Progress In Electromagnetics Research C, Vol. 145, 167-172, 2024

PIER C

(Received 16 May 2024, Accepted 15 July 2024, Scheduled 27 July 2024)

Design of Broadband Microstrip Grid Array Antenna Based on Dielectric Filling

Yuxuan Fang and Xinhua Wang*

College of Automation Engineering, Nanjing University of Aeronautics & Astronautics, Nanjing 210016, China

ABSTRACT: Based on dielectric filling, a microstrip grid antenna with six grids is designed in this paper. The broadband characteristics are achieved by increasing the thickness of substrate. An N-type penetrating coaxial port is adopted to feed the antenna for realizing high power capacity. Firstly, the influence of the grid parameters variation on the reflection coefficient was analyzed through the simulation model. Then, the structure of the antenna was optimized. Secondly, a prototype of the antenna was fabricated according to the optimized results. The measured results of the fabricated antenna show that the impedance bandwidth of the designed microstrip grid antenna can reach (taking $|S_{11}| < -10\,\text{dB}$ as the reference) 24.3% ranging from 2.22 GHz to 2.83 GHz. The power capacity of the antenna in the 2.5 GHz can reach 229 Watts according to the measured result of power capacity. Therefore, the designed antenna can be effectively applied in the field of high power irradiation test and high power interference performance test of electronic equipment.

1. INTRODUCTION

Grid array antenna (GAA) is a planar array antenna, which is composed of multiple metal rings [1]. This type of antenna was firstly proposed as frequency-swept antenna in the sixties of the twentieth century [2, 3]. With the development of antenna technique, the traditional metal rod is replaced by microstrip lines. Then, microstrip lines are adopted to design grid array antenna. Microstrip grid array antenna (MGAA) has many characteristics such as simple structure, low profile, convenient feeding, high gain, beam concentration, low side lobe, linear polarization, and other radiation characteristics. Thus, MGAA becomes an ideal alternative to replace microstrip antenna. Meanwhile, a lot of research on the radiation characteristics, grid form, and feeding mode of microstrip grid antennas has been carried out.

Due to the narrow band characteristic of microstrip lines, the input impedance of the antenna near its resonance point is sensitive to changes. Thus the impedance bandwidth of microstrip grid antenna is usually narrow [4, 5]. The prototype grid array with 7 radiating grids proposed by Assimonis et al. has a simulated impedance bandwidth of less than 3%. The impedance bandwidth of the microstrip grid array antenna with 13 radiating elements designed by Chen et al. [5] is about of 4.5%. So it is a meaningful work to design a broadband microstrip grid array antenna. In order to solve the problem of narrow band of microstrip grid array antennas, some methods have been proposed to increase the impedance bandwidth of microstrip grid array antennas [6–8]. The impedance bandwidth of MGAA can also be effectively improved by using ground resistance loading or adopting a multilayer structure [9, 10]. The multi-resonant structure or meandering current technology can also effectively improve the impedance matching for wideband performance [11, 12]. However, the antenna structure will become more complex using the above methods.

In this paper, a broadband MGAA based on dielectric filling is designed. The proposed antenna adopts a rectangular grid as its radiating unit. An N-type penetrating coaxial port is used to feed the antenna. Wideband characteristics are realized by adopting a thicker substrate. The characteristic of wideband and high power capacity are obtained simultaneously. A prototype of the antenna was fabricated to demonstrate the effectiveness of the proposed design. The measured results show that the impedance bandwidth of the designed antenna in this paper is ($|S_{11}| < -10\,\text{dB}$), reaching 24.3% ranging from 2220 to 2835 MHz. Meanwhile, the simulated impedance bandwidth is about 21.1% which ranges from 2230 to 2755 MHz. The measured result of power capacity shows that the fabricated antenna can withstand the power of 229 Watts. Thus, the designed antenna can be effectively used in the field of high-power microwave radiation at 2.4 GHz frequency band.

2. STRUCTURE OF THE GRID ANTENNA

The structure of the designed microstrip grid array is shown in Fig. 1(a). In this figure, the red part represents the metal, and the light part is the substrate. The substrate is made of microwave material with the relative permittivity of $\varepsilon = 4.4$. A 50-Ω coaxial feeding port is adopted to excite the antenna for the simulation. The total size of the antenna is $L_x \times L_y \times h$.

For the designed grid array antenna, it is composed of six rectangular grids. The grids are divided into four rows. The first row and third row are composed of one rectangular grid, respectively. The second and fourth rows are composed of two grids, respectively. For simplicity, the dimensions of the six rectangular grids are set as the same. The parameters of the grid are $d_1 \times d_2$.

* Corresponding author: Xinhua Wang (xh_wang2024@163.com).

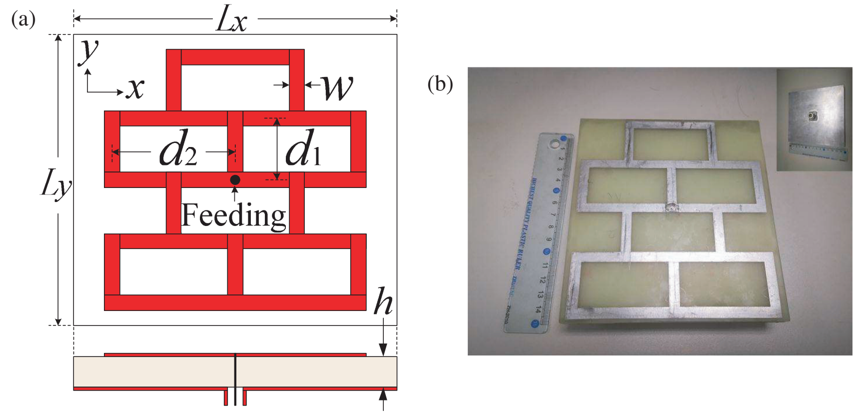

FIGURE 1. The structure of the microstrip grid antenna and the fabricated photograph of the designed antenna, (a) antenna structure, (b) photograph of the fabricated antenna.

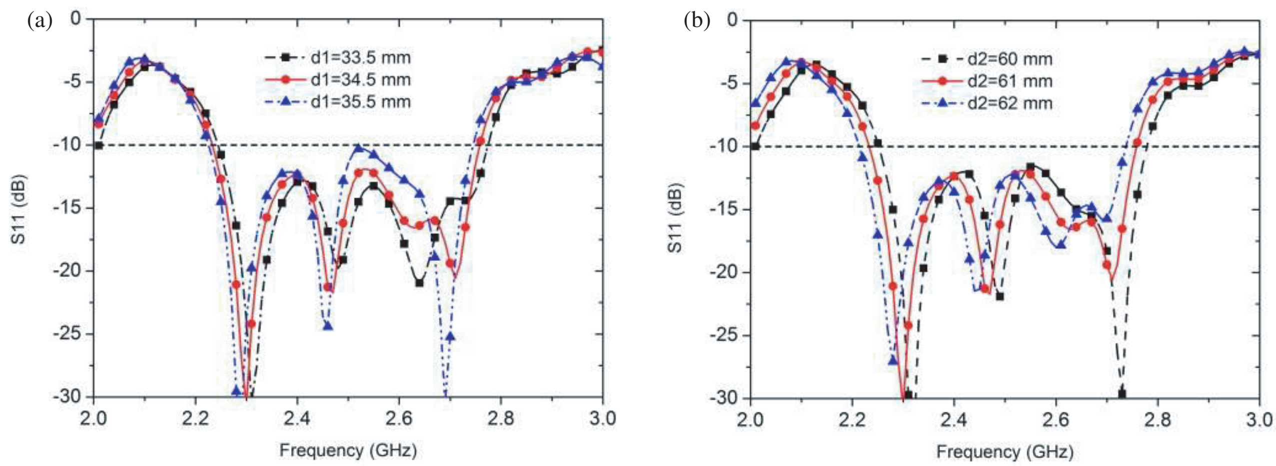

FIGURE 2. The influence of grid size on reflection coefficient of the antenna, (a) effect of the parameter d_1 of grid and (b) effect of the parameter d_2 of grid.

According to the radiation principle of a grid antenna, the instantaneous phase of surface current is in-phase for the grids in the Y-axis direction. Thus, the main radiation characteristics of antenna are determined by the strip line in Y-axis direction. The rest strip lines of the grids along X-axis direction can be regarded as transmission lines. They play the role of transmission energy and impedance matching at the same time. Different from traditional grid antenna, although the feeding point of the designed antenna is set at its center, dividing unidirectional radiation characteristic can be obtained. This antenna is penetrating fed by using a coaxial feeding port with 50-Ω characteristic impedance. The inner conductor of coaxial feeding port is connected to the grid that passes through the ground and substrate, and meanwhile the outer conductor of coaxial feeding port is connected to the ground. For the accuracy of simulation result, the size of N-type connector is adopted as the sizes of the coaxial feeding port for the simulations.

3. PERFORMANCE AND PARAMETER ANALYSIS

For the designed microstrip grid antenna, its structure is mainly determined by the height of the grid (d_1), the length (d_2) of the grid, the width (w) of strip line, and the thickness (h) of the substrate. The parameter d_1 of the grid in Y direction determines the working frequency band of the antenna, and the parameter d_2 of the grid in the X direction represents the characteristic impedance of the microstrip transmission line. The characteristic impedance of the coaxial feeding port is 50-Ω. Thus, the impedance matching between microstrip transmission line and 50-Ω coaxial feeding determines the impedance bandwidth of the antenna. Then, the parameter analysis is carried out for obtaining the great impedance matching.

The influence of grid size on reflection coefficient of the antenna is firstly analyzed. Fig. 2 shows the influence of grid size on the reflection coefficient of antenna. As can be seen from Fig. 2, the designed antenna has a wide impedance bandwidth when $|S_{11}| < -10$ dB is used as the reference. The simulated impedance bandwidth is about 21.1% which ranges from 2230 to 2755 MHz. The dimensions variation of grid mainly determines the impedance matching. It has a little effect on the working frequency band.

The influence of parameter d_1 on the reflection coefficient is given in Fig. 2(a). It can be seen from Fig. 2(a) that the impedance matching can be effectively improved by increas-

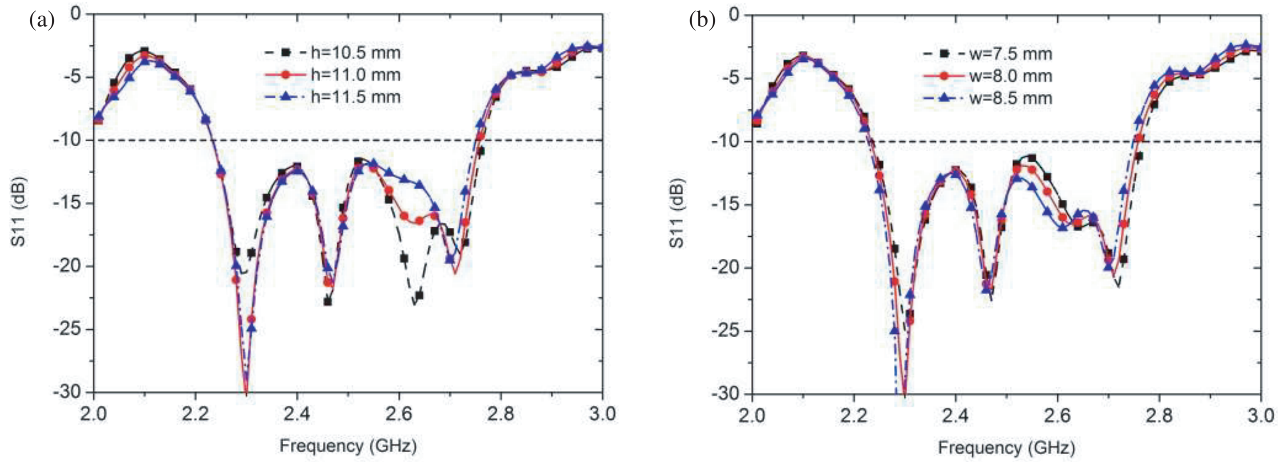

FIGURE 3. The influence of substrate thickness variation and the grid width variation on the reflection coefficient of antenna, (a) effect of substrate thickness h and (b) effect of grid width w.

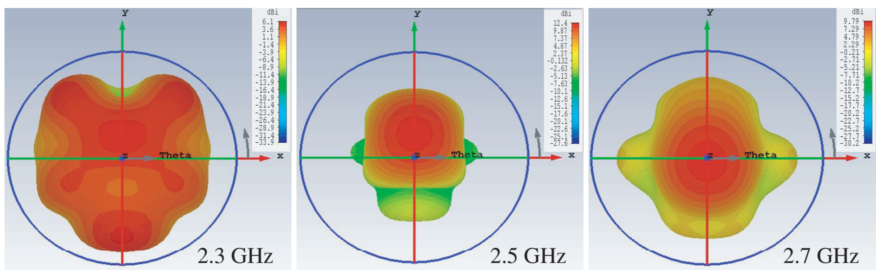

FIGURE 4. The simulated 3D-dimensional radiation patterns of the proposed antenna at the different frequencies.

ing the parameter d_1. The operating frequency band of the antenna will move to the lower frequency band when parameter d_1 is increasing. Fig. 2(b) shows the effect of parameter d_2 on the reflection coefficient of the antenna. Similarly, the operating frequency band of the antenna will move to the lower frequency band when parameter d_2 is increasing. But the impedance matching has a little improvement compared to that of the parameter d_1. It means that parameter d_2 mainly changes the frequency band position. Therefore, the operating frequency band of antenna can be flexibly changed by adjusting the parameters of grid.

Figure 3 shows the influence of substrate thickness variation and grid width variation on reflection coefficient of antenna. As can be seen in Fig. 3(a), the variation of thickness h mainly affects the impedance matching performance of the antenna at the high frequency band. But it has little effect on the impedance matching of lower frequency band. As can be seen from Fig. 3(b), the grid width also mainly affects the impedance matching performance of the antenna in the high frequency band. The impedance matching of 2.5 GHz can be effectively improved by increasing the width of the strip line. The influence of grid width variation is also very small. The impedance matching at the lower frequency band has little improvement by changing the strip line width. Therefore, the wideband characteristic can be obtained by adjusting the thickness of the substrate and the width of the grid simultaneous for improving the impedance matching of the antenna in the high frequency band.

Figure 4 shows the 3D-dimensional radiation patterns of the proposed antenna at different frequencies. As can be seen from Fig. 4, the antenna has a very wide beamwidth at 2.3 GHz. Along with the increase of the operating frequency, and the beamwidth of the antenna becomes narrow at 2.5 GHz. The gain is increased. At the same time, the main radiation direction of the antenna has a little shift to the Y-axis. This is mainly caused by the asymmetry of the antenna structure. The beam shift can be reduced by increasing the sizes of the floor. With the further increase of the operating frequency, and the main radiation direction of the antenna basically points to the Z-direction at 2.7 GHz. The side lobes of the antenna are raised, and the antenna gain is decreased. Although the designed microstrip grid antenna has a wide impedance bandwidth, the main radiation direction of the antenna has a little change along with the change of the working frequency. The beamwidth of radiation patterns will also be changed along with the change of the working frequency. Thus, it is necessary to optimize the parameters and radiation direction of antenna simultaneously according to the actual requirements, especially the radiation characteristics of the antenna. The simulated gain the proposed antenna in the z-axis direction is given in Fig. 5. It is noticed that the gain of the proposed antenna fluctuates

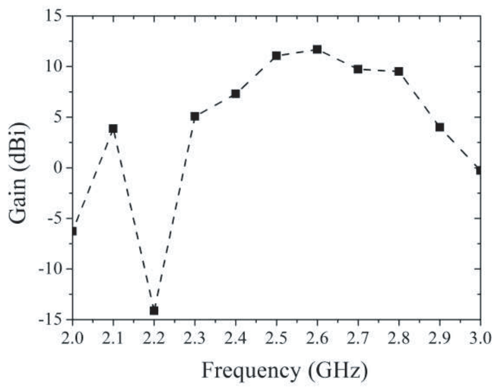

FIGURE 5. The simulated gain the proposed antenna in the z-axis direction.

from 5 to 10.6 dBi within the operating frequency ranging from 2300 to 2835 MHz. unidirectional radiation characteristic with a relatively stable gain can be obtained.

For the designed antenna, its radiation characteristic is mainly determined by the size of to the grid size. Thus, the sizes of the ground are fixed in the optimization process. The ground size is set as $145 \times 155\,\text{mm}^2$ in the optimization process. After the analysis of grid antenna parameters, the grid parameters of the designed antenna are selected as follows after optimization: $d_1 = 34.5\,\text{mm}$, $d_2 = 61\,\text{mm}$. The thickness of the substrate is $h = 10\,\text{mm}$, and the width of microstrip line is $w = 8\,\text{mm}$.

4. MEASUREMENT RESULTS

In order to demonstrate the effectiveness of the proposed design, a prototype of the antenna was fabricated according to the simulated results. A photograph of the fabricated antenna is shown in Fig. 1(b). The total sizes of the proposed antenna are $145 \times 155 \times 11\,\text{mm}^3$. A 50-$\Omega$ N-type connector is adopted to feed the antenna for measurement. The impedance bandwidth of the fabricated antenna is obtained by using an Agilent E8363B performance network analyzer. The radiation patterns of the fabricated antenna are obtained using the antenna measurement system.

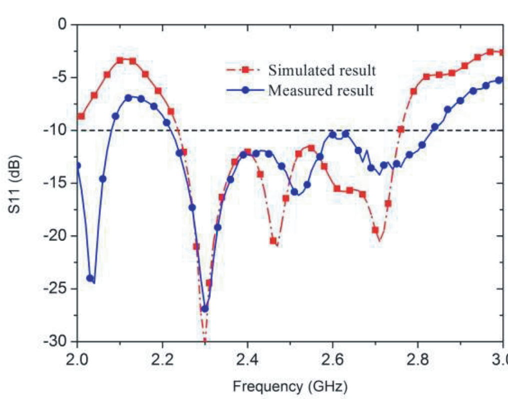

FIGURE 6. Comparison of the simulated and measured reflection coefficients of the proposed antenna.

Figure 6 shows the simulated and measured reflection coefficients of the designed antenna. As shown in this figure, the measured results are in decent agreement with the simulated ones. Taking $|S_{11}| < -10\,\text{dB}$ as the reference, the impedance bandwidth of the designed antenna is about 24.3% ranging from 2220 MHz to 2835 MHz. The measured result of reflection coefficients reflects that the designed antenna has the characteristic of wide frequency.

Figure 7 shows the radiation patterns of the microstrip grid antenna at different frequencies. As shown in Fig. 7, the black line represents the radiation characteristics at the XZ-plane, and the red line represents the radiation characteristics at the YZ-plane. As can be seen from Fig. 7, the designed antenna has wide beam radiation characteristics. The main radiation direction of the antenna has a little shift along with the changing of working frequency. It is mainly caused by the asymmetry of the antenna structure. Within the operating frequency band, the measured F/B ratio is better than 10 dB. Good unidirectional radiation characteristics are obtained. Furthermore, the designed antenna has a simple feeding network with an integrated structure. Thus, the gain of antenna can be easily improved by increasing the number of grids. It does not require an additional feeding network design for the antenna. The complexity of the antenna is much less than that of the traditional microstrip array antenna.

The antenna designed in this paper is mainly used for the radiation of high-power microwave, so high power capacity is needed. The power capacity must be measured for high power applications. The schematic diagram for measurement of power capacity is given in Fig. 8. As shown in Fig. 8, the power amplifier is connected to the coupler through a high power attenuator, and the designed antenna is connected to the output of the coupler. The measurement principle of power capacity is that the output high-power microwave generated by the power amplifier is transmitted to the designed antenna for free space radiation after passing through the attenuator attenuation and coupler. Because the coupler is integrated inside the power amplifier, the results of forward monitoring and reflection monitoring are displayed on the front panel of the power amplifier. Then, the real setup consists of a power amplifier and an antenna which is needed to be measured. Thus, the antenna set at outside is given in Fig. 9(a). A photograph of the front panel of the power amplifier is given in Fig. 9(b) for obtaining the results of forward monitoring and reflection monitoring.

The high-power microwave can be adjusted by changing the higher power attenuator. The forward monitoring of coupler is used to couple some output power for determining the output high microwave power. The reflection monitoring of coupler is used to monitor the reflected power for checking the working state of the designed antenna. When the output power exceeds the power capacity of the fabricated antenna, the reflected power will change abnormally. Then, the power capacity of the fabricated antenna can be determined according to the monitored reflected power.

For safe taking, the measurement of power capacity for the fabricated antenna is carried out at the outdoor. Fig. 9(a) gives a measurement photograph. As shown in Fig. 9(a), the antenna

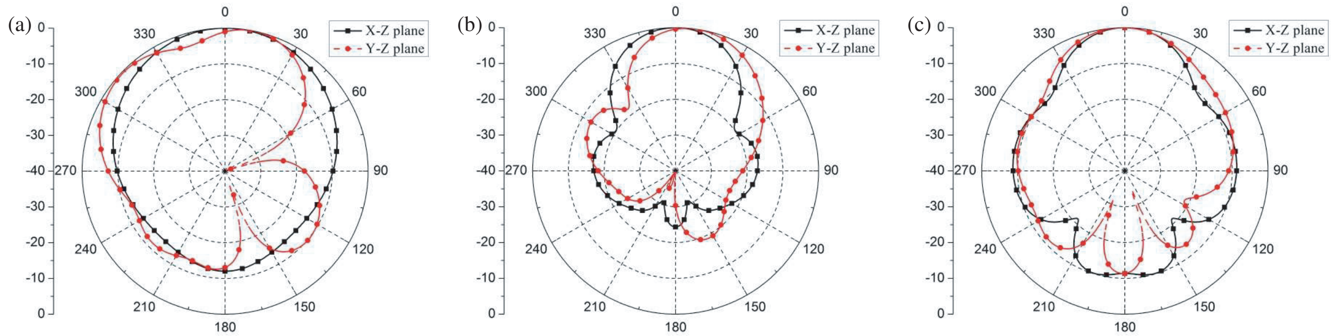

FIGURE 7. The normalized radiation patterns of the designed antenna in XZ-plane and YZ-plane at (a) 2.3 GHz, (b) 2.5 GHz and (c) 2.7 GHz.

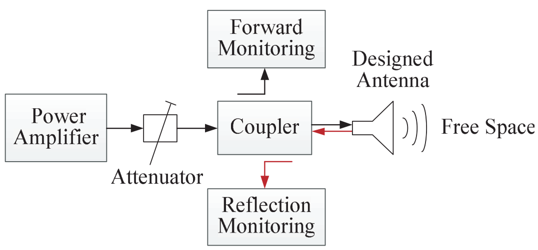

FIGURE 8. Schematic diagram of antenna power capacity measurement.

is placed on the top of tree. The radiation direction of antenna is set towards the upper half of space. The carrier frequency of the high-power microwave is selected at 2.5 GHz.

The monitored results of forward power (i.e., the power fed into the fabricated antenna) and reflected power (i.e., the power reflected from the antenna) are given in Fig. 9(b). According to the monitored results, the power fed into the antenna is 229 Watts (53.6 dBm), while the reflected power is 18.6 Watts (42.7 dBm). The reflection coefficient of the antenna is about -10.9 dB in this high-power exciting condition. The antenna is in the normal working state, and the reflected power remains unchanged. It means that the antenna can work normally when the feeding power is 229 Watts with high radiation efficiency. The proposed antenna has a power capacity of more than 200 watts. Then, this antenna is mainly used in the field of high power irradiation test and high power interference performance test of electronic equipment.

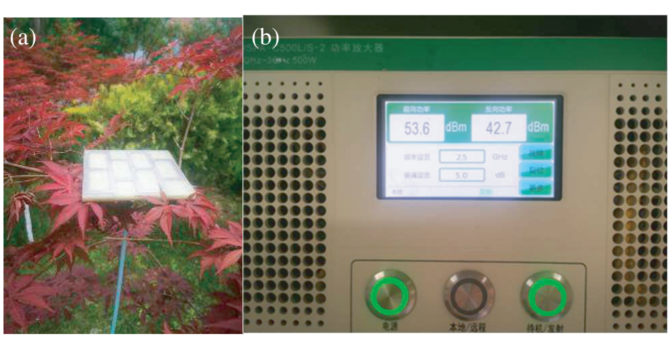

FIGURE 9. Photograph of power capacity measurement and results, (a) the antenna set at the top of tree for power capacity measurement, (b) the monitored forward and reflected power.

5. CONCLUSIONS

In this paper, a broadband microstrip grid array antenna based on dielectric filling is proposed and studied. According to the simulated results obtained from the optimized design, an antenna prototype is fabricated, and an N-type connector is adopted to excite the antenna for measurement. The measurement results show that the designed microstrip grid antenna has a wide impedance bandwidth of 24.3% ranging from 2220 MHz to 2835 MHz. The measured power capacity of the antenna at the 2.5 GHz frequency point can reach 229 Watts. Wideband and high power capacity make the designed microstrip grid antenna be applied in the field of high-power microwave radiation.

REFERENCES

[1] Sun, M. and Y. Zhang, *Handbook of Antenna Technologies*, 1250–1253, 2016.

[2] Kraus, J., "A backward angle-fire array antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 12, No. 1, 48–50, 1964.

[3] Kraus, J. and K. Carver, "Wave velocities on the grid-structure backward angle-fire antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 12, No. 4, 509–510, 1964.

[4] Assimonis, S. D., T. Samaras, and V. Fusco, "Analysis of the microstrip-grid array antenna and proposal of a new high-gain, low-complexity and planar long-range WiFi antenna," *IET Microwaves, Antennas & Propagation*, Vol. 12, No. 3, 332–338, 2018.

[5] Chen, X., K. Chen, and K. Huang, "A microstrip grid array antenna optimized by a parallel genetic algorithm," *Microwave and Optical Technology Letters*, Vol. 50, No. 11, 2976–2978, 2008.

[6] Anguera, J., C. Puente, and C. Borja, "A procedure to design wide-band electromagnetically-coupled stacked microstrip antennas based on a simple network model," in *IEEE Antennas and Propagation Society International Symposium. 1999 Digest. Held in conjunction with: USNC/URSI National Radio Science Meeting (Cat. No.99CH37010)*, Vol. 2, 944–947, Orlando, FL, USA, Jul. 1999.

[7] Pues, H. F. and A. R. V. D. Capelle, "An impedance-matching technique for increasing the bandwidth of microstrip antennas," *IEEE Transactions on Antennas and Propagation*, Vol. 37, No. 11, 1345–1354, Nov. 1989.

[8] Anguera, J., C. Puente, C. Borja, G. Font, and J. Soler, "A systematic method to design single-patch broadband microstrip patch antennas," *Microwave and Optical Technology Letters*,

Vol. 31, No. 3, 185–188, Nov. 2001.
[9] Chen, Z., L. Zhang, B. Zhang, and Y. P. Zhang, "A multiport microstrip grid array structure," *IEEE Transactions on Antennas and Propagation*, Vol. 64, No. 11, 4953–4958, 2016.
[10] Khan, O., J. Pontes, X. Li, and C. Waldschmidt, "A wideband variable width microstrip grid array antenna," in *2014 11th European Radar Conference*, 341–344, Rome, Italy, 2014.
[11] Chen, X., G. Wang, and K. Huang, "A novel wideband and compact microstrip grid array antenna," *IEEE Transactions on Antennas and Propagation*, Vol. 58, No. 2, 596–599, 2010.
[12] Arnieri, E., F. Greco, L. Boccia, and G. Amendola, "A reduced size planar grid array antenna for automotive radar sensors," *IEEE Antennas and Wireless Propagation Letters*, Vol. 17, No. 12, 2389–2393, 2018.