Design of vehicle rear window antenna with mesh-grid structure

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Proposed is the design of a rear on-glass antenna for a commercial saloon/sedan. It adapts the mesh-grid structure and proposes the optimum design parameters to maximise matching bandwidth and improve the average vertical gain for the entire FM radio band. The detailed design parameters are determined using the Pareto genetic algorithm with an EM simulation tool. The optimised rear on-glass antenna is built and installed on a commercial saloon/sedan. The measurement results show a half-power matching bandwidth (VSWR < 5.8) of about 25%, an average bore-sight gain of about −5.43 dBi in the entire FM band, and an average gain of about −3.29 dBi along the azimuth direction.

Introduction: To improve the durability and appearance and to reduce the wind noise of the pole-type FM antenna, an internal on-glass antenna that is printed on the rear or quarter window has been widely adopted by new types of saloon/sedan models. However, because on-glass antennas are etched directly on the lossy dielectric material of the glass and the antenna's conducting stripline offers only low conductivity to function as defroster lines, antenna performance, including matching bandwidth and radiation gain, is diminished [1]. Therefore, various techniques such as adding vertical lines to improve the vertical radiation gain or inserting additional tuning bars to improve the bandwidth characteristics have been introduced [2]. Nevertheless, the radiation characteristics of on-glass antennas with those techniques cannot reach the desired performance when compared to a conventional pole-type antenna.

In this Letter, we propose a novel rear-window antenna using virtual mesh-grid vertical segments between horizontal defroster lines. This mesh-grid shape is known to provide a broad matching bandwidth by more uniformly distributing the currents on the antenna, and the complete shape is determined by connecting or disconnecting each vertical grid line. We optimise grid connections and disconnections using the Pareto genetic algorithm incorporation with the full-wave EM simulation tool (FEKO of EM Software and Systems) [3, 4]. To achieve multiple design goals of broad matching bandwidth with high vertical gain, we used multi-objective cost functions in our GA approach. In the EM simulation, we include the entire vehicle to estimate the antenna performance more accurately because the total length of the vehicle is in the order of the wavelength of the FM band. To verify the optimised result, the optimum design is printed on the rear window of a commercial vehicle, and its antenna performances, such as VSWR, radiation pattern, and antenna gain, are measured. The optimised design showed a half-power matching bandwidth of about 25% (VSWR < 5.8), an average bore-sight gain of about −5.43 dBi for the entire FM band, and an average gain of about −3.29 dBi along the azimuth direction.

Antenna structure and optimisation: Fig. 1*a* shows the geometry of the mesh-grid structure on a rear window, which has dielectric material properties of $\varepsilon_r = 7$ and tan $\delta = 0.03$ at 100 MHz. To obtain a sufficient degree of design freedom, we insert 14 × 14 virtual vertical grid segments between the horizontal defroster lines. The length of the vertical grid segments is 3 cm, and each vertical segment is separated by 6 cm in *y*-directions. Thus, the size of the total mesh-grid structure contains 196 segments within an 84 × 42 cm, and the vertical lines and virtual grid lines are represented by solid and dashed lines, respectively, by connecting or disconnecting each vertical grid line. In each grid segment, the solid line represents the conducting stripline residing along the string, and the dashed line means that the conducting stripline has been removed.

In our GA, we represent each segment as 2D chromosomes, and the vertical grid lines are created in the virtual grid lines when the '1' value bit is recognised. To accurately estimate the performance of the rear on-glass antenna, we used FEKO of EM Software and Systems. In our EM simulation, we used the equivalent coated-wire method to improve the accuracy and the simulation speed. The equivalent conditions for the coated wire are given by 0.1 mm diameter for the conducting core ($\sigma = 5.7 \times 10^7$ S/m) and 12 mm diameter for the dielectric coating ($\varepsilon_r = 8$, tan$\delta = 0.03$ at 100 MHz). To obtain the optimised mesh-grid antenna structure and achieve the stated design goals of low VSWR and high vertical gain in the entire azimuth direction, we used the PGA in conjunction with the FEKO EM simulation tool.

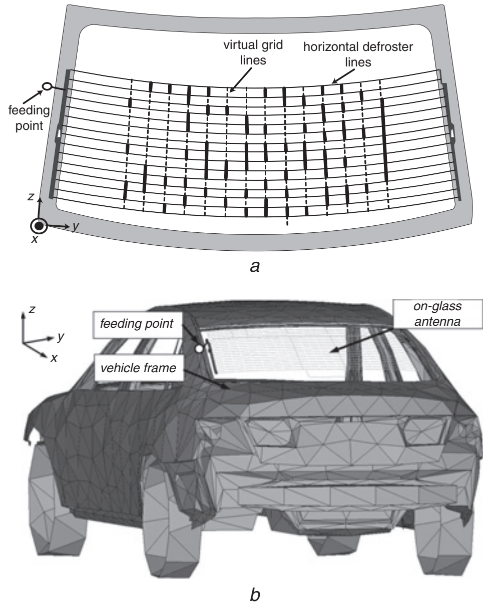

Fig. 1 *Proposed antenna structure and vehicle model*

a Proposed antenna based on mesh-grid structure
b Vehicle model for on-glass antenna

Fig. 1*b* shows the vehicle body for the EM simulation. As the length of the vehicle body (4.895 m) is similar to the wavelength of the FM band, the input impedance and the radiation pattern are significantly changed by the specific geometry of the vehicle, such as the location of the window, the feed position, and the shape of the vehicle frame. The entire vehicle body is reproduced with the triangular piece-wise meshes to simulate the effect of the vehicle frame when running EM simulation. Although simulation accuracy is further improved with a denser mesh model, we set the mesh number at about 4000 by dividing the vehicle meshes more densely near the antenna and coarsely for other parts. Therefore, we obtained a simulation accuracy of greater than 80 % compared to the mesh size of about 4000 and the simulation speed of around 2 minutes at each frequency.

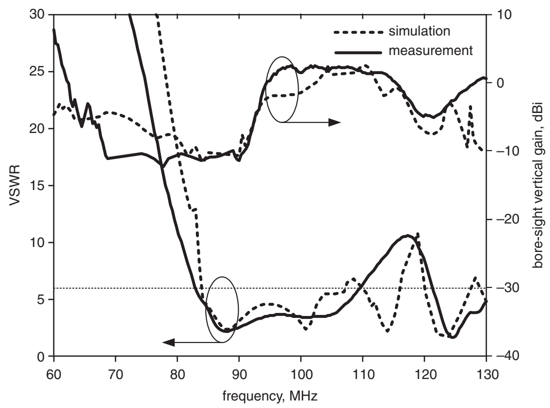

Fig. 2 *VSWR and bore-sight vertical gain of proposed antenna*

Simulation and measurement results: To verify the optimised results, the optimised mesh-grid antenna was built and installed on the rear window of a 2009 TG Grandeur manufactured by Hyundai Motor Company. We then measured the antenna performances, such as VSWR, bore-sight vertical gain ($\theta = 90°$, $\phi = 0°$), and radiation patterns in a semi-anechoic chamber having dimensions of 30 × 30 m. An ETS-Lindgren 3121C dipole was used as the transmitting antenna and an Agilent E5071A network analyser was used for extracting the full S-parameters. In Fig. 2, the simulated and measured results of VSWR and bore-sight vertical gain are plotted as dashed and solid lines, respectively, and they show agreement. The half-power matching bandwidth (VSWR < 5.8) of the optimised antenna was measured to be in the frequency range of 83 − 108 MHz. The bore-sight vertical gain exceeds −13 dBi, and the average gain is about −5.29 dBi, where the FM radio channel exists from 80 to 110 MHz.

Because the omnidirectional property is an important design requirement for designing vehicle antennas, we also measured the radiation pattern of antennas in the whole azimuth direction. As shown in Fig. 3, the maximum radiation gain of the optimised antenna occurs in the bore-sight direction ($\theta = 90^\circ$, $\phi = 0^\circ$), and the average vertical gain in the entire azimuth direction exceeds −3.95 dBi at 88, 93, 98, 103, and 108 MHz.

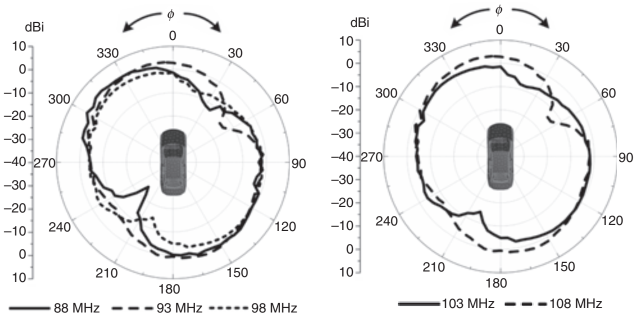

Fig. 3 *Measured radiation patterns of proposed antenna*

As shown in Table 1, we conducted field tests to verify the optimised antenna performance in actual outdoor conditions. We selected four measurement sites based on the density of buildings and the signal strength in Seoul, Korea (the channels for sites 1 and 2 are similar to the multipath fading channel, and the strength of the signal in sites 1 and 3 are more stronger than sites 2 and 4). The vehicle speed is about 60 km/h and the travelled distance is 4.1 km per each site. To accurately measure the antenna performance, we used a spectrum analyser connected to the feed of the rear on-glass antenna and collected the power level in real time at a sampling rate of 3 Hz (8 minutes per each site). To demonstrate the superiority of the optimised antenna performance, we compared the optimised antenna using a mesh-grid structure (ant. 1) with a commercial antenna having two vertical lines (ant. 2). The average received signal power of the optimised antenna (ant. 1) is −52.54 dBm (ant. 1), whereas that of the commercial antenna (ant. 2) is −55.87 dBm.

Table 1: Received signal power of each antenna under actual outdoor conditions

Received power (dBm)		88 MHz	93 MHz	98 MHz	103 MHz	108 MHz	Average
Site 1	Ant. 1	−43.0	−56.4	−55.6	−54.8	−56.0	−53.2
	Ant. 2	−42.2	−59.4	−61.4	−58.8	−65.7	−57.5
Site 2	Ant.1	−51.0	−63.8	−60.0	−63.0	−62.2	−60.0
	Ant. 2	−47.0	−65.8	−65.8	−61.4	−63.4	−60.7
Site 3	Ant. 1	−56.6	−46.2	−45.2	−47.2	−47.0	−48.4
	Ant. 2	−53.6	−48.4	−55.8	−47.2	−51.8	−51.4
Site 4	Ant. 1	−48.6	−57.4	−55.6	−51.6	−53.2	−53.3
	Ant. 2	−48.4	−59.6	−68.4	−61.2	−60.2	−59.6

Conclusion: We have proposed a rear on-glass antenna with a mesh-grid structure. To obtain optimum parameters, we used a PGA in conjunction with a full-wave EM simulation tool to decrease VSWR and to increase the average vertical gain in the FM band. To verify our PGA results, we built and installed the optimised antenna on a commercial vehicle, and the antenna performances were measured in a semi-anechoic chamber. The measurement results of the optimised rear on-glass antenna showed a matching bandwidth (VSWR < 5.8) of about 25% in the FM radio band, a vertical gain of about −5.43 dBi along the bore-sight direction, and an average gain of about −3.29 dBi along the azimuth direction.

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References

1 Abou-Jaoude, R., and Walton, E.K.: 'Numerical modeling of on-glass conformal automobile antennas', *IEEE Trans. Antennas Propag.*, 1998, **46**, (6), pp. 845–852

2 Noh, Y., Kim, Y., and Ling, H.: 'Broadband on-glass antenna with mesh-grid structure for automobiles', *Electron. Lett.*, 2005, **41**, (21), pp. 1148–1149

3 Horn, J., Nafpliotis, N., and Goldberg, D.E.: 'A niched Pareto genetic algorithm for multiobjective optimization'. Proc. 1st IEEE Conf. Evolutionary Computation, 1994, Vol. 1, pp. 82–87

4 Chatterjee, A., Volakis, J.L., and Kent, W.J.: 'Scattering by a perfectly conducting and coated thin wire using a physical basis model', *IEEE Trans. Antennas Propag.*, 1992, **40**, (7), pp. 761–769