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DESIGN OF ELECTRONICALLY PHASE-TUNING REFLECTARRAY ANTENNA FOR AIRBORNE RADAR APPLICATION

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Abstract

An electronically phase-tuning airborne radar reflectarray antenna is proposed and designed in this paper. The antenna is designed with variable capacitor, which lays a foundation for improving the beam-scanning speed of airborne radar antenna. The electronically phase-tuning airborne radar reflectarray antenna is designed in a sandwich form with faster phase-tuning speed. Three capacitors are loaded inside the reflectarray unit to realize good reflected amplitude response and phase response. Analysis of the position and size of the metallized through holes is made. The power capacity of the airborne radar antenna is improved by optimizing the structure of patch and placing the patch and capacitors inside dielectric substrate. An X-band reflectarray antenna is designed and the performances of electronically phase-tuning and high power capacity of the airborne radar antenna is simulated and discussed. The electronically phase-tuning modulation control network is designed with feature of compactness and simplification.

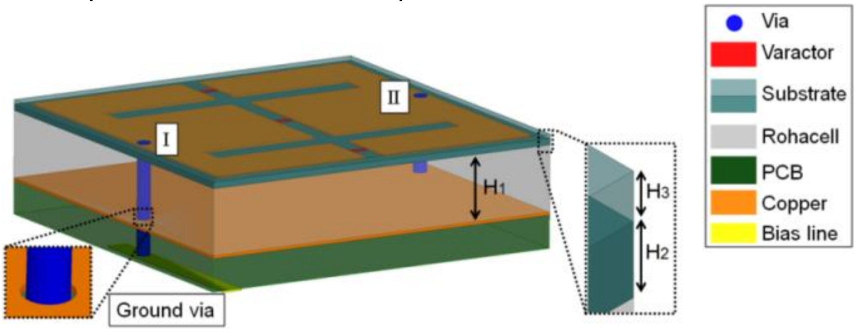
Keywords: airborne radar antenna, electronically phase-tuning, reflectarray antenna.

1. Introduction

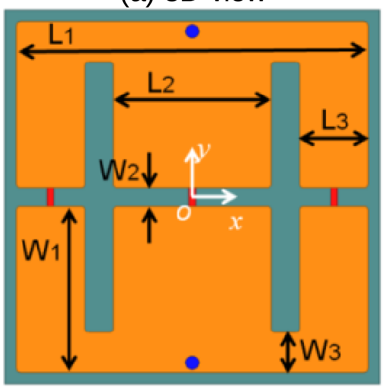
As one of the important parts of fighter, airborne radar antenna insure the communication system and navigation system safe [1-4]. In recent years, with the development of aerospace technology and high-power microwave technology [5], the electromagnetic environment of the battlefield in which fighters survived is extremely complex. In order to improve the battlefield survivability of the airborne radar antenna, the antennas should not only meet the requirements of basic radiation characteristics, but also meet the high-power capacity performance to improve the environmental adaptability. In addition, the antenna is also required to have fast beam scanning performance.
Reflectarray antenna makes the energy fed by the feed to every units, so it has the potential for high power capacity applications [6]. The antenna designed with variable capacitor has the response time of several ms with the bias voltage within 30 V [7-9]. In addition, the available study shows that the electronic components with high withstand voltage have the potential of high power capacity. Therefore, based on the capacitors with high withstand voltage, an electronically beam-scanned high power capacity reflectarray antenna is designed in this paper. And the electronically phase-tuning modulation control network is designed.

2. Design of reflectarray unit

The configuration of the proposed airborne radar reflectarray unit based on variable capacitors is shown in Fig. 1. The radiating antenna consists of two "E"-shaped patches, which form a sandwich structure with the upper and lower layers of Rogers 5880 dielectric plates. Three variable capacitors are loaded between the two "E"-shaped patches and are also placed inside the medium. The two "E"-shaped patches are respectively connected to the bias line at the bottom of the PCB by the metallized through hole I, and the metallized through hole II is connected to the ground plane, wherein the metallized through hole I is not connected to the ground plane. The configuration enables a simple control network structure of the airborne radar reflectarray antenna. In order to obtain good reflected amplitude and phase response results at normal incidence and 25° oblique incidence, the parameters of the unit are optimized and designed, and the optimized parameters of the patch are shown in Table I. The unit spacing is 22.6 mm, the patch thickness is 0.15 mm, and the thickness of Rohacell HF polymethacryimide closed-cell rigid foam layer (dielectric constant is 1.03 , the loss tangent is 0.0001) H_1 is 4 mm, the thickness of the lower dielectric plate H_2 is 0.381 mm, and the thickness of the upper dielectric plate H_3 is 0.254 mm. The capacitance range of the variable capacitor is 0.1~3.2 PF. In high frequency structural electromagnetic simulation software, the lumped series RLC circuit is used to simulate the variable capacitance of different capacitors.



(a) 3D view

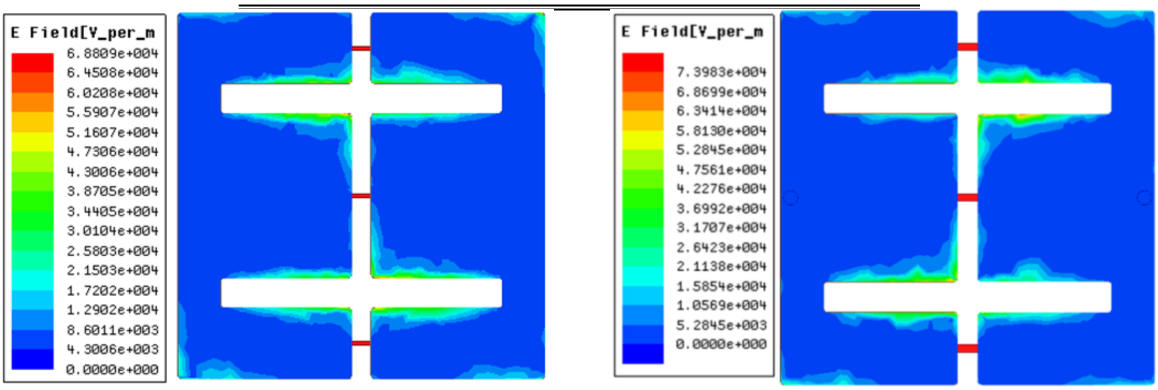


(b) Top perspective view

Fig. 1. The configuration of the proposed airborne radar reflectarray unit.

Table I Optimized parameters

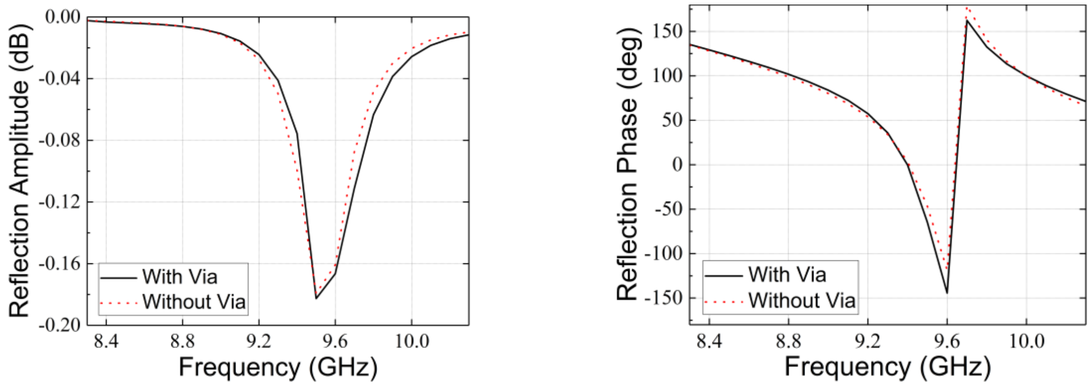
Parameter	L_1	L_2	L_3	W_1	W_2	W_3
Value (mm)	21.2	9.5	4.1	7.6	1.4	2.4



(a) without metallized through holes (b) with metallized through holes

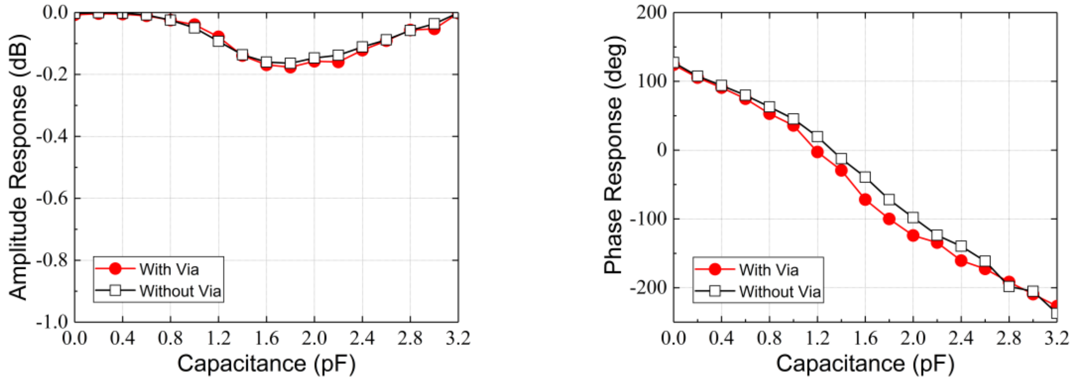
Fig. 2. Electric field strength distribution of the key part of the reflectarray antenna without and with metallized through holes.

The position and size of the metallized through holes are analyzed with the aim that the introduction of the metallized through holes has little effect on the electric field strength of the reflectarray unit. For the convenience of analysis, based on the fixed capacitance value (C=1 pF), the simulation analysis is carried out for the reflectarray unit without metallized through holes and with metallized through holes added in different positions with different dimension. The input power is 1 W, and the electric field distribution on the surface of the reflectarray unit without metallized through holes is obtained as shown in Fig. 2 (a). The metallized through holes are placed in a position with the electric field strength relatively small. After careful optimization, the center of the two metallized through holes are placed at (0, 10) and (0, -10) in the coordinate system shown in Fig. 1 (b). The diameter is 0.8 mm. The electric field distribution on the surface of the patch loaded with the metallized through holes reflectarray unit is obtained as shown in Fig. 2 (b). The results of the metallized through-hole reflectarray unit is similar with that without metallized through holes. The metallized through-holes do not cause the increase of the electric field strength. At the same time, the reflected amplitude and phase response results corresponding to the above two reflectarray units are relatively consistent as shown in Fig. 3.. At normal incidence, the reflected amplitude and phase response results of reflectarray units with and without metallized through holes under different capacitance values are compared and analyzed. The results are shown in Fig. 4. The reflected amplitude and phase response results are less affected.



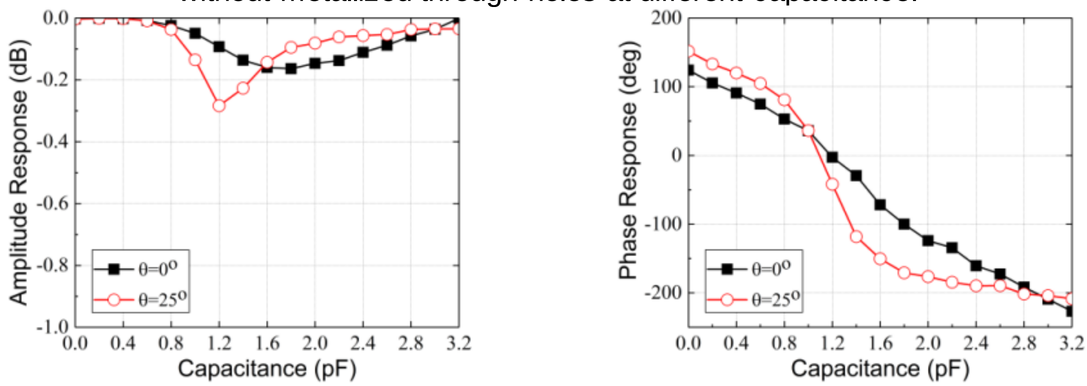
(a) Amplitude (b) Phase

Fig. 3. Reflected amplitude and phase response results of reflectarray units with and without metallized through holes at different frequencies.



(a) Amplitude (b) Phase

Fig. 4. Reflected amplitude and phase response results of reflectarray units with and without metallized through holes at different capacitance.



(a) Amplitude (b) Phase

Fig. 5. Reflected phase and amplitude responses.

The adjustment of the reflected phase is realized by adjusting the capacitance of the variable capacitor of the reflectarray unit. The reflectarray unit is simulated and analyzed based on the master-slave boundary method, and the TM linearly polarized plane wave is input to excite the reflectarray unit, and the reflected amplitude and phase response results corresponding to different capacitance values under normal incidence and 25º oblique incidence are obtained as shown in Fig. 5 . At the operating frequency of 9.3 GHz, the reflected phase responses satisfy the 360º phase compensation at normal incidence and 25º oblique incidence, the reflected amplitude at normal incidence is greater than -0.06 dB, and the reflected amplitude at 25º oblique incidence is lower than -0.37 dB. Under different incident angles, the unit can achieve good reflected amplitude and phase response. Since the reflectarray unit designed in this paper adopts the method of loading multiple capacitors to adjust the phase, a large phase response range and a small reflected loss is achieved.

3. Design of reflectarray antenna

The simulated results show that the reflectarray unit based on variable capacitors has stable reflected amplitude and phase response performance and has the potential of high power microwave applications. In order to verify the above performance, a 11 × 11 reflectarray antenna with a rectangular grid arrangement was constructed using the reflectarray unit, a linearly polarized pyramid feed antenna was used to feed the reflectarray forward, and the height of the feed was adjusted to meet the requirements of edge tapper. The feed antenna is the pyramid horn antenna, and the required phase of each units is calculated as shown in Fig. 6. According to the phase response results in Fig. 5(b), the capacitance of each reflectarray unit capacitor are adjusted. Considering that the feed antenna and the reflectarray are separated, in order to avoid occupying simulation resources by meshing the air medium between the two components in the simulation, air boxes are added to the feed antenna and the reflectarray respectively, and the FE- BI boundary conditions is used.

The simulated results show that when the main beam direction is axial at the operating frequency of 9.3 GHz, the radiation patterns of the antenna in two orthogonal planes are shown in Fig. 7. The antenna gain is 23.1 dB and the side lobe level is -9.2 dB, which achieving good directional beam radiation. Under different beam scanning angles, the 3D pattern and gain results at the center frequency of 9.3 GHz are shown in Fig. 8.-Fig. 9.. Within the scanning range of 0~20º, the gain variation of the antenna is about 2 dB, both achieve pencil beam radiation in the specified direction. When the main beam is 10º, the antenna achieves a maximum gain of 23.4 dB, and the corresponding aperture efficiency is 29.3%. The aperture efficiency of the proposed reflectarray antenna is not high due to the power consumption of the capacitor, phase shift error of the unit, etc.

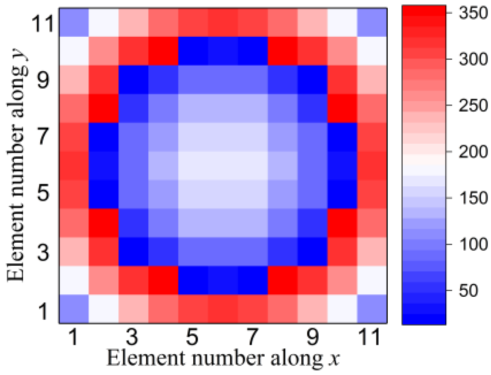


Fig. 6. The required phase of each units.

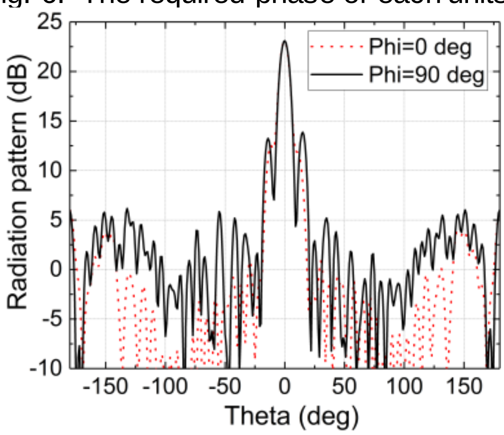


Fig. 7. Radiation patterns at 9.3 GHz.

At the center frequency of 9.3 GHz, taking the main beam direction at the axial radiation direction as an example, the power capacity of the reflectarray antenna is analyzed. The input power is 1 W, and the electric field strength distribution of the key part of the reflectarray antenna is shown in Fig. 10. The maximum field strength of the internal patch is 3921 V/m. The breakdown threshold is 40 MV/m [10], the calculated power capacity of the internal patch is $\left(4\times10^{7}\div3921\right)^{2}$=104 MW. The maximum field strength on the antenna surface is 2197 V/m, and the breakdown threshold in air is 3 MV/m, the calculated power capacity of the antenna surface is $\left(3\times10^{6}\div2197\right)^{2}$=1.9 MW. The power capacity of the reflectarray antenna is mainly limited on the surface of the array. A radome can be loaded on the surface of the reflectarray antenna, and an atmospheric pressure SF_6 gas can be filled inside the radome to increase the breakdown threshold of the array surface, thereby increasing the power capacity of the antenna. The breakdown threshold in an atmospheric pressure SF_6 gas is 11 MV/m. The calculated power capacity of the antenna surface is $\left(11\times10^{6}\div2197\right)^{2}$=25 MW. Simulated results show that the reflectarray antenna has the potential for high power capacity microwave applications.

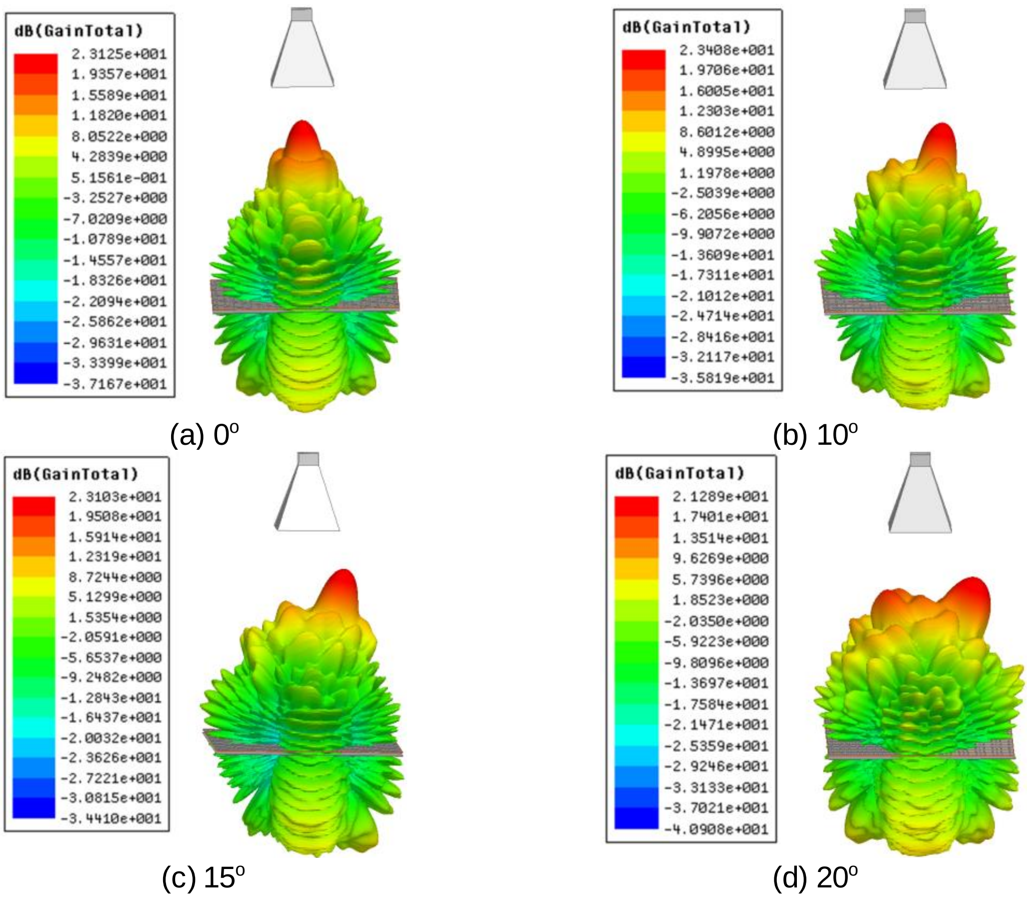


Fig. 8. 3D pattern of different scanning angles.

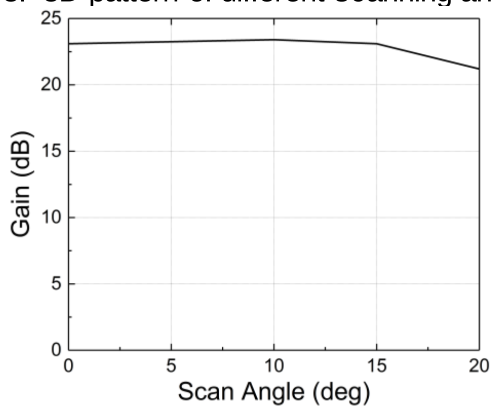
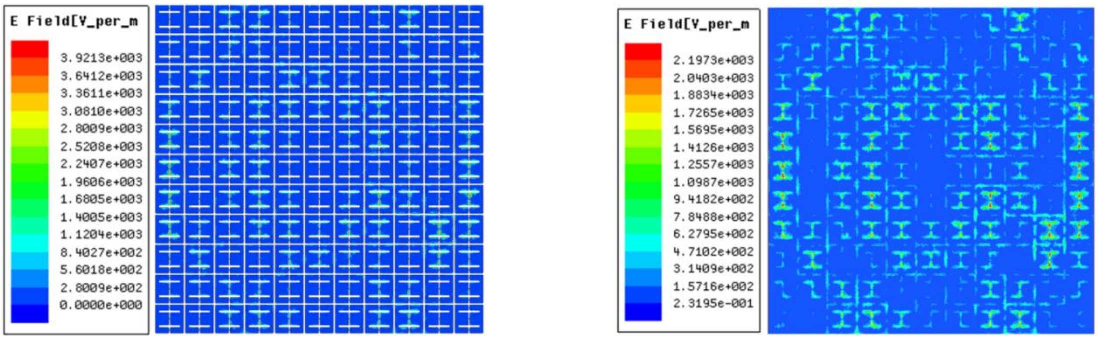


Fig. 9. Gains of different scanning angles.



(a) Internal patch (b) Antenna surface

Fig.10. Electric field strength distribution of the key part of the reflectarray antenna.

4. Design of phase control network

The amount of phase compensation required by each reflectarray unit in the reflectarray antenna is different, correspondingly, the required bias voltage value is also different. In order to satisfy the independent phase control of each unit of the designed electronically controlled phase-modulated reflectarray antenna, in the design of the reflectarray unit, the structure of the unit, and the position of the metallized through hole have been optimized. The key components are analyzed and designed. Based on the designed unit bias loop, the designed array layout of the reflectarray antenna and the basic structure of the electronically controlled phase modulation control network are shown in Fig. 11. For the convenience of description, only the ground plane and the bias line structure at the bottom of the PCB are shown in the figure. Each reflectarray unit is connected to the positive electrode of the bias voltage source through the metallized through hole I and the conductive bias line at the bottom of the PCB board, and the metallized through hole II of each unit is connected to the ground plane. For the connection of the negative electrode of the bias voltage source, when the control network is used, the entire array only needs one RF choke and one negative bias line, which realizes the compactness and simplification of the control network.

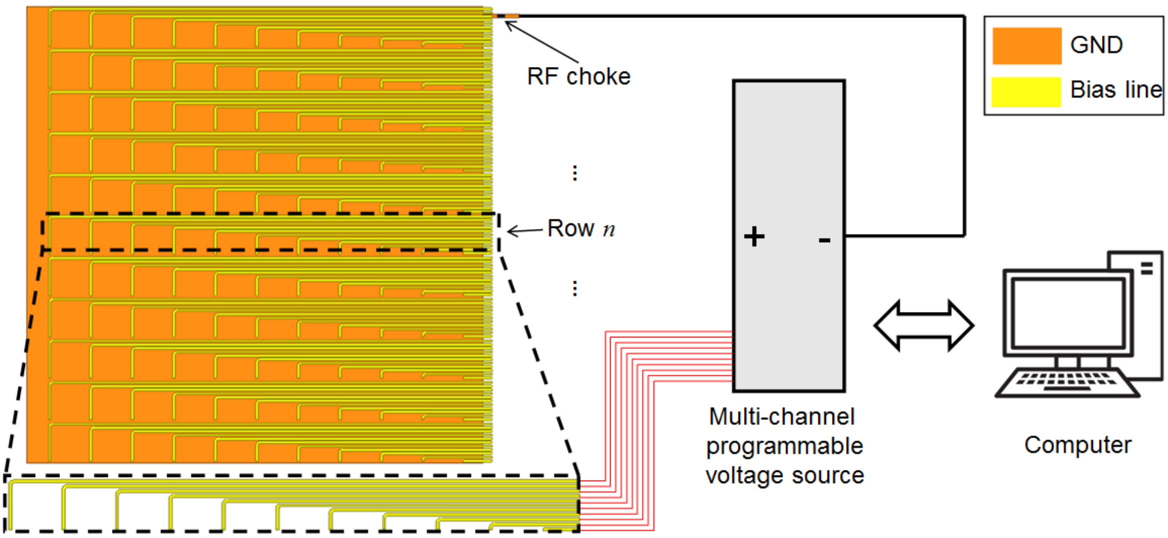


Fig. 11. Schematic diagram of electronically controlled phase-tuning control network.

5. Conclusion

In order to improve the environmental adaptability of electronically phase-tuning airborne radar antenna, this paper proposed and designed a high power capacity electronically phase-tuning airborne radar reflectarray antenna based on variable capacitor. The reflected phase and amplitude responses performance of the reflectarray unit is analyzed and optimized. And the primary performances of the 11 × 11 airborne radar reflectarray antenna are analyzed. A compact electronically phase-tuning modulation control network is designed. The airborne radar antenna shows good environmental adaptability and electronically beam-scanning performance.

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