GA 최적 설계된 최소 후방방사특성의 S-대역 Quadrafilar 배열 안테나

논 문
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S-Band Quadrafilar Array Antenna with the Elements of Lowest Backradiation Designed by the GA Optimization

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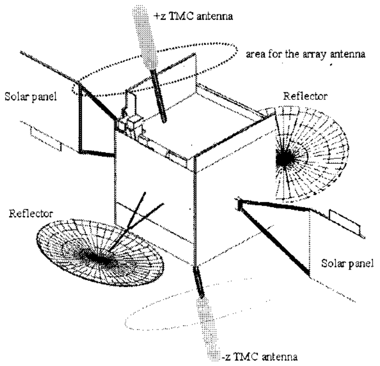
(Sungtek Kahng · Joongpyo Kim)

Abstract – In this paper, a quadrafilar antenna is designed to have a lower profile as an essential part of the size reduction technique and lower backradiation(namely, higher forward radiation) for the S-band telemetry/telecommand(TM/TC) function of a communication satellite. Particularly, to meet the challenging requirements on the higher isolation between the TM/TC antennas and simultaneously a smaller size, the lowest backradiation and lowest cross-polarization, the optimal physical dimensions of the quadrafilar antenna are found by using the Genetic Algorithm(GA). To prove the validity of the proposed antenna design, its 3D electromagnetic analysis and measured results are compared to show good agreement. Using this antenna as the elements, an array antenna is made to have directivity. .

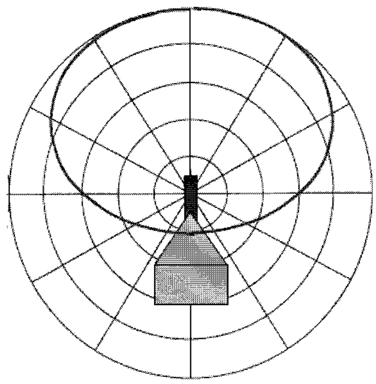
Key Words : Antenna Design, Quadrafilar Antenna, Genetic Algorithm, Backradiation, Array Antenna

1. Introduction

Showing the unique feature compared to other antenna applications, the satellite is required to be equipped with a variety of antennas for different multiple functions, but calling for strict and tough specifications of the high quality performances including the environment-qualification. The waveguide horn antennas represent the antennas for the satellite communication.



(a)



(b)

Fig. 1 Sketch of a communication satellite with multiple antennas mounted on its surface, including wire antennas on purpose of TM/TC(Telemetry/ele-command) (a) Satellite (b) Forward radiation required for TM/TC functions

Meanwhile, helical antennas are also adopted. The helical antennas are easy to design and handle. But this is true for easy-to-realize cases occurring in the ground wireless communication, and it is quite complicating and difficult to meet the satellite telemetry and tele-command functions which, most of the times, drive the antenna design to have the lowest interference possible between the telemetry and tele-command antennas with the' low back-radiation'(or 'forward radiation') and low cross-

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polarization level. This stems from the fact that a helical antenna has relatively a smaller number of design parameters[1].

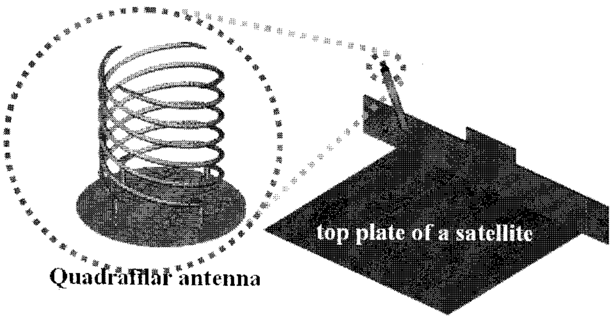
When it comes to the application to the telemetry and telecommand, the circular polarization(CP) is recommended and one type of CP antenna(say, Right-handed CP or RHCP) is assigned to the telemetry and the other type of CP antenna(say, Left-handed CP or LHCP) is for the telecommand to maximize the cross-polarization performance and isolation between the Tm and TC functions. They are separated from each other by 180 degrees in order to minimize the interference between them. However, assuming the RHCP antenna is positioned in the top region with respect to the horizontal bisection-line of a satellite and the LHCP is with the bottom area, the cross-polarization component of the RHCP turns into the LHCP which is the backradiation from the top region to the bottom region and will interfere with the LHCP of the original antenna for the bottom. To avoid this, Kilgus suggested a method to lower the backraidation and maximize the forward radiation by the quaradfilar helical antenna which shows very flat forward pattern in either of RHCP or LHCP[2].

In this paper, we use the GA(Genetic Algorithm)[3] to find the optimal values of the quadrafilar antenna design parameters, not limited to the Kilgus' design guideline. Through the GA optimization process, we find the way to lower the backrdiation and to have flatness in terms of the RHCP antenna residing the top area of the satellite, and show the optimized performances.

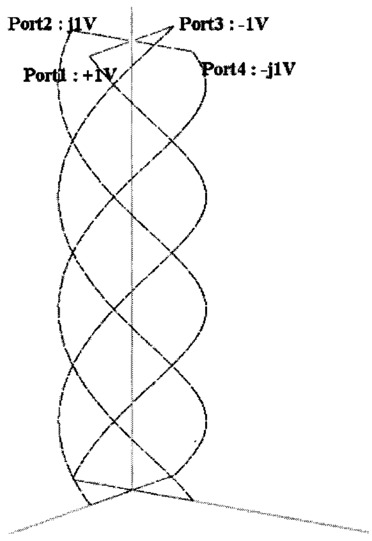
2. Design and Implementation

2.1 Quadrafilar antenna to be used for the communication satellite

The quadrafilar antenna is placed in the top or bottom area of a satellite, working in an S-band.



(a)



(b)

Fig. 2 Illustration of the quadrafilar antenna as an element on the top area of a satellite : (a) 3D quadrafilar antenna fed at the bottom (b) quadrafilar antenna fed at the top. for the proposed design.

The quadrafilar antenna takes the compound of four helical antennae with sequential 90° phase difference between the two neighboring helixes. This antenna is assigned to the telemetry function in the top area of a satellite and will be designed to have the RHCP propagation. To avoid the interference from the metal plates of the top region and the degrading interference to the antenna on the other side, this antenna should have the lowest and weakest backradiation possible. Here the number of the turns, the radius and the height are designated as the physical dimensions for the design. To predict the electromagnetic field from the antenna according to the geometrical, boundary and material conditions, the Method of Moment(MoM) solver of the FEKO is used. By the way, in terms of the degree of freedom in design, due to the limited number of the physically changeable parameters, it is a tough call to satisfy the challenging requirements. This is why we need a robust optimization algorithm.

2.2 Genetic Algorithm

Now the GA is proposed to get the design parameters' values that are optimal in producing the required performances[3]. It is briefly addressed about the GA that it stochastically searches the global minimum point in the cost function, while doing selection and mating, crossover, mutation, and reproduction. As always, this optimization scheme work starts with defining the cost function as

$$Cost_1=\sum_{q=1}^{N_q} n_q |P(\Theta_q)-P(\Theta_{q-1})|^{N_e} \quad (1)$$

$$Cost_2=1/\sum_{p=1}^{N_p} x_p |P(\Theta_p)-(-20\text{dB})|^{N_e} \quad (2)$$

where the cost function 1 in eqn. (1), with weight ξ_p considering the budget quota of the total cost, is the error between the two immediate samples along the elevation angle about the RHCP and in order to have the flat RHCP pattern. At the same time, with another weight ξ_p and order N_e, P_q at N_q angular points and the -20 dB-line as the reference threshold for the cross-polarization or backradiation, say, LHCP. Once again, eqn(2) is to maximize the gap between the -20dB and backradiation level in the minus sign. The genes are generated for the data set number of varying N_{turn}, R_{qudra}, and h_{qudra} each of which has N_{bit} binary bits. Each of N_{pop} individuals comprizes 5 N_u genes. Afterwards, the population undergoes Selection, Crossover with rate P_{Cr} and Mutation with rate P_m over N_{genr} generations, with Elitism specifically for this work.

2.3 Design, realization and validation

The working frequency is 2.09 GHz and the total gain is set at 3 dBi. In line with this, the following table shows the detailed specifications on the quadrafilar antenna design.

Table 1 specifications on the quadrafilar antenna performance

Item	Specification
Center frequency	2.09 GHz
Bandwidth(Reflection < -10dB)	0.7 GHz
Gain	≥ 3 dBi
Type of Co-polarization	RHCP
Half power beamwidth(=HPBW)	≈ 60 degrees
Cross-polarization level at the broadside	LHCP ≤ -55 dB
Isolation at the broadside	≥ 55 dB

Although most of the specifications above are dependent on this particular satellite development, the gain, bandwidth and polarization look very similar to other helical-type of antennas. However, what makes difference between the present design and the standard antenna design is that isolation and cross-polarization level observed at the broadside side angle, say, Θ=0°. Even if neither the gain nor the HPBW seems very large, it does not matter for this case where the TM antenna on the top and/TC antenna beneath the bottom of the satellite should not interfere with each other and this is determined by the highest isolation(≥ 55 dB) and lowest cross-polarization level. This leads the forward-only radiation or lowest backradiation possible from each of the TM and TC antennas.

Note we facilitate the means to assign each set of the varying individuals to a number and use this as the pseudo-individual as the pointer in computer language C. Prior to the presentation of the GA optimization results, the optimization is carried out with cost funo a nu1 to have the flat forward radiation and cost funo a nu2 to have the lowest backradiation separately. First, we have the convergence watch according to the optimal set of physical dimensions and the cost to secure the flatness in the radiation in the forward direction.

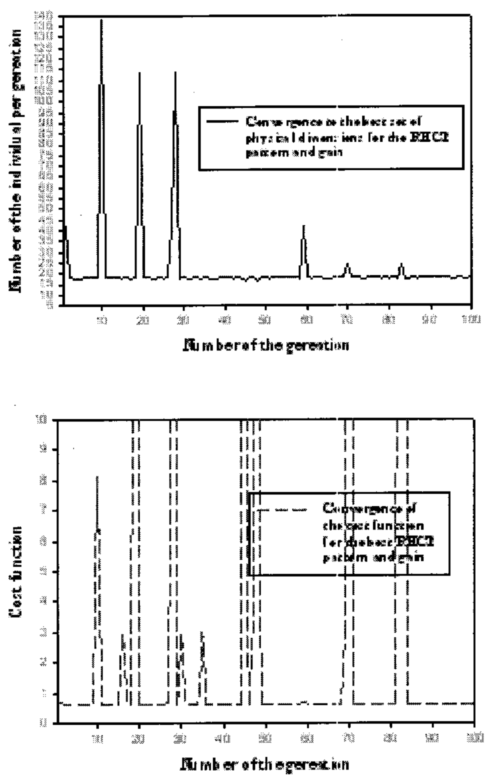


Fig. 3 Searching the optimal set of physical dimensions and minimizing the cost function to flatten the field radiation in the forward direction.

Despite some fluctuations during the optimization, which is caused by the pseudo individual concept that does hardly relate the consecutive sets(no big concern), it provides us the optimized performance along with the final convergence. So we present the flat forward radiation solution as follows.

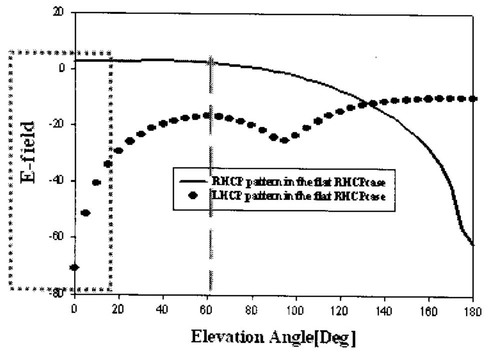


Fig. 4 The RHCP(solid line) shows the flat forward radiation, LHCP(dotted line) has not optimized

To check the forward-only radiation or lowest back-radiation as the key to the high isolation between the TM and TC antennas, it is noteworthy to see the difference between the RHCP and LHCP levels at $\Theta=0°$. It amounts to around 73 dB. It is a huge and enormous isolation. Also, the cross-polarization level is under -20 dB over the HPBW. Not being satisfied with this step of design, we wanted to go further to confine more of the radiated field in the forward direction.

Second, we have the convergence watch according to the optimal set of physical dimensions and the cost during the optimization for prioritizing the reduction of the LHCP.

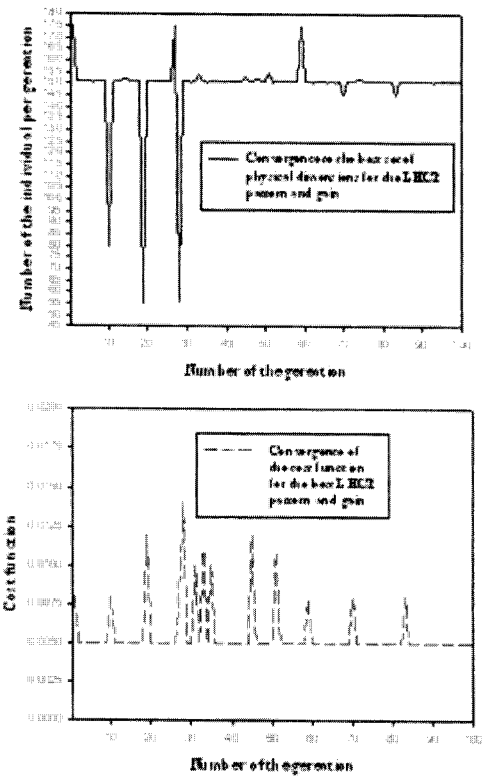


Fig. 5 Searching the optimal set of physical dimensions and minimizing the cost function to lower the LHCP which degrades the other side's LHCP antenna.

Like Figure 3, it provides us the optimized performance along with the final convergence in lowering the LHCP as follows.

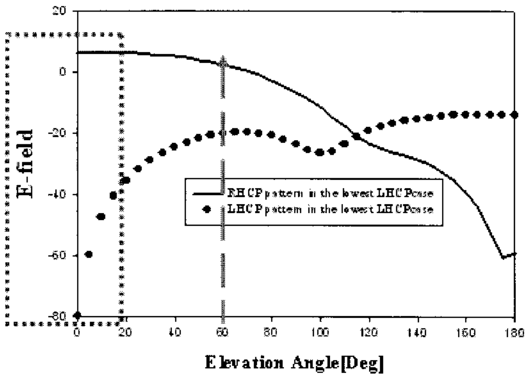


Fig. 6 The LHCP(dotted) optimized, but not with the RHCP(solid)

With Fig. 5 as the second design the forward-only radiation or lowest back-radiation essential to the high isolation between the TM and TC antennas, it is worth watching the difference between the RHCP and LHCP levels at $\Theta=0°$. It is read about 82 dB. It turns out another enormous isolation. Also, the cross-polarization level is under -20 dB over the HPBW. ThHPBgh the above process of the work , we finalize the design. The optimized antenna has got the physical dimensions, the radius of 11.5 mm and the height of 65 mm in a half-turn geometry. Using this physical structure, the return loss of the optimized antenna is as follows.

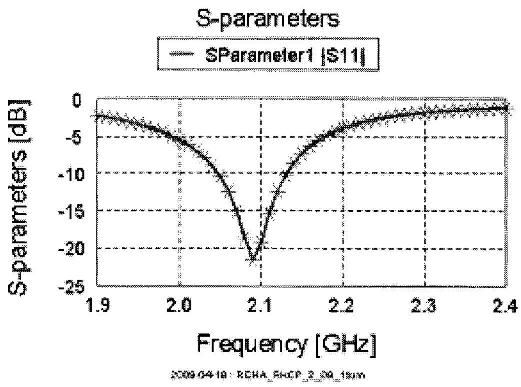


Fig. 7 Return loss of the proposed antenna.

As is targeted, the frequency band below the -10 dB-reflection coefficient has the center frequency of 2.09GHz and bandwidth of 700 MHz. Finally, the E-field pattern is analyzed with respect to the proposed quadrafilar antenna.

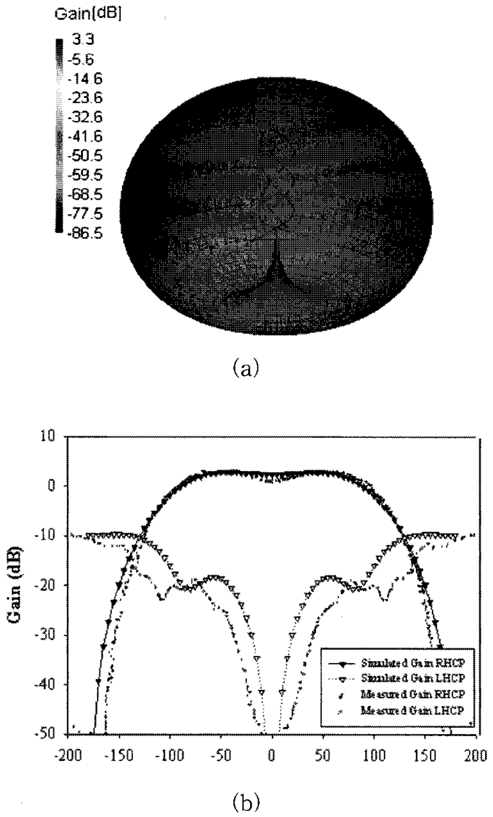


Fig. 8 Field patterns (a) 3D electric field pattern (b) Co-pol(RHCP) and Cross-pol(LHCP)levels

The optimized antenna's pattern performance is addressed with the 3D electric field pattern and the comparison between co-polarization and cross-polarization levels as a check to the isolation. Both results show the wanted gain(3.3 dBi), the maximum radiation in the forward direction, and almost zero backradiation at Θ =180°. In particular, the predicted field pattern agrees well with the ieasurement. Despite the smalctioscrepancy in Fig. 8(b), we can see the analyzed and measured patterns with low cross-polarization and maximized isolation for the TM and TC antennas. Finally, adopting this antenna as the elements, an array antenna is made to have the directivity in the far-field pattern.

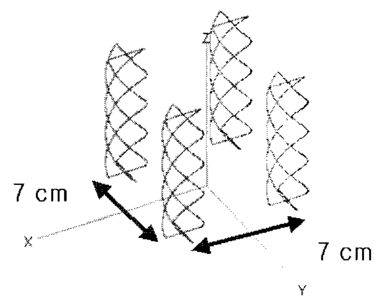


Fig. 9 Configuration of the array antenna

The elements are spaced 7 cm away from each other in both X and Y directions. The spacing is found to have the gain of each element three times greater.

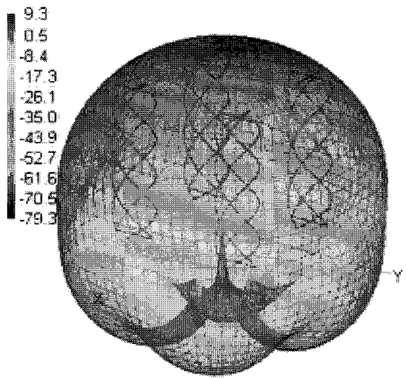


Fig. 10 Far-field co-polarization pattern

The array factor due to the space between the elements is proven to make the growth in the gain. The gain reads 9.3 dBi, which is indebted to the directivity from the array placement. When it is realized, the quality of the satellite communication will be improved much.

3. Conclusion

We presented the design of the highest RHCP radiation and lowest LHCP(forward-only) radiation using a low-profiled S-band quadrafilar antenna on the satellite. The challenging requirements on the size and the tough specifications on the lowest back-radiation have been met by the use of the GA optimificationpproach. The design hroabeen validated by comparioptime predictg requirements onerformeqces. Also, the array antenna based upon the optimized quadrafilar antenna as the elements is designed to have higher gain in the pattern.

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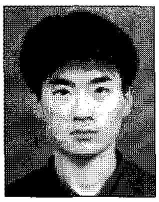

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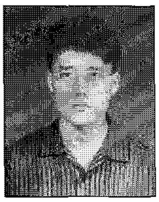

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