The Design of a Dielectric Rod Antenna Using Genetic Algorithm Optimization for Vessel's Collision Avoidance Applications

Sungtek Kahng · Jeongho Ju

Abstract

In this paper, we present the development of an antenna specialized for the maritime collision avoidance system. This antenna is configured as the dielectric rod partially embedded in the metal cavity to reduce the overall size, simultaneously assuring the mechanical sturdiness against the challenging oceanic weather conditions. More importantly, the design has been carefully done to meet the requirements on the radiation pattern(with the slope<5 dB/deg in the elevation(E-plane), circular in the azimuth) suitable to receiving the reflected signals from the other objects on the sea. To find the optimal design parameters, the genetic algorithm has been used to meet the goals of the desired return loss and pattern. This design methodology is validated by the good agreement between the calculation and measurement.

Key words : Dielectric Rod Antenna, Antenna Optimization by G.A.

Ⅰ. Introduction

Dating a century back, scientists and engineers recognized the importance of the roles that antennas play. In modern societies, with the advent of needs on expanded wireless communication, antennas become undoubtedly an essential part to the telecommunication system. And the demand on the antenna development has driven designers to devise a variety of kinds of antennas from wire-type through planar-basis to bulky waveguide type[1],[2].

Showing the unique feature compared to other types of antennas, the dielectric rod antenna, so far, has been used for high directivity performance as the feed for the reflector antenna using the perpendicular feeding[1]~[4]. This comes from the excitation of hybrid modes or the aperture adjustment. For instance, a study was conducted on investigating the radiation mechanism related to the increasing length of the dielectric rod. Also, the relatively smaller volume of the structure for radiation can be designed using the dielectric rod antenna unlike dipole and waveguide horn antennas.

Wireless communication technology has seen unprecedented demands on the radar system for cars' anti-collision practices. On the road, cars need to sense the reflection from other land vehicles and adopt the narrow beamed antenna patterns and if necessary, the electronic scanning function is equipped. Besides the case of the land, similar things are issued about the oceanic traffic caused by the boats and vessels. See Fig. 1.

A ship will host to have the radar operating with wavelength 3 cm to 10 cm that emits microwave pulses through the antenna: referenced to a U.S. based company's product(Collision Avoidance Radar Detector). When it comes to the choice of the antenna type which is suitable to the collision avoidance radar detector of vessels, size-wise, the dielectric rod antenna is a good candidate, taken into account the limited room for placement on the board. However, the beam pattern along with directivity of the conventional dielectric rod antenna needs to be modified in the event of the incoming vehicle at any angle.

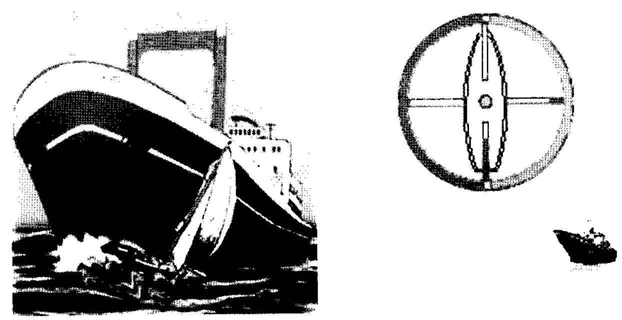

Fig. 1. Ships almost collide, and a commercial on-board radar's scheme.

In this paper, the pattern that is omni-directional and broad in the azimuth and elevation angles, respectively, is required to generate by the use of a dielectric rod antenna. Simultaneously, the good return loss performance at a narrowband is needed. According to these require-

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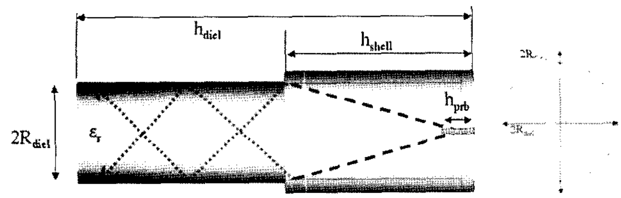


Fig. 2. Side and front-views of a dielectric rod antenna.

ments, the design is done by the optimization method of the GA[5]. Its procedures are addressed following the brief explanation on the electromagnetic method of solution. Finally, the design parameters are input to have the return loss and pattern that lead to validating the suggested work.

Ⅱ. Theory

The circularly cylindrical dielectric rod is excited by a electric probe as a monopole back at the bottom of the metal shell. h_{diel}, h_{shell}, and h_{prb} denote the heights of the dielectric, metal shell and excitation probe.

The front view shows the dielectric rod and the metal shell are concentric with respect to Z-axis and their diameters are $2R_{diel}$, and $2R_{shell}$. The thickness is around one eighth of R_{shell}. With regard to the radiation mechanism, at the first step, Z-directed electric fields are generated in the metal shell with cylindrical cavity modes at multitude of lower frequencies due to the loading effect on the metal shell. And the magnetic fields along ϕ-direction bounce up to the rim of the metal shell and play the magnetic currents as the secondary source for radiation. Therefore, the choice of the physical dimensions of this geometry will determine the antenna performance where the pattern looks like Fig. 3 in the elevation(E-plane) to detect the reflected signlas from the bigger and smaller ships. Besides, the circular radiation patter is expected to receive the impinging fields from all the direction in the azimuth plane(H-plane).

The field analysis is accompanied to picture what kind of physics happens with the geometry for the design. As for the method of solution, the Method of Moment(MoM) solves the electromagnetic field integral equations throughout this work and the explanation is not repeated, since it is quite well-known.

Now the GA is proposed to get the design parameters' values that are optimal in producing the required performances. 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 opti-

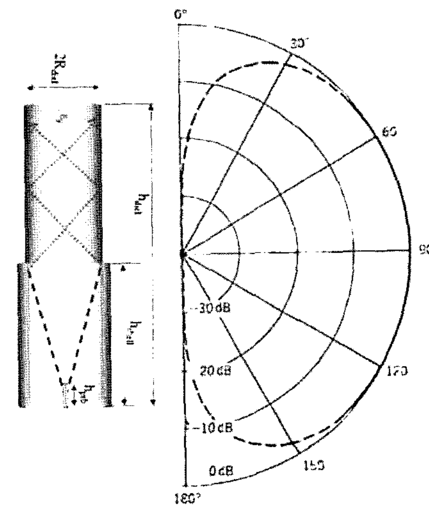


Fig. 3. Half of the elevation plane pattern.

mization scheme work starts with defining the cost function as

$$Cost_1 = \sum^{Np}{}_{p=1} \xi_p | S_{11}(f_p, GDPs) - S_{11p} |^{Ne} \quad (1)$$

$$Cost_2 = \sum^{Nq}{}_{q=1} \eta_q | P(\theta_q, GDPs) - P_q |^{Ne} \quad (2)$$

where the return loss $S_{11}(f_p, GDPs)$ at the p-th target frequency including the resonance is reduced to S_{11p} (demanded return loss at the frequency) with weight ξ_p and order N_e. Eqn. (2) is about the desired pattern of P_q at N_q angular points. N_p and $GDPs$ mean the number of the frequencies of interest and the geometrical design parameters, respectively. The $GDPs$ correspond to the genes, say, ε_r, h_{diel}, h_{shell}, h_{prb}, $2R_{diel}$, and $2R_{shell}$, each of which has N_{bit} binary bits. With N_u DeCaps, 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 .

Ⅲ. Realization and Validation

Prior to the design, let us remind ourselves of the requirements: Resonance at 4.8 GHz and '<−10 dB return loss bandwidth' of 150 MHz especially for the vessel avoidance of collision, and omni-directional in the azimuth and broad(gain slope<5 dB/Deg) in the elevation. Considering cases of the collision avoidance for vehicles on the road, the design concern on the beam pattern is forward-directed, since the antenna placed at the front of a car works only about other cars ahead. This means the conventional concept of a collision avoidance antenna has to handle fixed directions and narrow beamwidths. However, the story becomes different for the design of

Table 1. Design targets.

Item	Spec.
Operating frequency	4.8 GHz
Bandwidth	150 MHz
Pattern	
- Azimuth	-Equally distributed
- Elevation	-slope<5 dB/Deg (BeamWidth>90°)
Gain	3 dBi (injected by the amplified current for the actual use)
VSWR	<−10 dB

the anti-collision antenna for a vessel, because it can be hit by floating objects from any directions on the water. This explains why a broad radiation pattern is required. But we will be strict in guaranteeing the good return loss as the usual practices of antenna design. The design targets are summarized in Table 1.

Keeping the requirements above in mind, the design is proceeding to find the right values of the *GDPs*. For the sake of convenience, the probe's radius and aperture size are those of 50 ohms. And R_{shell} is excluded from the list of the design unknowns, since the thickness of the metal shell remains unchanged and R_{shell} will be automatically obtained from R_{diel}. Hence, the unknowns are ε_r, h_{diel}, h_{shell}, h_{prb}, and $2R_{diel}$. Varying these *GDPs*, the resultant return loss at frequencies of interest and the gain at interested angles are provided by the solver for each and every evaluation step in the middle of the optimization process. As for the ranges of parameters, ε_r, h_{diel}, h_{shell}, h_{prb}, and $2R_{diel}$ are varied from 2.00 through 4.3, from 20 mm through 160 mm, from 40 mm through 80 mm, from 7 mm through 70 mm, and from 4 mm through 80 mm, respectively. Along with these sets, the GA work is given 5 genes, 80 individuals, 100 generations, P_m of 0.01 and P_{Cr} of 0.80. And note the two weightings are set equal as 0.5. The following is the cost function satisfying the required return loss over the generation.

This GA operation has been done with $|S_{11p}|$ (demanded return loss) of −30 dB in the 150 MHz-bandwidth including 4.8 GHz. The cost function decreases from generation to generation, but never becomes 0 in that −30 dB is harsh to meet. If we have more *GDPs*' sets and expand the search space, the reduced scale fluctuation (convergence) will happen. Consequently, we could get the unknowns' set number 17 as the best return loss performance. The set is interpreted that ε_r, h_{diel}, h_{shell},

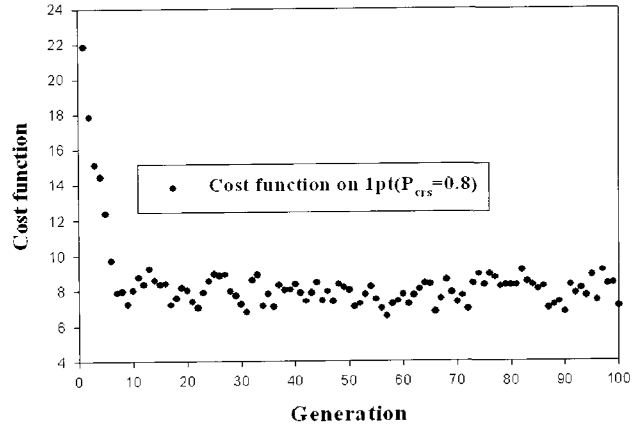


Fig. 4. Cost function behavior during the optimal parameter search for the return loss.

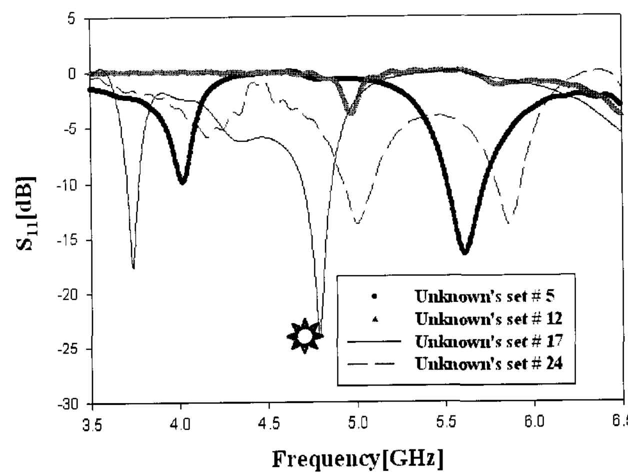


Fig. 5. Return loss curves on different unknowns' sets (optimal design parameters' set is included).

h_{prb}, and $2R_{diel}$ are 2.1, 110 mm, 71 mm, 15 mm, 54 mm, respectively. Including this set, a couple of the unknowns' groups result in the following frequency responses of the return loss.

Eqn. (2) is used to find the opimal *GDPs* for the required gain of the pattern (gain slope, more precisely here) as is done with the return loss requirement. In the first place, we need to know how the cost function related to Eqn. (2) behaves.

The desired gain slope has been set '<5 dB/Deg' from 0° to 180°(it is observed the elevation field pattern is symmetric with respect to *Z*-axis and the azimuthal plane is omni-directional pattern as expected from the circular cylindrical structure). Like the cost function of the return loss, the pattern design results in the seemingly convergent cost function variation. Still, the shaking in the cost function results from the fact that P_q of less than 5 dB/Deg is neither very accute nor strin-

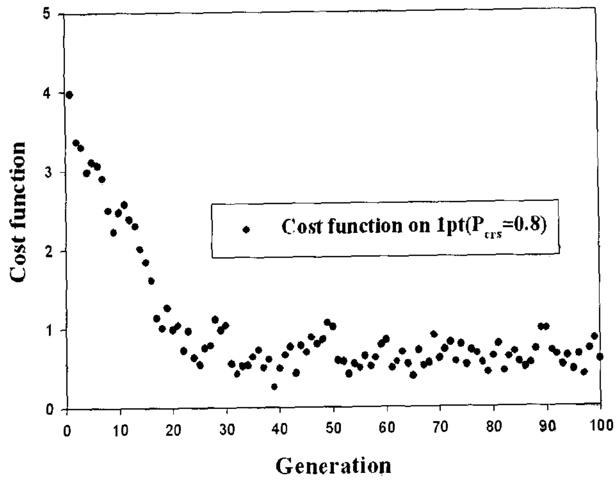


Fig. 6. Cost function behavior in the optimal parameter search for the pattern.

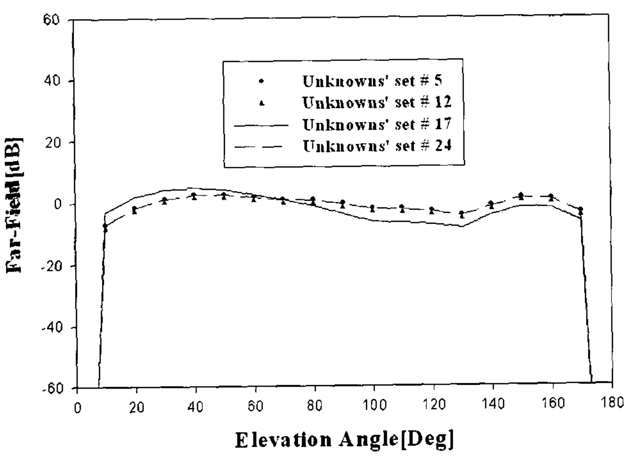
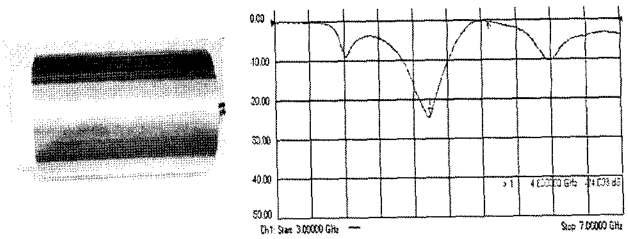


Fig. 7. Radiation pattern curves on different unknowns' sets(optimal design parameters' set is included).

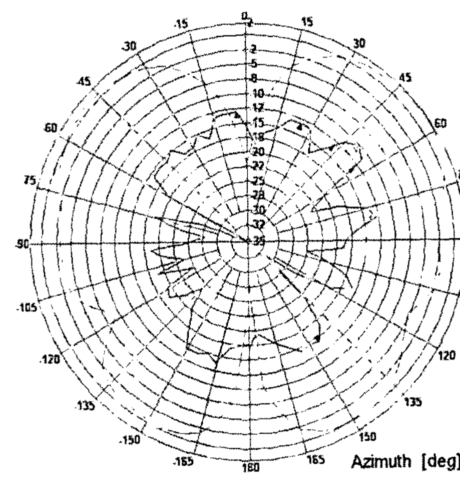
gent, and it opens the room for different sets of the unknwons to enter. But it can be fixed with enlarging the search space. As a consequence of the optimization, we have the pattern with the gain below.

The simulated gain amounts to 5 dBi. The overall performance shows the comliance with the design target, if you refer to the Table 1. Finally, we present the measurements on the return loss and the radiation pattern.

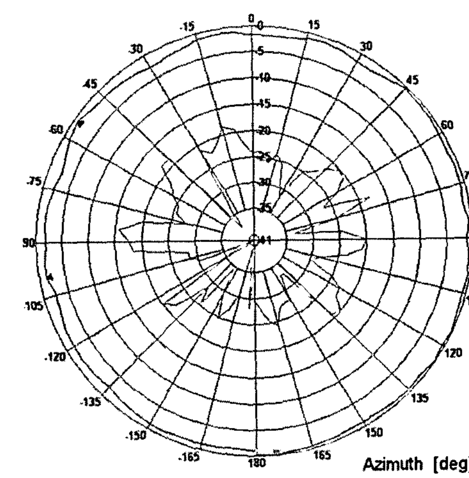
The retun loss in Fig. 8(a) complies with the specification with less than −10 dB over the band. The radiation patterns with approximately 3 dBi of gain also are compliant to the values in the targets. Also, it is noted that the corsspolariztion levels are satisfactory. And it needs to be addressed again that the excitation current will be amplified in the real radar system. So the gain in the measurement is sufficinet.



(a) Photo of the fabricated antenna and its measured return loss



(b) Measured E-plane pattern



(c) Measured H-plane pattern

Fig. 8. Photo of the antenna, measured return loss and radiation patterns in the E- and H-planes.

Ⅳ. Conclusion

This paper conducts a GA optimization to design the dielectric rod antenna that suits the vessel's collision avoidance on the water. The resultant performances of the return loss and the pattern show that the design methodology works well in terms of the less than −10 dB at the wanted resonance frequency and the omni-direction and broad beamwidth for the purpose.

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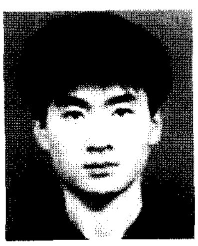

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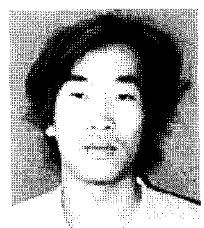

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