Design of a double-faced glass-integrated antenna for military aircraft FM radio communication

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*Abstract***—This paper proposes a double-faced glass-integrated antenna for military FM radio communication on aircraft. The proposed antenna, consisting of a feed, a parallel strip, and a radiator, uses both sides of the window. The feed strip and the parallel strip are directly printed on the inner surface, while the radiator is printed on a thin transparent film to be placed on the outer surface. This allows the antenna characteristic to be replaced by changing the radiator without replacing the entire window. A multi-loop structure is adopted for the radiator, and the parallel strip is applied to broaden the coupling bandwidth. The proposed antenna is optimized by a genetic algorithm in conjunction with the FEKO EM simulator. The optimized antenna shows a half power matching bandwidth of 31% and an average azimuth gain of about -3.75 dBi. The results show that the proposed antenna can be adopted as a military FM antenna for aircraft applications.**

Keywords-Glass-integrated antenna, aircraft antenna, coupled feed structure

I. INTRODUCTION

Military aircrafts use military FM radio frequency (30 MHz – 88 MHz) to communicate with either a base station or another aircraft, usually at great distances. Thus, military FM radio communication systems require high performance antennas such as pole-type and blade-type antennas. However, such antennas have long and heavy profiles because of their low frequency operation (λ = 10 m at 30 MHz), which causes considerable drag, wind noise, and increased oil consumption [1], [2]. Antenna integration technologies, therefore, have become an important research area since the aerospace industry recognized such drawbacks as serious problems to be resolved. One of the most common integration technologies is glass-integrated antennas that were widely adopted by the automobile industry [3]. Since the antenna structure is integrated onto the glass surface, glass-integrated antennas make zero additional drag and have almost zero weight. Moreover, they have low fabrication cost because they require no structural alterations. Nevertheless, the cost can be increased unexpectedly if the entire window needs to be replaced, for example, when the window is broken or other antenna characteristics are required.

In this paper, we propose a double-faced glass-integrated antenna to reduce the risk of such undesired cost increase discussed above. The antenna, mounted in the left window of the Korean Utility Helicopter (KUH-Surion) for military FM radio communication, consists of a feed structure and a radiator that are separated into different sides of a window. The feed structure is directly printed on the inner surface while the radiator is printed on a thin transparent film (PET, thickness = 0.05 μm, ε_r = 2.3, tanσ = 0.002) on the outer surface. This allows the antenna characteristics to be changed easily by alternating the film without replacing the window. In addition, since the antenna uses both sides of the window, its matching characteristic and radiation gain can be improved by increasing the antenna area. Because of such structural characteristics, the feed structure should be designed to cover as wide a frequency range as possible, which provides flexibility in choosing a radiator on outer surface. To address this, we added parallel strips along the feed structure which helps to broaden the coupling bandwidth with the radiator. Then, a multi-loop structure was adopted to allow the resonator to achieve multi-resonance, and the targeted resonance frequencies are achieved by varying the lengths of the loops. The antenna strips were designed to have the same shape as the window frame to make the strips visually less obstructive. The proposed antenna structure is optimized using the genetic algorithm (GA) in conjunction with the FEKO EM simulator [4], [5]. Then, the optimized antenna was evaluated by its half power matching bandwidth and its radiation gain. The data shows that the proposed antenna is suitable for use as a military FM radio antenna for aircraft applications.

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II. ANTENNA STRUCTURE AND OPTIMIZATION

A. EM simulation and antenna structure

Fig. 1 shows the geometry of the KUH-Surion and the position of the antenna. To reduce the simulation time without accuracy degradation, some parts, such as propellers and landing gears were removed, and the density of the mesh triangles was readjusted according to the induced current distribution. As a result, the geometry was re-modeled as 3,300 piecewise mesh triangles in our EM simulation. To estimate the antenna performance, an equivalent coated wire method was employed; thus, the antenna structure (width = 1 mm, $\sigma = 5.8 \times 10^7$), printed on glass, is expressed as a conducting wire (radius = 0.02 mm) that is coated with a dielectric material (radius = 0.03 mm, $\varepsilon_r = 4$, $\tan\sigma = 0.02$).

The antenna uses both sides of the window to separate the feed structure and the radiator. The inner surface, as shown in Fig. 2a, shows a printed feed and parallel strips. The feed strip is grounded at the upper window frame, and its length (L_1) is designed to be around a $\lambda/4$ in the military FM band (30 MHz – 88 MHz). The parallel strips, adopted to broaden the coupling bandwidth, are inductively coupled with the feed strip and their coupling strength is controlled by the distance D in relation to the feed current. They are grounded at both ends to prevent their own resonance, since they need to affect the radiator only as an additional current source. Their lengths are determined by W_2, H_2 with the distance D. Fig. 2b shows the outer surface of the window with a multi-loop strip that is adopted for the radiator. Unlike the inner surface, the radiator is printed on a thin transparent film (PET, thickness = 0.05 μm, $\varepsilon_r = 2.3$, $\tan\sigma = 0.002$) to stick to the outer surface. This enables us to change the antenna characteristic by alternating the film without replacing the window. The multi-loop lengths are designed to be around a $\lambda/2$ in the military FM band and they are determined by W_1, H_1, and D. Each loop is connected electromagnetically at four corners in order to achieve multi-resonance. Then, we designed antenna strips to mimic the shape of the window frame to improve visibility for the pilot.

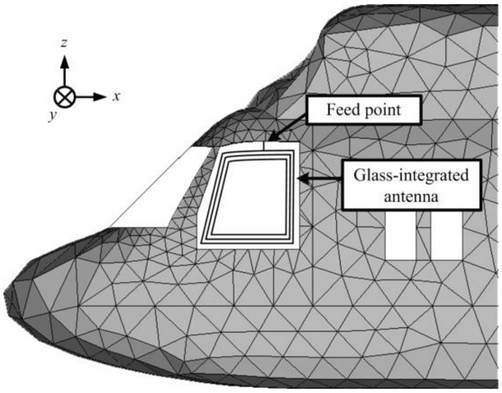
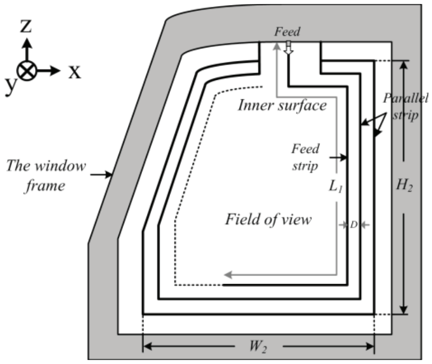
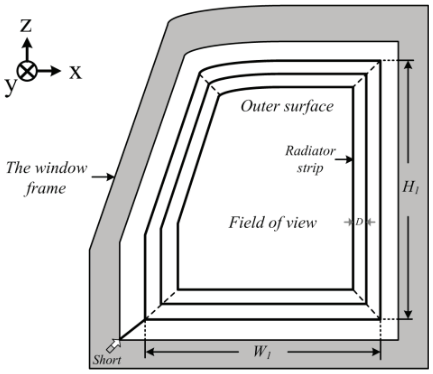


Figure 1. Geometry of the KUH-Surion



a. Inner surface



b. Outer surface

Figure 2. Proposed antenna structure

B. Optimization

The proposed antenna structure was optimized by the GA in conjunction with the FEKO EM simulator. A single cost function, as shown in (1), was used to broaden the matching bandwidth, which is the ratio of the antenna's bandwidth (BW_{ANT}) to the military FM radio band (BW_{FM}). Equation (2) was used to filter out designs having a narrow field of view (FOV) of less than 60% to ensure the maximum FOV. As in (2), the FOV is determined by the antenna area (S_{ANT}) and the window area (S_{WIN}, 0.56 m^2).

$$Cost1 = 1 - \frac{BW_{ANT}}{BW_{FM}}. \tag{1}$$

$$\begin{gathered} if\ FOV = 1 - \frac{S_{ANT}}{S_{WIN}} < 0.6, exclude\ the\ design. \\ 30\,MHz \le frequency \le 88\,MHz \end{gathered} \tag{2}$$

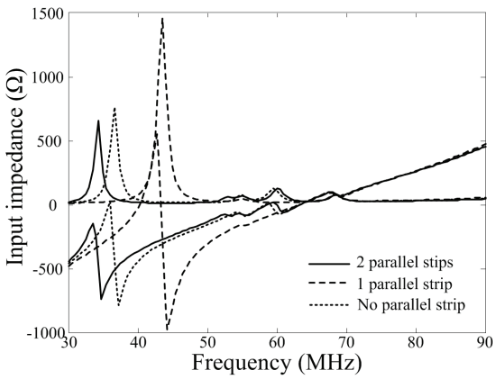
The optimized antenna shows a pilot's FOV of about 63 %, and the optimized parameters are as follows: L_1 = 1115 mm,

W_1 = 701 mm, W_2 = 704 mm, H_1 = 781 mm, H_2 = 784 mm, D = 25 mm.

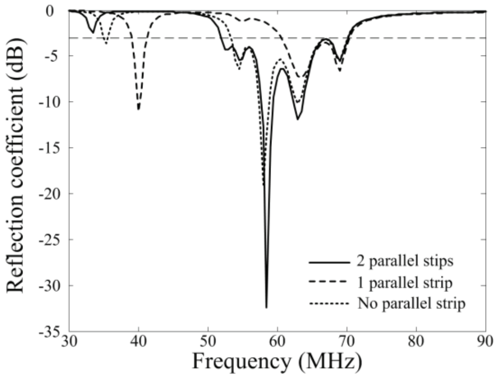
III. ANALYSIS AND EVALUATION

Fig. 3a and 3b show comparisons of input impedance and reflection coefficients, respectively, according to the number of parallel strips. The optimized antenna is expressed by the solid line in both figures. As expected, we can verify that the matching characteristic can be improved as the number of parallel strips increases. This is because the current induced on the parallel strip works as another current source for the radiator, thus, additional resonance is achieved. As a result, the optimized antenna shows a half power matching bandwidth of 31% (18 MHz, 53 MHz – 71 MHz) in the military FM band.

To verify the radiation characteristic of the antenna, we simulated its average azimuth gain and azimuth patterns, as shown in Fig. 4a and 4b. Azimuth patterns are very important for aircraft applications because most signals come from a horizontal direction [6]. The antenna shows an average azimuth gain of about -3.75 dBi and an average gain deviation of about 9.38 dB in the military FM band. This shows an appropriate omni-directional property when considering the size of the KUH-Surion (15 m × 2 m × 4.5 m).

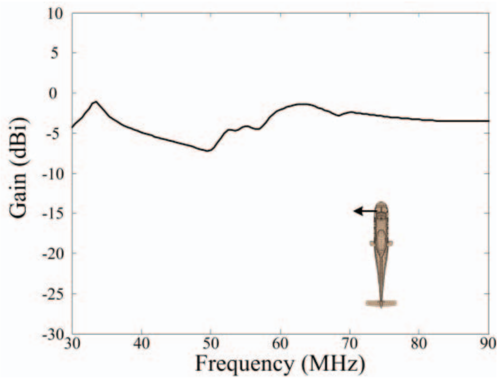


a. Input impedance

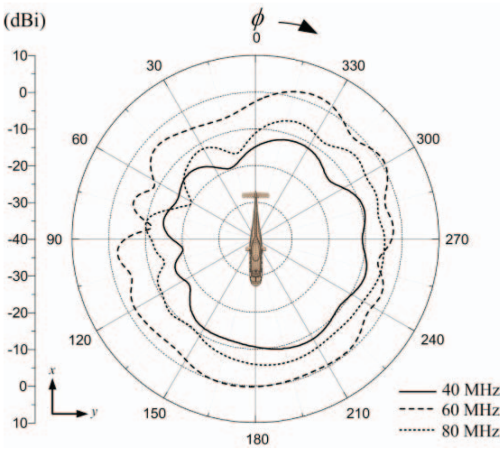


b. Reflection coefficient

Figure 3. The effect of the parallel strip



a. Average azimuth gain



b. Radiation patterns

Figure 4. Gain of the optimized antenna

IV. CONCLUSION

We investigated the design of a double-faced glass-integrated antenna with a coupled feed structure. The feed structure was placed on the inner surface, while the radiator was placed on the outer surface. Antenna strips were linked electromagnetically, and the coupling strength was controlled by the distance between the strips. The multi-loop structure was adopted as a radiator for its broad matching characteristic, and the parallel strip was employed to further improve the matching characteristic by supplying more H-field to the radiator. Then, the antenna structure was optimized by the GA. The optimized antenna showed a half power matching bandwidth of about 31 % and an average azimuth gain of about -3.75 dBi in the military FM band. The results demonstrate the antenna's suitability for use in aircraft.

ACKNOWLEDGMENT

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