Multi-band Adaptive Array Antenna Using the Sierpinski Monopole

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1. Introduction

Growth of ITS made a vehicle an advanced information equipment. An antenna that can operate efficiently at various frequencies or in wide bandwidth is demanded since various contents are transmitted at various frequencies and bandwidth. In case of wireless access of high-speed data transmission, application of adaptive antenna or diversity antenna is studied to overcome the fading and inter symbol interference (ISI). As these antenna use several radiating elements, more antenna elements stand on vehicular body. This condition is not desirable in the viewpoint of the cost and the design. In this paper, we propose a multi-band adaptive antenna with one aperture. Sierpinski monopole [1] with multi-band capability is applied to a central radiating element of the ESPAR antenna [2]. There are several parasitic elements on various concentric circles. A circular parasitic element array corresponding to the specified frequency is selected. Value of reactor connecting to each parasitic element is optimized by the Genetic Algorithm (GA) [3].

2. Antenna Aperture

Fig.1 shows the aperture of 2 band adaptive antenna. The aperture consists of a Sierpinski monopole located at the center and 2 concentric circular parasitic element arrays on the counterpoise. There are 6 linear parasitic elements on each circular array. The ratio of r_1 and r_2 is the same as that of $f_1$and f_2. Connecting the parasitic element with the counterpoise, induced current becomes invalid. On the other hand, connecting the parasitic element with the reactor, amplitude and phase of induced current are adjusted. In Low Band, since 6 inner parasitic elements are connected to the counterpoise, these elements become invalid. 6 outer parasitic elements are connected to the reactors, and the optimized reactance set is searched. In High Band, 6 outer parasitic elements are connected to the counterpoise and 6 inner parasitic elements are connected to the reactors.

3. Adaptive Beamforming by the Genetic Algorithm

Though a steepest gradient algorithm is known as adaptive beamforming of the ESPAR antenna, we propose a simple method in which optimum reactance set is searched by means of the GA. When m signals $s_1(t),s_2(t)\ldots s_m(t)$ are incident from DOAs of $\varphi_1,\varphi_2,\ldots\varphi_m$, signal received by central radiating element y(t) is expressed by next formula..

$$y(t)=\mathbf{I}\mathbf{A}(\varphi)\mathbf{S}(t) \qquad (1)$$

Here, $\mathbf{I}=[i_0, i_1, \ldots ,i_6]^T$, $\mathbf{A}(\varphi)= [\mathbf{a}(\varphi_1), \mathbf{a}(\varphi_2),\ldots, \mathbf{a}(\varphi_m)]$, $\mathbf{S}(t)=[s_1(t),s_2(t)\ldots s_m(t)]^T$ are excited currents of the central radiating element and parasitic elements , the array manifold, and signal vector, respectively. The excited currents can be calculated by use of the mutual admittance between elements and reactance set. In order to receive only $s_m(t)$, such reactance set that correlation co-efficient ρ_m between the output y(t) and $s_m(t)$ are maximized is settle to each reactor.

$$\rho_m = \frac{\sum_{p=1}^{P} y(p\Delta t) s_m^*(p\Delta t)}{\sqrt{\sum_{p=1}^{P} y(p\Delta t) y^*(p\Delta t)} \sqrt{\sum_{p=1}^{P} s_m(p\Delta t) s_m^*(p\Delta t)}} \tag{2}$$

Δt and P are interval of sampling and number of samples, respectively. $s_m(t)$ is the reference signal. Such value set $x_n(n=1,2,\ldots,6)$ that ρ_m are maximized is searched by means of the GA.
In the first, M chromosomes $(a_1,a_2,\ldots a_M)$ are generated by means of random sequence. Second, it is evaluated whether each chromosome can satisfy a goal by use of the cost function $y(a_m)$,. If a chromosome achieved to the goal, the GA is finished. If not, I parent chromosomes are selected using the rule of roulette that imitates the natural selection. Using degrees of aptitude of each chromosome $f_1,f_2,\ldots,f_I$, probability of the selection of chromosome i p_i is calculated by next formula.

$$p_i = \frac{f_i}{\sum_{l=1}^{I} f_l} \tag{3}$$

Accumulative probability of chromosome i q_i is expressed by

$$q_i = \sum_{j=1}^{i} p_j \tag{4}$$

Third, random number r $(0 \le r \le 1)$ is generated and is compared with each accumulative probability. When next unequal formula is satisfied, i+1 th chromosome is selected.

$$q_i < r \leqq q_{i+1} \quad (i=0,1,\ldots,I, \quad q_0=0) \tag{5}$$

This process is repeated J $(J \le I)$ times, and a group of J chromosomes is formed. After parent chromosomes are selected from the group based on a probability of the crossover, crossover point is decided randomly and a pair of chromosomes is rearranged. After the crossover, mutation is generated in the renewed group based on a probability of the mutation. When a series of the selection, crossover and mutation is repeated, the group is converged to a group of which chromosome give a high value to the cost function. Reactance is set to an integer value among -255~255Ω. In order to express 511 conditions by binary code, 9 bits are used. 1 chromosome is consisted of 54 bits binary code for 6 parasitic elements. Next Sigmoid function is used for the cost function.

$$f(y) = \frac{1}{1+exp(-y+mean(y))} \tag{6}$$

Here, mean(·) is averaging. We used the cost function around y=0. Because the function changes conspicuously in the range and difference of aptitude of each chromosome can be seen clearly.

4. Sierpinski Monopole

Second resonant frequency of Sierpinski monopole can be adjusted by changing an angle between the equal sides and height to the lacuna. Fig.2 shows an appearance of Sierpinski monopole that resonates at 0.8GHz and 2GHz. Fig.3 and Fig.4 show simulation results of return loss and radiating patterns of the resonant frequencies. The red lines and the green lines show the vertical pattern on (r, ψ, θ) coordinate system at $\psi=0°$ and $\psi=90°$, respectively. Change of the horizontal pattern at 2GHz is less than 10dB and pattern null cannot be seen till vertical angle of 50˚. It is considered that this element can be sufficiently used as a central element.

5. Simulation

For simplicity, we consider a single band adaptive antenna that has only parasitic elements on a circle corresponding to an used frequency. Also, it is assumed that Sierpinski monopole has omni-directional pattern. Fig. 5 shows the converged adaptive pattern. 6 parasitic elements are arranged on a circle of which radius is 0.5λ. When 2 uncorrelated QPSK modulated signals with equal amplitude are incident from 135˚ and 45˚, signal from 135˚ is received. A chromosome that makes achieve correlate coefficient of 0.9996 can be seen till 20th generations. When the optimum chromosome is used, main beam directs to the desired signal and null steers to the interference. Also, when DOA of the desired signal is set to 180˚ and those of the undesired signals are set to 30˚ and 90˚, 2 nulls steer to directions of the interferences and high correlate coefficient of 0.9925 is found till 60th generations.

6. Conclusion

A multi-band adaptive array antenna has been proposed. The aperture is consisted by a central radiating element and several parasitic elements on the counterpoise. Sierpinski monopole with multi-band capability is applied to the central radiating element. The parasitic elements are located on various concentric circles of which radius is proportional to the frequency. Output of the parasitic element is connected to either the counterpoise or a reactor. When the parasitic elements on a circular array corresponding to the specified frequency are used, each reactor is set such that the correlation between symbols received by the central element and the reference is maximized by means of the Genetic Algorithm. The performance has been demonstrated by preliminary numerical simulation.

References

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[2] J. Cheng, Y. Kamiya, and T. Ohira, "Adaptive Beamforming of ESPAR Antenna Based on Steepest Gradiant Algorithm," IEICE Trans. Commun. Vol.E84-B, No.7, pp.1790-1800, July 2001.
[3] R. L. Haupt and S. E. Haupt, "Practical Genetic Algorithm," Wiley Interscience, New York, 1998.

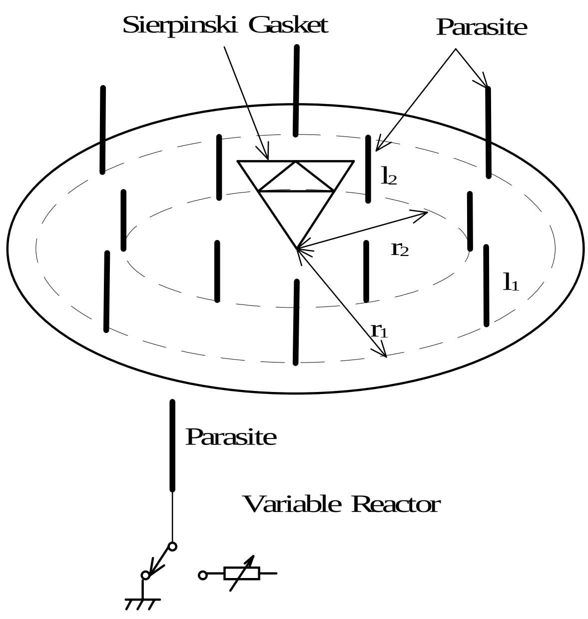


Fig.1 Aperture of Multi-Band Adaptive Array Antenna

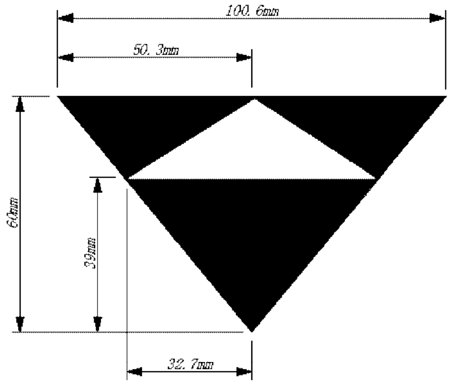


Fig.2 Sierpinski Monopole

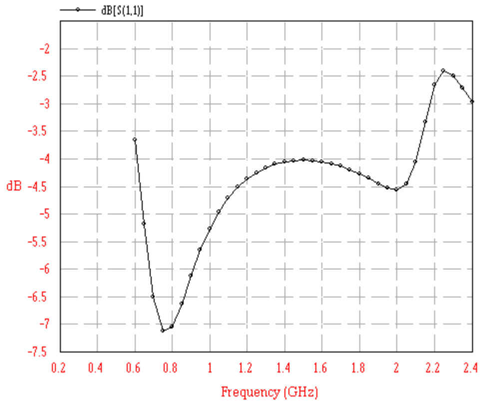
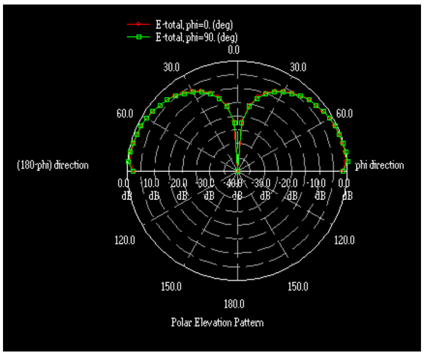
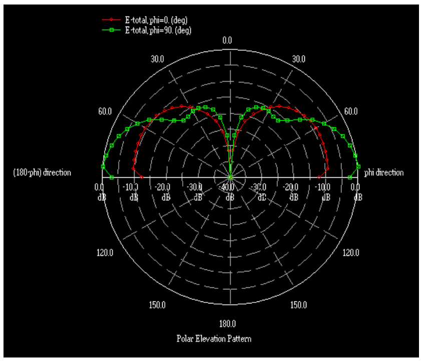


Fig.3 Return Loss

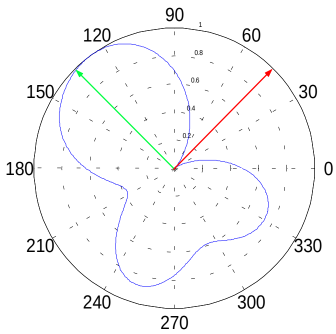


0.8GHz

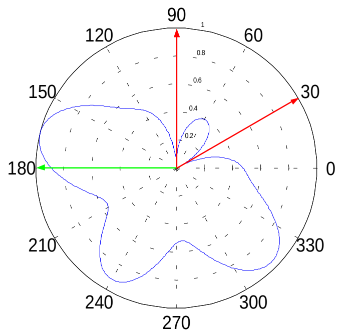


2GHz

Fig.4 Directivity of the Sierpinski Monopole



DOA of Desired Signal =135°
DOA of Interference=45°



DOA of Desired Signal =180°
DOA of Interferences=30°, 90°

Fig.5 Simulation Results