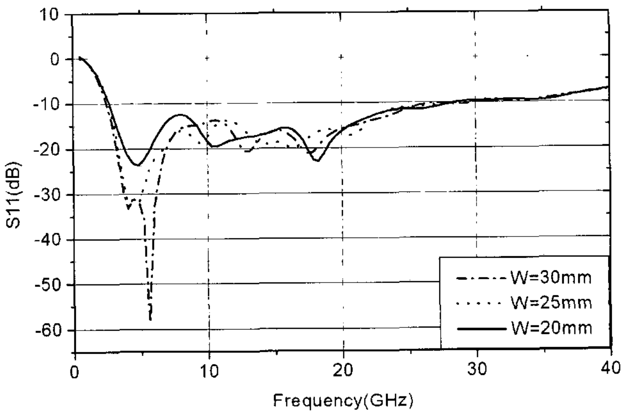


Fig. 2. Antenna reflection coefficient for various cylinder diameters.

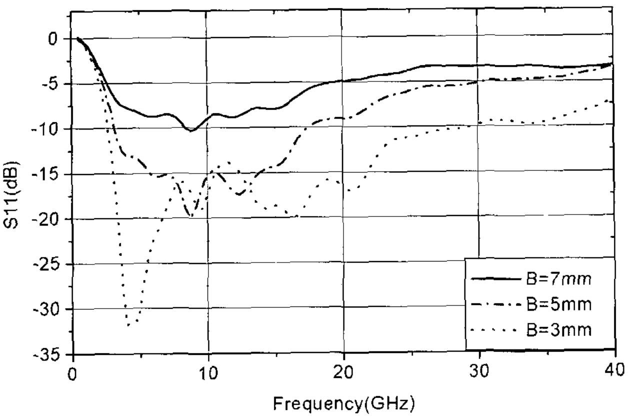


Fig. 3. Antenna reflection coefficient for various cone base diameters.

the reflection coefficient. Fig. 3 shows the result, where we note that the reflection coefficient is very sensitive to the change in the cone base diameter. The low reflection coefficient is obtained over the wide frequency range for small values of the cone base diameter, whose value is limited by the probe diameter 2*b*. Fig. 3 shows that *B*=3 mm gives a good impedance match over 3~20 GHz. Smaller values of *B* would lead to manufacturing difficulties since the cone base should be able to accept the insertion of the 1.3-mm diameter probe.

In the third step of the parameter sweep, we investigate the influence of the feed gap *G*. Fig. 4 shows the antenna reflection coefficient for various values of the feed gap. The antenna impedance match is very sensitive to the feed gap. The best performance is obtained when *G* is 1 mm. Smaller values of *G* yield higher values of the reflection coefficient.

The fourth parameter to sweep is the cone angle α. Fig. 5 shows the antenna reflection coefficient for various values of α. The reflection coefficient is less than −10 dB over 3~20 GHz when the angle is between 50° than 60°. The best performance is obtained when α =57°.

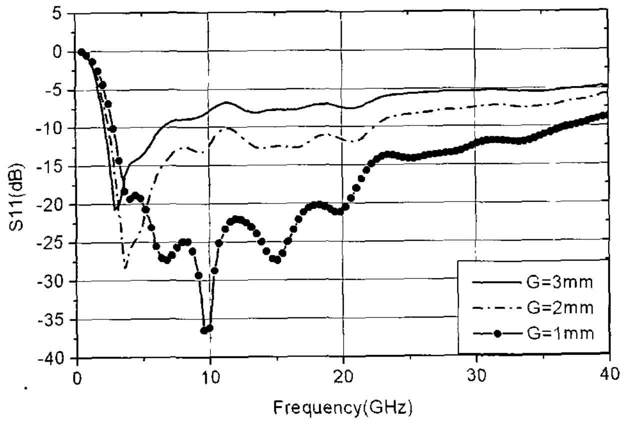


Fig. 4. Antenna reflection coefficient for various feed gaps.

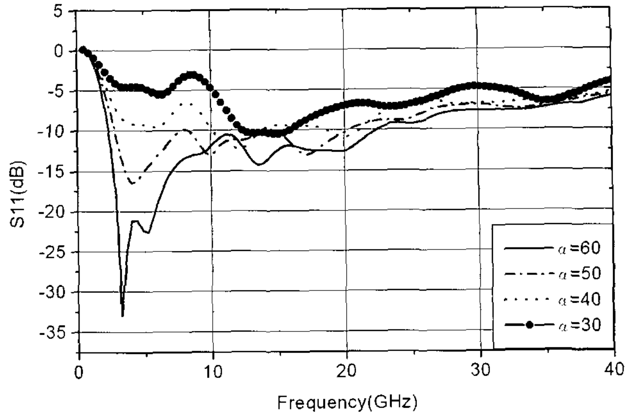


Fig. 5. Antenna reflection coefficient for various cone angles.

In the fifth step of the parametric analysis, we investigate the effect of the ground plane diameter *D* on the antenna reflection coefficient. Fig. 6 shows the result. Ground plane diameters in the 20~60 mm range offer similar levels of the reflection coefficient except that larger ground planes give a better impedance match at the lower limit of the operating frequency band. Fig. 7 shows the vertical-plane gain pattern for various values of the ground plane diameter. The vertical gain pattern does not change significantly with varying ground plane diameters in 20~60 mm range. There are small variations in the gain in the horizontal direction. The thickness of the ground plane has a minimal effect on the antenna performance.

In the final step, we study the dependence of antenna characteristics on the cylinder length *P*. Fig. 8 shows the reflection coefficient versus the cylinder length, where

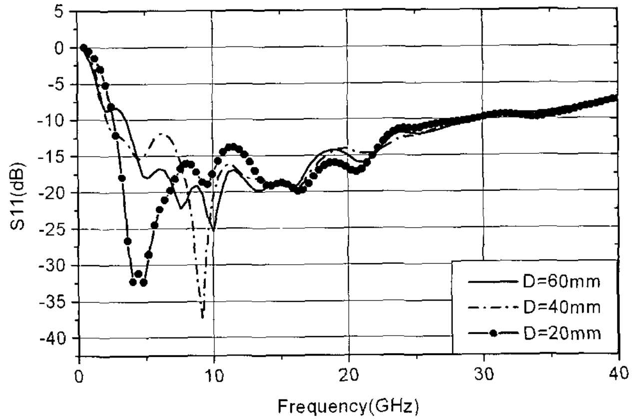
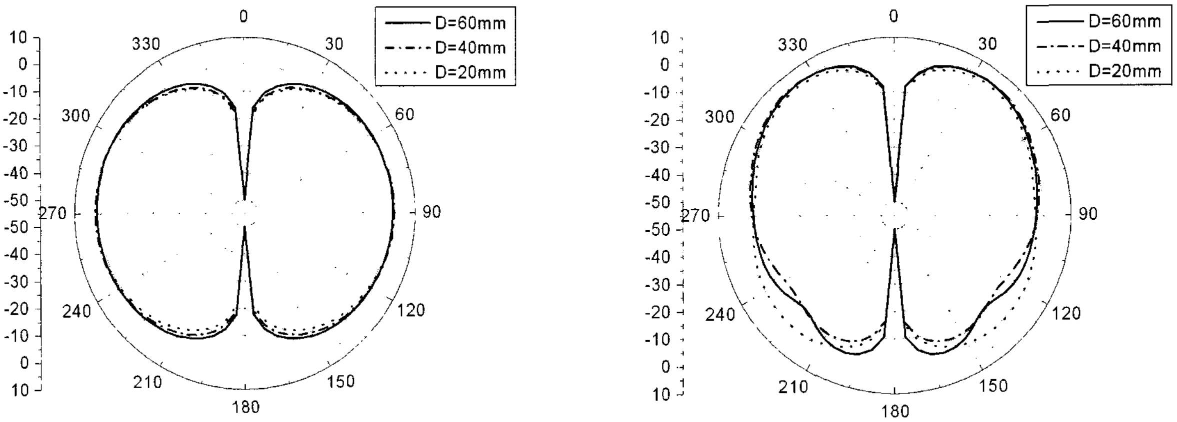
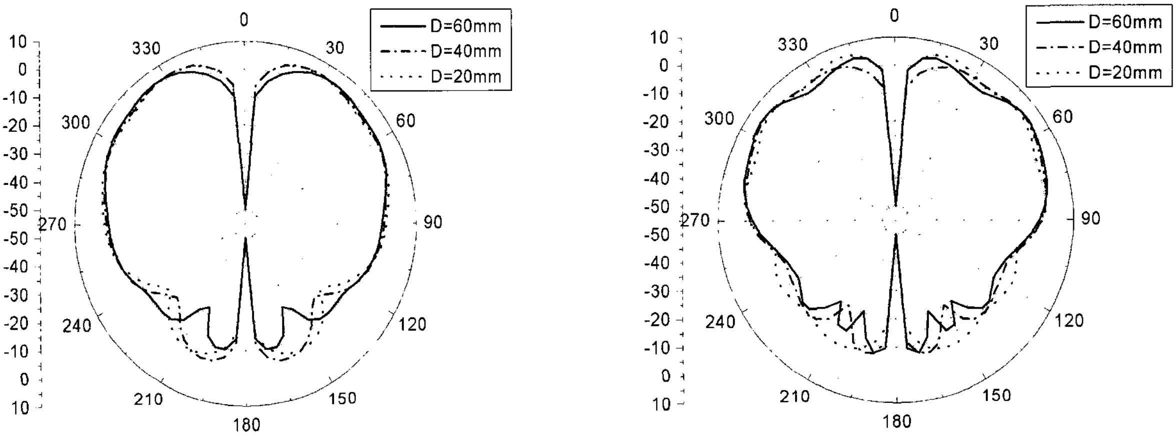


Fig. 6. Antenna reflection coefficient for various ground plane diameters.



(a) 3 GHz (b) 8 GHz



(c) 13 GHz (d) 18 GHz

Fig. 7. Gain pattern in the vertical plane for various ground plane diameters.

we observe that with a proper choice of P, the reflection coefficient can be made less than -20 dB over 4~20 GHz. Fig. 9 shows the gain pattern in the vertical plane for various values of the cylinder length. As expected the vertical pattern does not change significantly with varying cylinder lengths. Fig. 10 shows the horizontal gain for various cylinder lengths. The horizontal gain shows a variation of a few decibels depending on the operating frequency. One can employ the cylinder length as a parameter controlling the horizontal gain at a specific frequency.

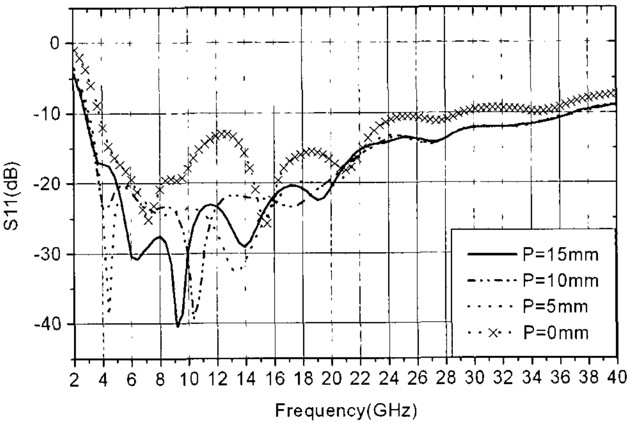
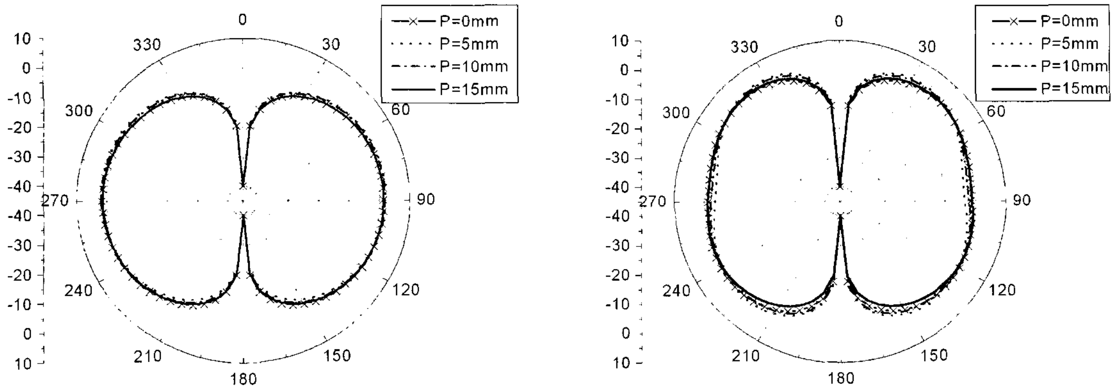


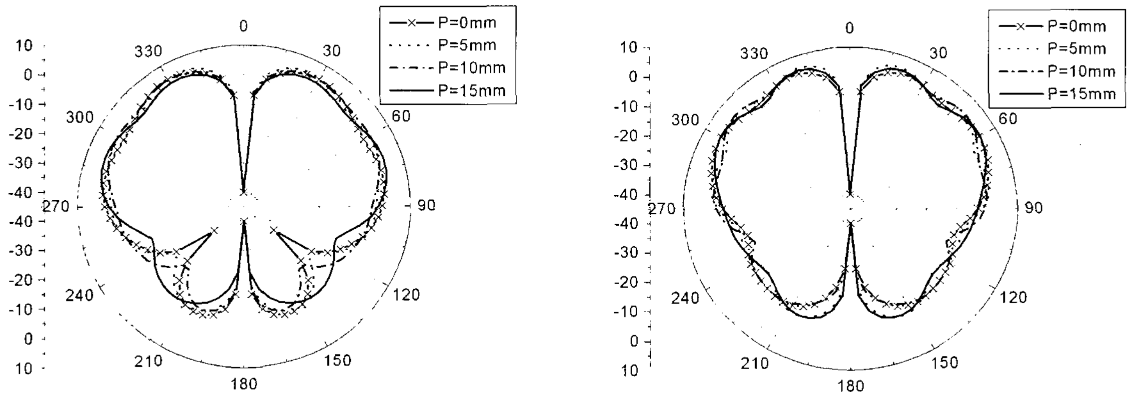
Fig. 8. Antenna reflection coefficient for various cylinder lengths.

2-3 Optimum Antenna Design

Results of the parametric study are employed in the optimum design of the conical-cylindrical monopole antenna. Critical design parameters such as cylinder diameter, cone base diameter, feed gap, and cylinder length are adjusted sequentially in many iterative parameter-sweep type simulations until the best result is obtained. The final antenna dimensions are W=22 mm, B=3 mm, G=1 mm, α=57°, D=20 mm, P=13 mm, C= 2 mm, t=3 mm. Simulated performances of the designed antenna are presented in the next section along with measured results.



(a) 3 GHz (b) 8 GHz



(c) 13 GHz (d) 18 GHz

Fig. 9. Gain pattern in the vertical plane for various cylinder lengths.

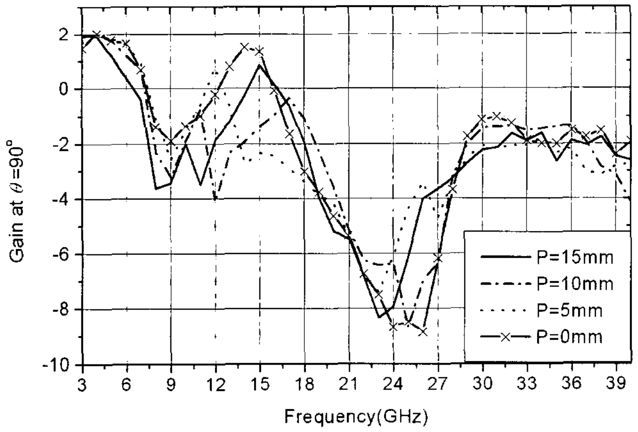


Fig. 10. Gain in the horizontal plane versus the frequency for various cylinder lengths.

III. Antenna Fabrication and Measurements

The designed antenna is fabricated using standard machining techniques. Fig. 11 shows the fabricated antenna.

Simulated and measured performances of the antenna are given in Figs. 12~15. Fig. 12 shows the reflection

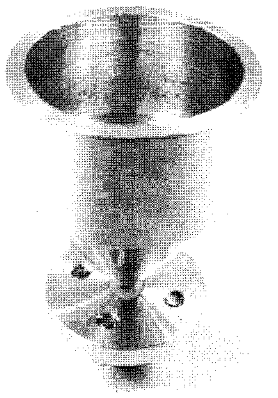


Fig. 11. Fabricated conical-cylindrical monopole antenna.

coefficient. The measured reflection coefficient is less than −10 dB over 3~20 GHz, in good agreement with the simulation. Fig. 13 shows measured vertical radiation patterns at various frequencies, which agree fairly well with the simulation. There are no deep nulls in the vertical pattern at upper frequencies. The horizontal pattern shown in Fig. 14 remains truly circular over the whole frequency range.

Fig. 15 shows measured values of the peak or maxi-

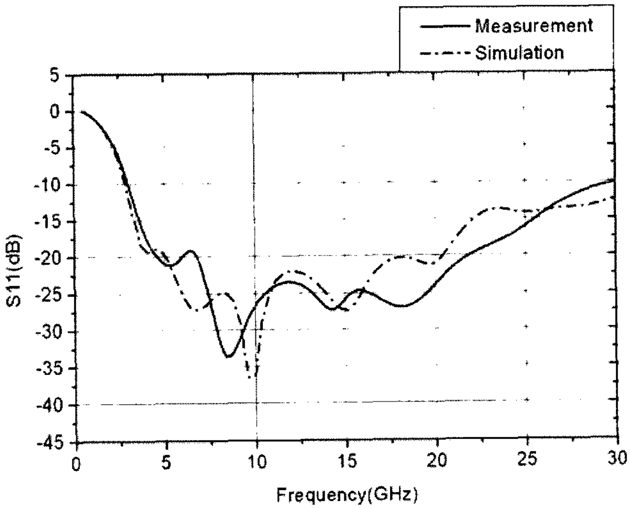


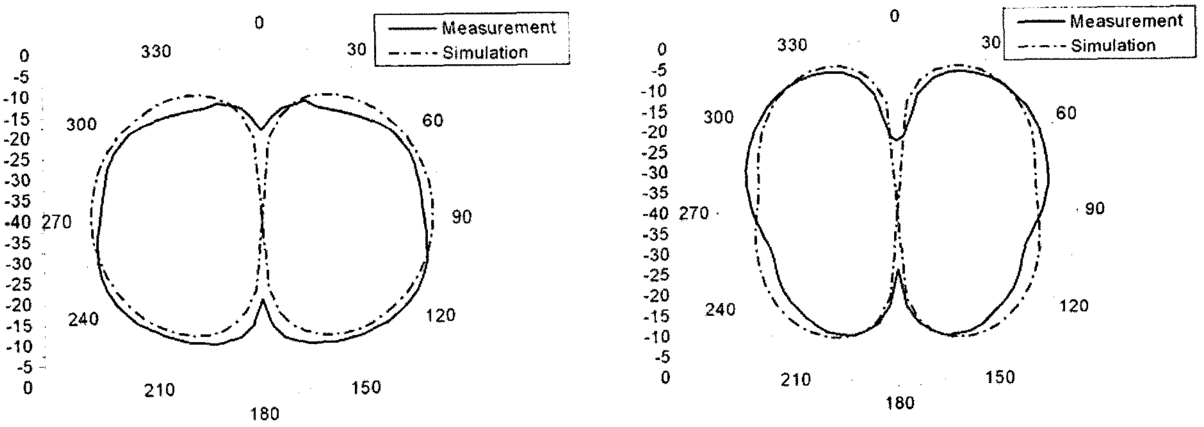
Fig. 12. Reflection coefficient of the fabricated antenna.

mum gain. The measurement agrees well with the simulation. The measured gain ranges from 1 dB to 6 dB with higher values at upper frequencies.

Ⅳ. Conclusions

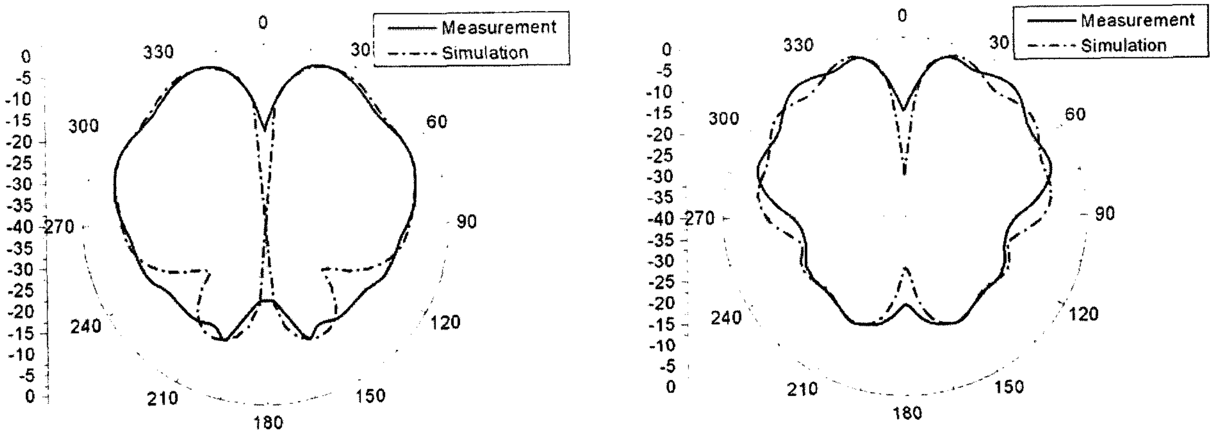
The design and performance conical-cylindrical mono pole antenna are presented. The dependence of the antenna performance on various geometrical parameters is investigated, from which an optimum design of the conical-cylindrical monopole antenna is derived. It is shown that the cylindrical section of the proposed antenna can be utilized in reducing the antenna reflection coefficient to lower levels and in controlling the horizontal gain.

The designed antenna is fabricated in a solid metal form, and it performance is measured and compared with the simulation. The fabricated antenna shows a reflection coefficient less than −10 dB and a gain of 1~6 dB over 3~20 GHz. The vertical pattern has no deep nulls, and the horizontal pattern remains truly circular over the whole operating frequency range. Having a very wide bandwidth and good radiation pattern characteristics, the proposed antenna can be utilized in many applications that require such performances.



(a) 3 GHz

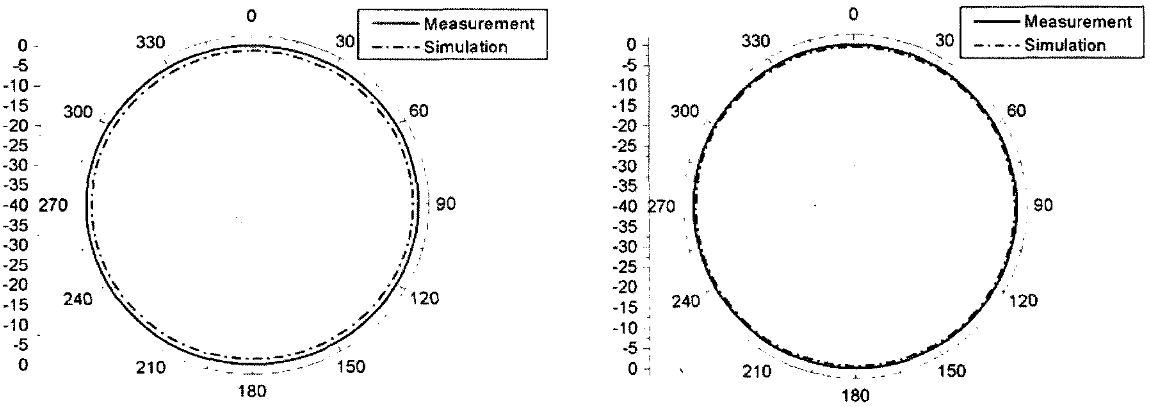
(b) 8 GHz



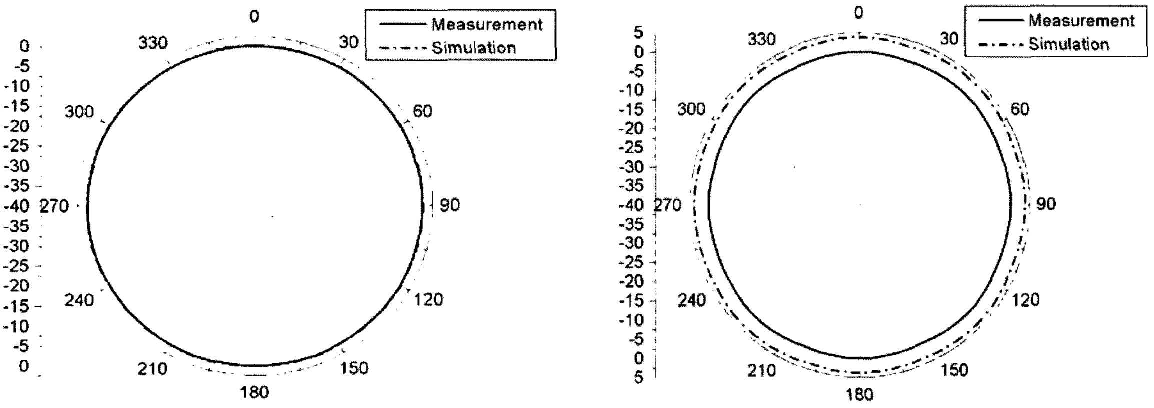
(c) 13 GHz

(d) 18 GHz

Fig. 13. Vertical radiation pattern of the fabricated antenna.



(a) 3 GHz (b) 8 GHz



(c) 13 GHz (d) 18 GHz

Fig. 14. Gain pattern in the horizontal plane for various cylinder lengths.

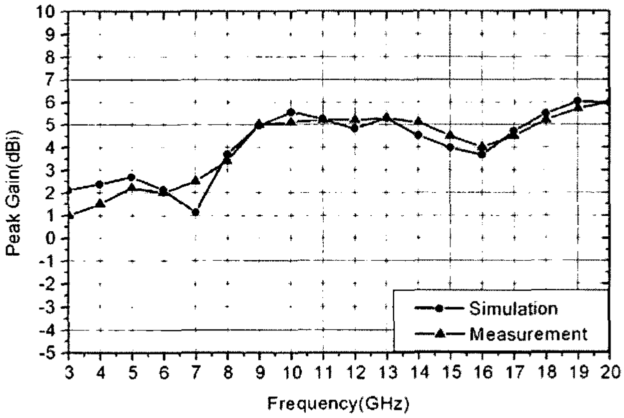


Fig. 15. Peak gain of the fabricated antenna.

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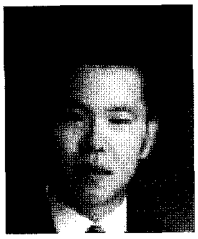

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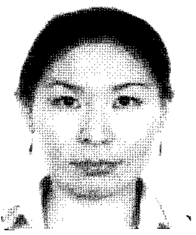

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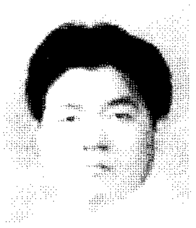

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