Radome Design with Improved Aerodynamics and Radiation for Smart Antennas in Automotive Applications

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***Abstract*-More applications are using wireless communication, where the radomes become more important as they are essential in the performance of antennas as well as protect antennas from environmental conditions. The focus in this study is to design a radome for a customized smart antenna such that the attenuation of antenna signal and the increase in drag coefficient of vehicle are minimized. This paper presents a novel method of radome design and the simulation results demonstrate that the drag coefficient of the vehicle is slightly increased by less than 2% while the loss to the signal strength is less than 0.5 dB.**

I. INTRODUCTION

With the advancement of technology, wireless communication technology is on the rise. The performance of the antennas is crucial in the wireless communication application such as direct video streaming on the move and transmission of high throughput data between mobile terminals and the base station. In the transportation market, this advanced wireless communication allows users to enjoy seamless data connectivity while transporting from point A to point B using various modes of transport such as car, bus, train, ship etc. Therefore, the antennas must be protected from environmental conditions when in use. These include high wind speed, rain, snow and icing. Such protection is done by covering the antennas with a protective dome, known as a radome [1]. The radome design has been investigated extensively in literature. In [2], a design approach was proposed to design a composite radome for airborne surveillance where the load and electromagnetic impact were well presented. In the commercial satellite and marine communication market, KING [9] and RAYRAMINE [8] have presented their symmetrical radomes with nice artistic impression, however, they didn't fully address the aerodynamics features of the radome which is extremely important in the automotive applications.

The design of a radome is a multidisciplinary task that involves mechanical and electrical studies [2]. Antenna sidelobes are unwanted signals that are emitted from the antenna and will increase when a radome is used to house the antenna [3], affecting the performance of other nearby antennas. Boresight error is the error between angle of arrival of received and the actual angle of arrival. This happens when electromagnetic waves pass through a dielectric radome wall and causes inaccuracy in signal. A well designed radome will minimize the radiation distortion and boresight errors.

Since the smart antenna will be used in the automotive industry, the radome will contribute to the drag coefficient of the vehicle. Aerodynamics of the overall vehicle contributes a substantial amount to the fuel consumption of the vehicle as depicted in Fig 1 [4], which means that the designed radome must be well aerodynamic in order to allow minimal increase in fuel consumption. When an object is exposed to UV light for a long period of time, the properties of the material degrades [5] as a result of the breaking of polymer chains in the material, which produces free radical and reduces the molecular weight. Since the radome will be exposed to extended periods with sunlight, this is an important factor to consider.

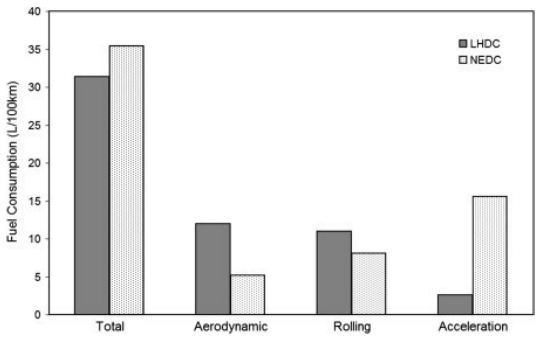


Fig. 1 Contributing factors of fuel consumption for vehicle [4]

In this work, a unique radome is designed to house a smart antenna array with the customized shape and dimension. The radome is able to minimize the impact on the increase of the overall vehicle drag coefficient due to introducing this additional structure, while maintaining and reducing the distortion to the radiation pattern and signal strength of the antennas. Furthermore, the features for outdoor and automotive environment are fully addressed. The design considerations for the radome are listed below:

a. Design a radome that houses 3 types of antenna arrays
b. Ruggedized radome design for installation on roof of automotive
c. IP67 outdoor environment and UV protection
d. Minimum impact on antenna radiation
e. Aerodynamic design with minimum impact on automotive speed and fuel consumption

This paper is organized as follows. In section II, the features and the aerodynamics design of the radome is presented. Section III presents the simulation result of the radiation performance and aerodynamic performance of the radome, follows by a comparison with the state of the art radomes. Section IV concludes the paper.

II. Design of Radome

There is no single radome that fits all antennas. The design of a radome depends on the antenna and the application of use. Furthermore, the smart antenna is in-house designed for transportation applications. So, the requirements from the antenna and the transportation must be met at the same time. The antenna structure consists of 4 units of 90° phase arrays to cover the entire 360° service angle, the array was specially customized internally to support the transportation market with smart antenna features. The array [6] comes with different size and gain as shown in Fig. 2, the dimensions are 60 mm, 100.875 mm, 141.75mm with the same width of 141.75 mm and thickness of 9.12mm. The operating frequency of the arrays are between 4.9 – 5.9 GHz. Due to the uniqueness of the antenna arrays, it is necessary to design a customized radome to house the element for it to be deployed in the harsh outdoor transportation environment.

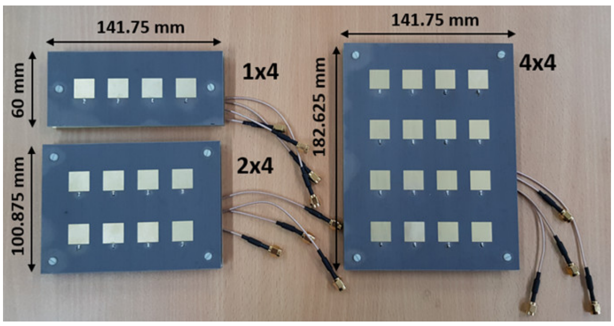


Fig. 2. Illustration of the array structure in the radome

The final radome design is shown in Fig 3. This design was chosen as it houses the antennas with minimal wastage of space inside the radome. Small radome size is crucial for vehicular mount antenna as the space on the roof of the vehicles is shared with other structures. Several features are incorporated in the design to make it a ruggedized structure to be used in the automotive industry.

i. Standard array mounting, the internal mounting structure allows all 3 types of antenna array to be securely mounted inside the radome.
ii. Ruggedized roof mounting, this roof mounting allows the radome to be secured on the roof in a mobile vehicle.
iii. Rubber sealing and ruggedized connector, the rubber sealing mechanism is used between the 2 radome parts. The weatherproof connector is for cable access with external transceiver. Furthermore, both these features are used to fulfill the IP67 requirement of the radome.
iv. Shape of radome, the shape of the radome is designed with aerodynamic concepts in mind. This is to reduce the impact of the radome has on the automotive speed and fuel consumption.
v. Material selection, to minimize the impact of radome on the antenna radiation and UV degradation, Polymethyl Methacrylate is used. This material has sufficient mechanical properties to withstand the drag forces experienced by the automotive and it has high UV protection.

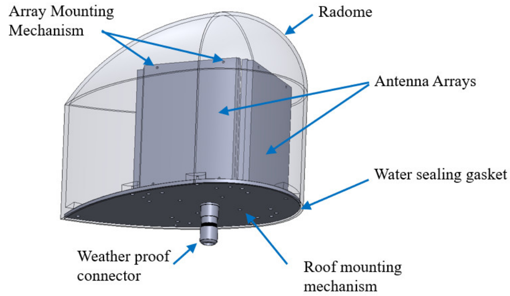


Fig. 3. Proposed Radome Design

III. Simulation Results and Discussion

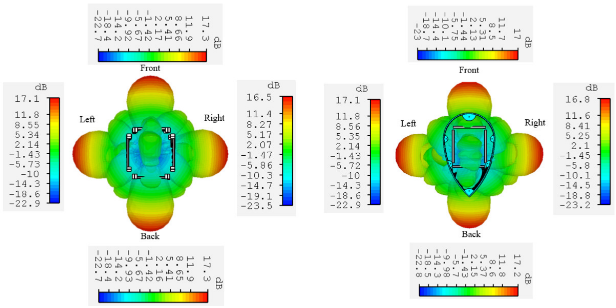
A. *Antenna Radiation Performance*

For the radiation simulations, the Computer Simulation Technology (CST) software package is used. The effects of radome on the signal strength can be determined based on the simulations. The simulations are done in 2 parts. First, the signal strength of the antennas is determined. The second simulation is done after adding the radome. For both simulations, materials used are applied to the individual components of the antenna array and radome.

To evaluate the impact of radome on the RF radiation efficiency, the RF radiation performance is evaluated with the antenna installed inside the radome compared with the radiation without the radome installed as described in Fig. 4. Each antenna system has 4 radiating sectors (front, back, left and right), the antenna radiation gain on each sector is simulated and captured in Table 1. From the results, it is seen that the gain generally decreases after the radome is used. This is because the electromagnetic waves pass through the radome wall. However, it is shown that the decrease in gain is negligible and would not cause serious attenuation in signal strength. From the results, the radome increases the sidelobe of the signal by just a small amount. This is a positive result as it will not affect nearby antennas. Another important point to note is the attenuation of the signal strength. For the front, left and back sector, the signal attenuation is less than 0.5 dB which means that it has an insignificant loss. For the right sector, it increases the signal strength. With this simulation, it can be confirmed that the designed radome has met the requirements in terms of the radiation performance.

Table 1. Gain of antenna in each direction

Direction	Gain (dB) without radome	Gain (dB) with radome
Front	17.3	17
Left	17.1	17.1
Back	17.3	17.2
Right	16.5	16.8



a) Farfield simulation without radome   b) Farfield simulation with radome

Fig. 4. Comparison of electromagnetic performance

B. *Aerodynamic Performance of Radome*

To study the aerodynamics of the radome, the ANSYS Fluent software package was used. Single deck and double deck buses were used for simulation purposes and the velocity was set at 60km/hr. A mesh convergence study was done to have the best balance between the accuracy of results and the computational time. A verification study was also done by using a model used in literature [7] to verify that the boundary conditions used for the simulation were correct. The percentage error between the simulation done and that of the paper's is 0.9%.

A comparison between the designed radome and 2 commercial products (KING [9] & RAYRAMINE [8]) that can fit the antennas and a cylinder-shaped radome is conducted. This allows us to know how aerodynamic the designed radome is, and the results are shown in Table 2.

Table 2. Increase in drag coefficient due to introduction of radome for single-deck and double-deck buses

	Single-deck	Double-deck
Designed Radome	3.87e-03	8.06e-03
KING [9]	13.26e-03	27.45e-03
RAYMARINE [8]	10.51e-03	23.46e-03
Cylinder-shaped Radome	6.25e-03	8.30e-03

The drag coefficient of the single deck bus is 6.4731e-01 while that of the double deck bus is 6.1186e-01. The designed radome only increases the drag coefficient of the single deck and double deck buses by 0.6% and 1.32% respectively. The difference in the increase of drag coefficient due to the introduction of radome as the exposed area to the flowing air is increased, causing a stagnation point to occur.

From the results, the shape and size of the radome affect the drag coefficient of the vehicle. Although the different radomes only increase the overall drag coefficient of the vehicle by a small margin, this would lead to higher fuel consumption for the vehicle. With many vehicles in consideration, that small increase in drag coefficient would become significant. Thus, to design a radome with less drag coefficient is of key practical interest. If the velocity of the wind is increased, the increase in drag coefficient caused by the radome would be higher, making aerodynamics aspect truly an important aspect when it comes to designing of radomes.

IV. Conclusion and Future Work

The proposed radome exhibits less than 0.5 dB of loss to the signal strength of the antennas it houses, which is a negligible effect on the radiation of the antennas, and only an increase of less than 2% in drag coefficient of the vehicle because of the designed shape of the radome, which allows air flow around it to be smooth. This proves that the proposed radome is well designed. To further improve the design, parametric studies can be carried out, that involves, changing minor dimensions, angles, etc. of the design to achieve an optimized aerodynamic design.

V. References

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