Progress In Electromagnetics Research C, Vol. 1, 87–93, 2008

STUDY ON AN UWB PLANAR TAPERED SLOT ANTENNA WITH GRATINGS

H.-Y. Xu, H. Zhang, and J. Wang

Missile Institute
Air Force Engineering University
San Yuan, Shan Xi 713800, China

Abstract—A new miniature ultra-wideband exponential tapered slot antenna with gratings, which is fed by a 180 degree microstrip phase shifter network, has been introduced in this paper. The switch characteristic and the reflecting loss of the phase shifter is also analyzed. Some subminiature rectangular gratings are etched at the front and back end, as a result of which, the inner band characteristic is improved and the frequency band of the antenna is extended to more than 3 : 1 ($S_{11} < -10\,\text{dB}$). The radiation pattern has good direction property in the entire bandwidth and favorable symmetrical endfire radiation characteristic as well as more than 10 dB gain in the central frequency band.

1. INTRODUCTION

The ultra-wideband (UWB) has been widely used in radar and communication systems in high resolution UWB radar, ground penetrating radar, precise orientation system, etc. [1–5]. In order to meet the demand of the miniature integration, the research and application of the UWB planar antenna attract more and more attention with the fast development of the high speed electronic integrate circuit. And one of the key technologies is the design and research of the UWB. Therefore, it has been a big hotspot in the area of antenna and propagation. Due to the limitation of the applied occasion, the UWB antenna should have the merits of small dimensions, low costs, easy fabrication and compatibility to the printed circuit board. Commonly speaking, the reduction in volume may result in a lessening of antenna efficiency and bandwidth. So the balance between the dimensions and the bandwidth and the efficiency should be found. Because the physical limit of the antenna miniaturization hasn't been realized [6], it is effective to adopt some steps in antenna configuration, the feed-in form, the material choice except the conductor, etc. The printing antenna has the merits of the light weight, small dimensions, low profile and easy integration, but its bandwidth is relatively narrow. A linear tapered antenna, whose VSWR bandwidth was 6 GHz ∼ 12.6 GHz, was designed in reference [7].

Based on it, an exponential tapered slot antenna with smaller dimensions (about 70% of its volume), wider VSWR bandwidth and the endfire radiation pattern is designed. Some subminiature gratings is etched at the front and back end of the radiation part, as a result of which, the inner band characteristic is improved and the frequency band of the antenna is extended more widely to more than 3 : 1 ($S_{11} < -10$ dB). This antenna can replace the traditional horn antenna to be the feed-in end of the bow-tie antenna because of its light weight, moderate gain, wide band and symmetrical radiation field pattern [8]. Besides, it can be easily integrated with monolithic microwave integrated circuits and the back end's positive and passive elements such as the diode.

2. ANALYSIS AND DESCRIPTION OF THE ANTENNA

Figure 1 illustrates the antenna geometry. The 50 Ω microstrip is connected with two 70 Ω microstrips which are vertical to each other through a 41.8 Ω microstrip matching switch. The length discrepancy of the two vertical 70 Ω microstrips is $0.5\,\lambda_g$ to make the phase discrepancy of the radiation slot's two sides 180 degree. Some additional phase change may be generated in the discontinuous places as a result of the curve of one 70 Ω microstrip. The resolution is to cut the corner of the corner place and adjust the length of the 70 Ω microstrip so as to obtain the 180 degree phase discrepancy. The width of the microstrips can be got by the estimation of the Designer software. The tapered slot radiation part follows the exponential gradual change.

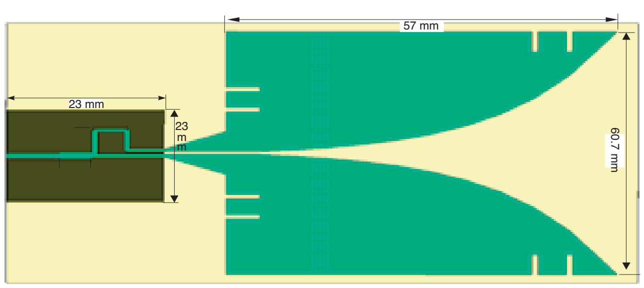

Figure 1. Geometry of the antenna.

One side of the tapered function is

$$y = 1.025e^{0.066x} \tag{1}$$

Some subminiature gratings are excavated at the front and back end of the radiation part to prevent the electric current from flowing to the edges [9, 10] to make the current to fasten on the tapered slot, as a result of which, the transmission characteristic of the antenna has been improved. The simulation results show that after the subminiature slots are etched, the radiation pattern is basically unchanged, but the inner band transmission characteristic is improved, and the bandwidth is enlarged for about 0.8 GHz in the high frequency range.

The most important factor which influences the antenna radiation pattern is the substrate parameter. In order to achieve good radiation pattern, the relatively thin substrate is usually chosen, and the relative permittivity is often chosen to be small. The substrate preferences is often concluded by the experiment, whose equivalent thickness is [11]

$$t_{eff}/\lambda_0 = t(\sqrt{\varepsilon_r} - 1)/\lambda_0 \tag{2}$$

It is between 0.005 and 0.03. And the λ_0 above is the wavelength in vacuum. Although too thick equivalent thickness increases the gain, it can also make the radiation asymmetric and the efficiency lower. But if it is too thin, the gain will be lessened and the intention of the substrate insufficient. The antenna in this paper is made on the microwave substrate with its relative permeability 3.25 and the thickness 0.5 mm.

The feed-in circuit can be regarded as the transition and the connection between the microstrip and the slot, which is on a single plane and coaxial with radiation direction of the antenna. The feed-in direction and the radiation direction of the antenna are on the same axis [12]. Fig. 2 is the transition and connection of single plane and back to back between the microstrip and the slot line. The black area

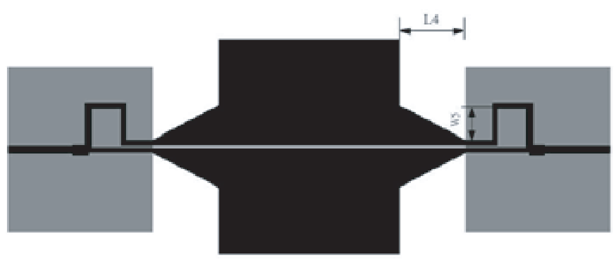

Figure 2. Conversion and connection of single plane and back to back between the microstrip and the slot line.

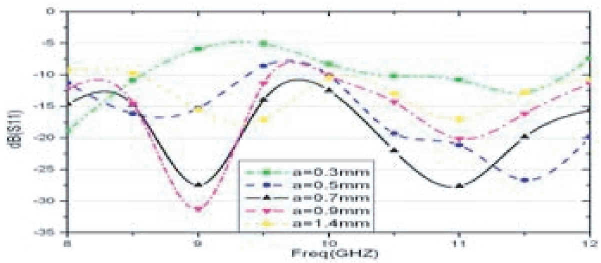

Figure 3. S_{11} about different slot width.

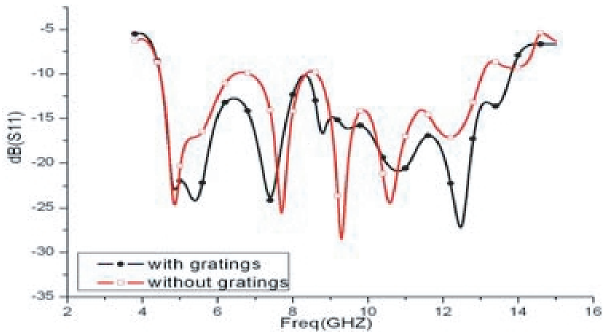

Figure 4. S_{11} variation.

is the microstrip and the slot line. The gray are the groundplane of the microstrip [7].

The width of the slot is an important factor that influences the transmission characteristic. So it is necessary to choose the best slot width. Fig. 3 is the reflection loss curves of the conversion and the connection part about different slot width (a is the slot width).

The transition and connection part is designed in X band with the center frequency 10 GHz in this paper. As can be seen in Fig. 3, in the range of $a = 0.5\,\text{mm} \sim 1.4\,\text{mm}$, the transmission characteristic of the slot line varies from poor to good first, and then to poor again with increasing of the slot width in the frequency range of 8 GHz $\sim$ 12 GHz. And it reaches the best point at $a = 0.7\,\text{mm}$. As can also be shown in Fig. 3, S_{11} curve of the 0.7 mm slot width is the only line below $-10\,\text{dB}$ in the whole frequency range.

If the antenna length is chosen to be less than λ_0, it is a resonance antenna with low gain and relative wide half gain frequency bandwidth. To be a traveling-wave antenna, its length should usually be more than $2\lambda_0$. Considering to reduce the volume of the antenna, the length was chosen to be 57 mm ($\approx 2\lambda_0$). In order to reach preferable matching

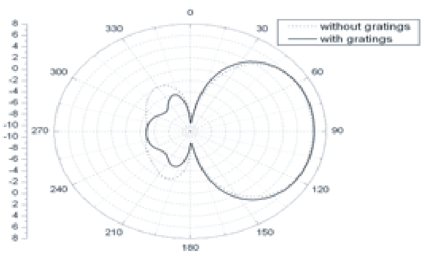

Figure 5. E-plane at 4.5 GHz.

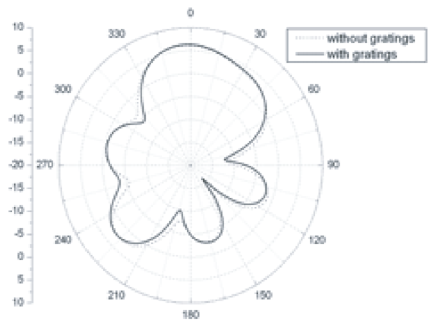

Figure 6. H-plane at 4.5 GHz.

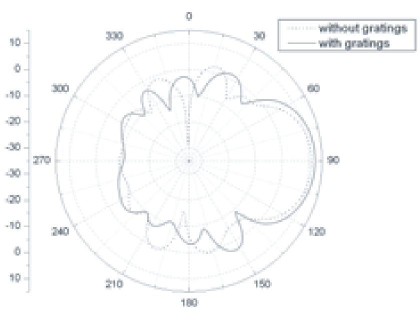

Figure 7. E-plane at 10 GHz.

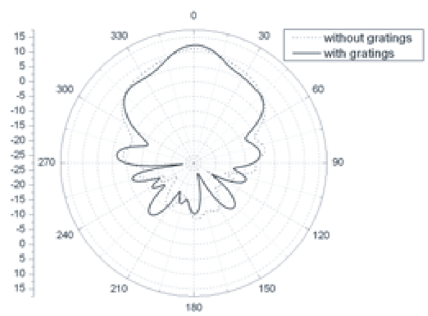

Figure 8. H-plane at 10 GHz.

from the antenna to the vacuum, the antenna hatch is chosen to be $2\lambda_0$ to make hatch angle 60 degree. If the angle is larger, the beamwidth at E plane is smaller. And the H plane is nearly not influenced. The most common three forms of tapered slots include: the linear, the exponential and the width-constant. The exponential form can increase the transmission characteristic. In three tapered forms, the exponential side beam power is the lowest. And it possesses the wide band characteristic itself. So this form is chosen.

3. SIMULATION RESULTS

Figure 4 is the simulation comparison result of the S_{11} parameters between the antennas with and without rectangular gratings at the front and back end. In the range of $5\,\text{GHz} \sim 7\,\text{GHz}$ and $11\,\text{GHz} \sim 13.8\,\text{GHz}$, the reflection loss of antenna with rectangular gratings improves evidently. The S_{11} is completely below $-10\,\text{dB}$ in

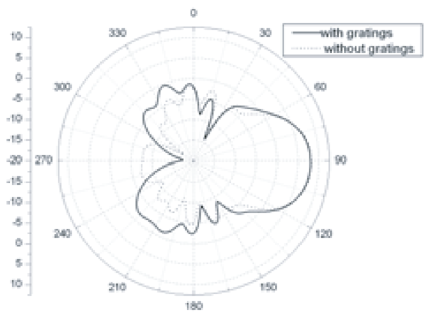

Figure 9. E-plane at 13.5 GHz.

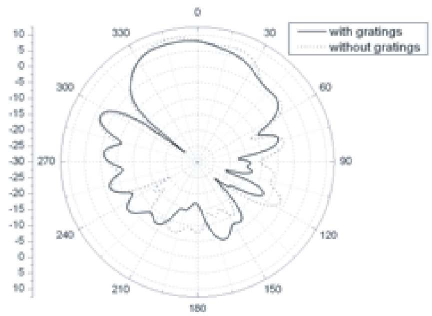

Figure 10. H-plane at 13.5 GHz.

the entire bandwidth.

The radiation patterns of the antennas with rectangular gratings and without them at the front and back end change little, which means that the subminiature rectangular gratings at the front and back part nearly didn't influence the antenna radiation property. Figs. 5∼10 are the radiation patterns.

As can be seen from the radiation, the E plane has favorable symmetry characteristic. The gain of the antenna is more than 10 dB.

4. CONCLUSION

The ultra-wideband (UWB) has been widely used as a wireless communication technology. Its miniaturization research becomes more and more important. An antenna with a new-style feed-in network of 180 degree phase shifter is designed in this paper. The tapered part follows the exponential form. It possesses more than 3 : 1 bandwidth with the frequency range 4.5 GHz ∼ 13.8 GHz. Its volume is greatly reduced compared with the reference [7] (about 70% of it). It has favorable symmetry end radiation pattern. And moreover, because it has high gain, small volume, light weight and low section plane, it can be applied in satellite communications and distant measure antenna and replace the traditional horn antenna to be the feed-in end of the bow-bie antenna. Besides, it can be easily integrated with other circuit elements and monolithic microwave integrated circuits. The bandwidth is widened by etching subminiature rectangular gratings in the front and back end. And the inner band characteristic is nearly unchanged, but the characteristic in the inner band is improved, too. The simulation results show that in both high and low frequency range, the radiation property becomes a little poorer, and the gain lower, too.

REFERENCES

1. Cheng, Y., W. J. Lv, C.-H. Cheng, and W. Cao, "Design and analysis of a compact planar ultra-wideband antenna," *Chinese Journal of Radio Science*, Vol. 21, No. 4, 582–583, Feb. 2006.
2. Wang, F. J. and J. S. Zhang, "Wide band cavity-backed patch antenna for PCS/IMI2000/2.4 GHz WLAN," *Progress In Electromagnetics Research*, PIER 74, 39–46, 2005.
3. Eldek, A. A., A. Z. Elsherbeni, and C. E. Smith, "Dual-wideband square slot antenna with a U-shaped printed tuning stub for personal wireless communication systems," *Progress In Electromagnetics Research*, PIER 53, 319–333, 2005.
4. Khodaei, G. F., J. Nouriniam, and C. Ghobade, "A practical miniaturized U-slot patch antenna with enhanced bandwidth," *Progress In Electromagnetics Research B*, Vol. 3, 47–62, 2008.
5. Elsadek, H. and D. M. Nashaat, "Ultra miniaturized E-shaped PIFA on cheap foam and FR4 substrates," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 3, 291–300, 2006.
6. Zhu, Y.-Z. and P. Li, "A novel ultra broadband planar monopole antenna for UHF," *Chinese Journal of Electron Devices*, Vol. 30, No. 2, 804–805, 2007.
7. You, M.-R., *Design of Microwave Wideband Antenna*, National Central University, Jungli, Taiwan, 2005.
8. Lee, K. F. and W. Chen, *Advances in Microstrip and Printed Antennas*, John Wiley & Sons, New York, 1997.
9. Chen, N. W., C. T. Chuang, and J. W. Shi, "A W-band linear tapered slot antenna on rectangular-grooved silicon sub-strate," *IEEE Antenna and Wireless Propagat. Lett.*, Vol. 6, 2007.
10. Sugawara, S., Y. Maita, K. Adachi, K. Mori, and K. Mizuno, "A mm-wave tapered slot antenna with improved radiation pattern," *1997 IEEE MTT-S IMS Dig.*, 959–962, Denver, 1997.
11. Yngvesson, K. S., D. H. Schaubert, T. L. Korzeniowski, E. L. Kollberg, T. Thungren, and J. F. Johansson, "Endfire tapered slot antennas on dielectric substrates," *IEEE Trans. Antennas Propagat.*, Vol. 33, 1392–1400, Dec. 1985.
12. Dib, N. I., R. N. Simons, and L. P. B. Katehi, "New uniplanar transitions for circuit and antenna application," *IEEE Trans. on Microwave Theory and Techniques*, Vol. 43, No. 12, Dec. 1995.