Design of A Novel Conical Conformal Linear Array Antenna for C-band Application

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Abstract. A Novel conical conformal linear array antenna made up of 7 elements is proposed in this paper. Each element employing independent feeding consists of the overlapping top square, medium dielectric layer, array supported layer and back ground. The linear array antenna is wrapped around a conical surface to realize the integration. Through analyzing element working performance and linear array antenna on plane, the conformal array antenna wrapped around a conical surface just smaller curvature can be of analogy to reduce the experimental process. The presented conformal antenna operates at 4.86GHz over C-band. Multi-ports excitations have a vigorous characteristic in terms of a wide scanning angle and high gain than 10dBi. This method of the conformal array antenna analysis and the proposed design of antenna array integrating with supported layer can be employed a morph antenna and reduce the manufacturing cost for C-band.

1. Introduction
Conformal array antenna as end-fire configuration [1] - [3] have been widely used because of their desirable aerodynamic characteristics [4] - [6]. The intricate assembly of integrated conformal array antenna like phased array wrapped around curved surfaces, such as airborne [7], missile-borne [8] and vehicle-bone [9], has an influence on integration of this equipment. Especially, the fixed profile of equipment restricts the good behavior of antenna [10]. Hence, employing a simple structure with convenient installation flexible array [11] is of great interest for seamlessness between antenna and equipment.

This letter below a novel linear array antenna wrapped around the supported layer as the outer wall of equipment design with simple profile and high gain performance. The proposed antenna consists of 7 elements of linear arrangement made up an overlapping top square patch. The curved structure is not only the array supported layer but also the dielectric layer. Multi-ports excitation achieves the scanning characteristics. Through the analysis of array on plane, the conformal antenna wrapped around conical surface just smaller curvature can be of analogy. This method is an efficient mean for arbitrary conformal configuration.
2. Theory and design

2.1. The Design of Array Element

Normally, an array element consists of three layers, consisting of the top radiation patch, the bottom ground and the medium substrate. In order to wrap array antenna to curved surface, a supported antenna array layer below the substrate is constructed on simulating processing. The presented antenna element illustrated in Fig.1 (a) is designed on the Flame Retardant 4 (FR4, $\varepsilon_r = 4.4$, $\tan\delta = 0.02$) bored with the thickness of $h=0.254\text{mm}$, the supported antenna layer underground substrate made up of Poly tetra fluoroethylene (PTFE, $\varepsilon_r = 4.4$, $\tan\delta = 0.02$). The top radiation patch consists of two overlapping square excited with coaxial feeding in the geometric center of the numerical model. To realize the impedance matching of the antenna element and feeding port, the impedance of coaxial cable should be $50\Omega$. The radius of coaxial cable inner conductor and outer dielectric coincide with the formula of $$Z_0 = 60/\sqrt{\varepsilon_r \ln(r_1/r_2)} \text{ hand } r_1 + r_2 \leq \lambda_{\text{min}}/\pi.$$ $r_1$ and $r_2$ are the radius of coaxial cable inner and outer respectively. $\varepsilon_r$ is the permittivity of outer dielectric. $\lambda_{\text{min}}$ is the operating wavelength of maximum frequency. Where the coaxial cable model can be acquired. The design of radiation patch is easy to simulate and optimize. The specific parameter values of the element are shown in Table 1.

| Parameter | Parameter Values of Element |
|-----------|-----------------------------|
| Parameter | $a$ | $b$ | $c$ | $t$ | $h$ | $r_1$ | $r_2$ |
| Value(mm) | 31 | 10 | 0.75 | 3 | 0.254 | 0.651 | 1.5 |

2.2. Simulated Results of Single Element

As showed in Fig.2, the array element can operate at the range of 4.8 to 4.93GHz and the resonant is 4.86GHz. The E-field magnitude pattern and 3D radiation pattern is computed as Fig.1 (b) and Fig.1(c). As illustrated, the majority of currents flow around the diagonal corner on patch and ground, which coincide with the theory of microstrip antenna edge radiation effect. Therefore, the relative position of the antenna patch and metal ground determines the radiation performance, which.

![Figure 1](image)

Figure 1. (a) The schematic diagram of antenna element (b) Simulated E-field magnitude of the antenna at 4.84GHz (c) 3D radiation pattern of the antenna at 4.84GHz

Provides a developed reference for the array structural design. The simulated element gain radiation pattern indicates the performance that the antenna exhibits hemisphere radiation as shown in Fig.1 (c). As showed antenna element parameter overlay in table 2, single antenna exhibits a good behavior, especially high radiation efficiency (97.9%) and realized gain (4.6dB).
Figure 2. Simulated return loss of the element

Table 2. Antenna Element Parameter Overlay

| Quantity          | Value          |
|-------------------|----------------|
| Max U             | 215.882mW/sr  |
| Peak Directivity(dB) | 4.56146      |
| Peak Gain(dB)     | 4.45692       |
| Peak Realized Gain(dB) | 4.31477     |
| Radiated Power    | 944.78mW      |
| Accepted Power    | 967.797mW     |
| Incident Power    | 1W            |
| Radiation Efficiency | 0.978703    |

2.3. Characterization of Linear Array Antenna

To verify the performance of the array antenna wrapped around a conical surface, the linear array antenna on the plane should be computed firstly. As illustrated in Fig.4 (a), the linear arrangement elements consist of the linear array. The distance (d) between two elements affects the coupling of element and the total gain of antenna. After simulation processing, the return loss efficiency and mutual coupling are obtained as Fig.3. Due to symmetry arrangement of total linear array, the characteristics of the half elements are only analyzed. As illustrated in Fig.3 (a), the operating frequency of 7 elements is almost same resonating at 4.8GHz. Additionally, value of return loss efficiency of the fourth element decreases gradually with the increasing variable of c as Fig.3. (b). through change the size of the square, the operating frequency and working bandwidth are influenced with the increasing value of b. The resonant frequency moves left first and then moves right as the length d decreases. As illustrated in Fig.3. (c), in order to acquire appropriate size of the element and bandwidth, the valid value is selected to 10mm. Finally, the mutual coupling of elements has an influence on the radiation behavior of array antenna, as showed in Fig.5 (d). Mutual coupling efficiency is higher when the distance both the proximity elements is minimum. Furthermore, the coupling is gradually decreasing as the distance increases. From above simulated and analyzed results, it is convenient to select the best antenna array profile for the perfect antenna performance. Utilizing the linear array antenna on plane, the array antenna wrapped around a conical surface only smaller curvature is similarly assessed in antenna characteristics.
Figure 3. Simulated S-parameters of array antenna with 7 elements (a) return loss efficiency of 1–4 ports when $b=10\text{mm}$, $c=3\text{mm}$ and $d=0\text{mm}$; (b) $S_{44}$ (return loss of 4 port) of antenna array with the variable of $c(b=10\text{mm})$; (c) $S_{44}$ of antenna array with the variable of $b(c=3\text{mm})$; (d) mutual coupling efficiency between two adjacent elements with the variable of $d$ at the working bandwidth.
2.4. Performance of the Conical Conformal Array Antenna

When the linear array antenna is wrapped around a conical surface just smaller curvature, the conformal antenna performance can be analyzed by this way which the method of

The characterization of linear array antenna on plane is obtained. As illustrated the design model of the conical conformal array antenna in Fig.4 (b), the array supported layer is a red conical model with the top radius of 106mm, the bottom radius of 109mm and the height of 229mm. An orange ground has been patched the inside of the conical cone.

To experimentally validate the radiation mechanism of the antenna. Firstly, conformal array antenna radiation performance is obtained at different scanning angle as shown in Fig.4(c). For the phase range of 0 to 60° of each incident port, the normalized gain as a constant are than 10dB and the half lobe scanning angle can reach 25°. There is a significant difference for the 25° scanning angle of the linear conformal array antenna with respect to the n×n planar case. This investigation will greatly make straightforward for the complexity in the configuration process of the conformal array antenna with a definite scanning angle. The radiation performance of conformal array antenna is illustrated as Fig.4 (d). In contrast with characteristics of an antenna on plane, the H-plane radiation pattern of conformal antenna makes approximately agree with the linear array antenna on plane. Just some back lobe down the back of antenna, the main radiation direction is uniform. So numerical radiation characteristics and impedance matching performance of linear array antenna can consider as conformal array antenna wrapped conical surface simply smaller curvature.
3. Conclusion

Study processing of an element to linear array, finally conformal array antenna, has been proposed. In order to achieve a vigorous radiation attribute, utilizing linear arrangement obtains the steering radiation at E-plane and H-plane, the wide scanning angle at E-plane and the pattern shape of “∞” in H-plane. Through feeding port with a certain incident phase, the linear array can obtain a special scanning angle that usually is realized by the composite array antenna. The method of numerical radiation characteristics and impedance matching performance of a linear array antenna considered as conformal array antenna wrapped conical surface just smaller curvature can be employed on some study. Due to the simple profile of element, the numerical processing and simulation become short. In addition, the process of antenna array integrating with the supported layer reduces the manufacturing cost. This conical conformal array antenna can be used at the front end of non-rotating speed flying platform to communicate with the base station over C-band, such as the drone, airplane.

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