

Development of Laminated Windshield Glass Antenna for Digital Terrestrial TV

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ABSTRACT

A front laminated windshield glass antenna for on-board digital terrestrial TV reception was developed. In order to reduce the visual unpleasantness of conventional silver-printed antenna lines, the new antenna structure consists of a copper thin film antenna with a line width of 0.25 mm clasped inside laminated windshield glass. In addition, the amplifier is mounted directly to terminals on the glass surface using capacity coupling with the glass as the dielectrics. As a result, this front laminated windshield glass antenna obtained flat directivity over the front 180° range, and ease of maintenance has also been secured. In addition, the thermal stress when soldering the base plate of the amplifier to the glass surface was confirmed to be sufficiently less than the permissible stress of the glass.

1. Introduction

Conventional on-board analog TV antennas configure the diversity by forming multiple antennas inside the rear windshield glass. In this first development of a digital terrestrial TV system, the diversity is configured using both front and rear windshield glass antennas to realize better receiving performance as a moving object.

This is the first time the antenna has been mounted to the front windshield glass, so the development goals were to secure adequate receiving performance and address the following issues.

- (1) The antenna lines are to be located within the field of view of persons in the front seat, so there should be no visual unpleasantness.
- (2) In the conventional method for connecting an analog TV antenna and coaxial cable, the lead wire produces a large drop in receiving performance, so the structure should form the amplifier directly below the antenna.
- (3) A method for connecting the antenna lines clasped inside the windshield glass with the amplifier should be established, and reliability secured.

2. Structure

2.1. Analog TV Antenna Structure

Figure 1 shows the structure of a conventional windshield glass antenna for analog TV reception. The antenna is formed by printing silver on the glass surface,

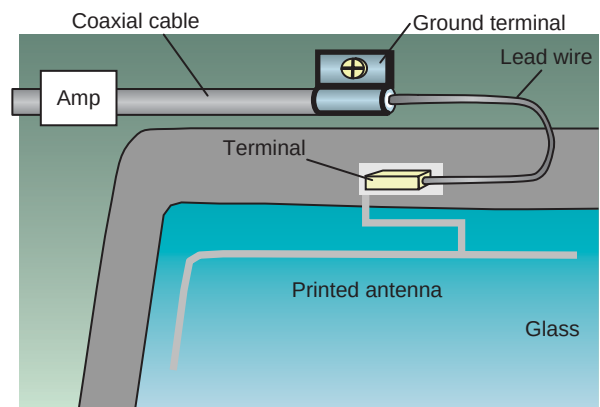


Fig. 1 Current analog TV antenna structure

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and has a structure that connects to a coaxial cable consisting of a lead wire and a ground terminal. Analog TV broadcast waves have a wavelength of approximately 42 to 280 cm in VHF and UHF band. When a 10 to 20 cm lead wire is connected to the antenna, the lead wire becomes part of the antenna and offsets the resonance frequency, creating the issue of unstable receiving performance. In addition, an amplifier is installed to compensate for signal loss along the coaxial cable.

2.2. Digital Terrestrial TV Antenna Structure

Digital terrestrial TV broadcasts have a wavelength of approximately 42 to 64 cm in UHF band. This is a short wavelength compared to the VHF band, so the resonance frequency offset due to the lead wire increases further, resulting in a drop in receiving performance. This issue was addressed by using a dipole type antenna that can form the input and ground terminals on the glass, and mounting the amplifier directly to the glass surface. This structure enabled the lead wire that had affected performance to be removed. Figure 2 shows a photograph of the antenna, and Fig. 3 shows the internal structure.

To reduce visual unpleasantness, the antenna element used copper thin film punched into the antenna shape, which reduced the line width to 0.25 mm compared to 0.7 mm for conventional silver-printed antenna lines. The structure clasps this antenna element inside laminated windshield glass, and fixes the amplifier on the inner glass surface. The antenna is laminated between the inner glass and the middle film of the laminated windshield glass during the manufacturing process, and the amplifier and antenna are connected by a non-contact structure that uses capacity coupling with the glass as the dielectrics.

A base plate for holding the amplifier is fixed to the inner glass surface by urethane adhesive, and the base plate and silver-printed terminal are connected by solder. The amplifier is secured to the base plate by screws, and a screw-lock structure is used to help prevent the screws from loosening and falling out due to vibration or other

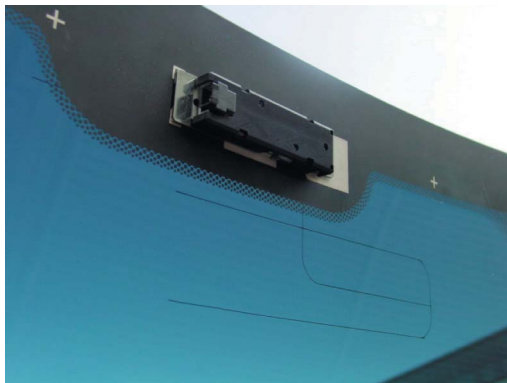


Fig. 2 Laminated windshield glass antenna and amp module

factors. This also enables replacement should the amplifier malfunction, in consideration of maintainability.

2.3. Antenna Structure and Principle

Figure 4 shows the copper thin film antenna structure and principle. This copper thin film antenna has a dipole terminal, and the element is bent in a “U” shape with a branch element and a loop element that create multiple resonance points and expand the bandwidth. A wide bandwidth of 300 MHz is realized by using an antenna element length of $3/4$ wavelength on the low-frequency side, and approximately $1/4$ wavelength on the high-frequency side.

2.4. Capacity Coupling Type Power Supply Terminal

One possible method of leading a terminal from the antenna clasped inside the windshield glass is to lead the copper thin film line that comprises the antenna from the

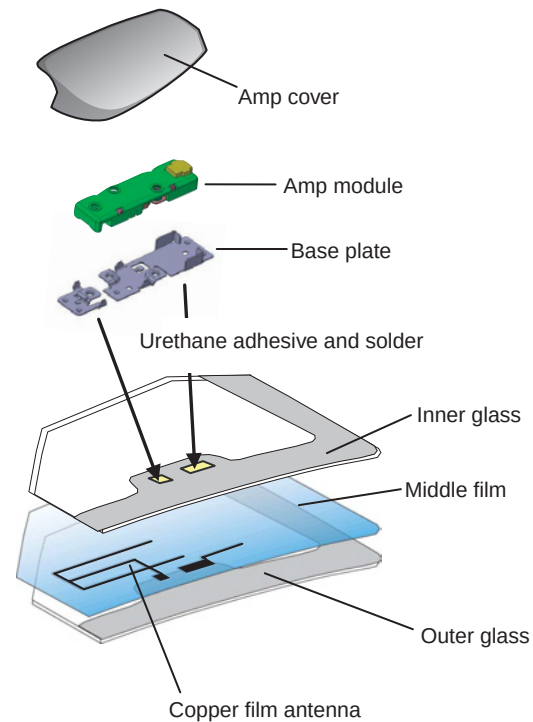


Fig. 3 Digital TV antenna structure

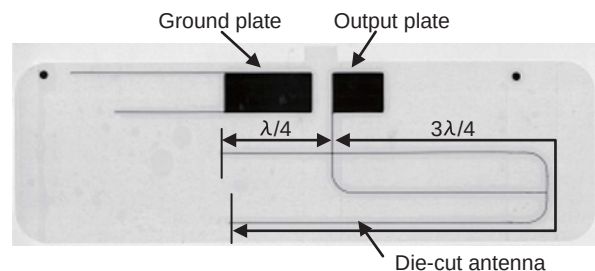


Fig. 4 Photograph of die-cut antenna

edge of the laminated windshield glass for connection. However, this method has the following issues:

- (1) A complex structure is needed to lead the antenna line from inside the laminated windshield glass, which not only adds a glass cutting process, but also raises concerns of disconnection.
- (2) The lead wire portion becomes part of the antenna and brings about a drop in performance due to interference with the vehicle body, electric disclosure, and the like.

These issues were addressed by printing the silver-printed terminal on the inner glass in a position directly opposite the antenna terminal to create a non-contact terminal structure that uses the capacity coupling method with the glass as the dielectrics. Figure 5 shows the relationship between the electrode area and electrostatic capacitance, and Fig. 6 shows the relationship between the electrode area and antenna loss, for glass with a dielectric constant of 7 and thickness of 2 mm. The electrode area was set at 500 mm², which provides stable characteristics at a UHF bandwidth of 470 MHz or more, and the electrostatic capacitance in this case is approximately 15 pF. This configuration does away with the need to lead a line from the copper thin film antenna to the terminal, and creates a simple power supply terminal with low loss.

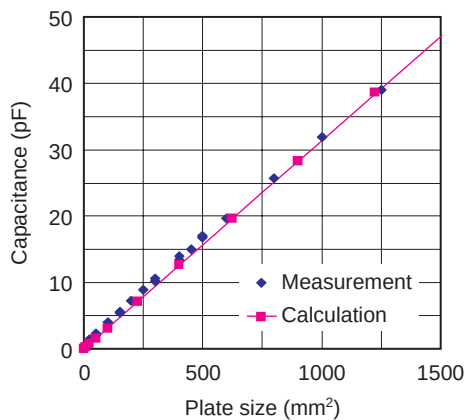


Fig. 5 Relationship of plate size and capacitance

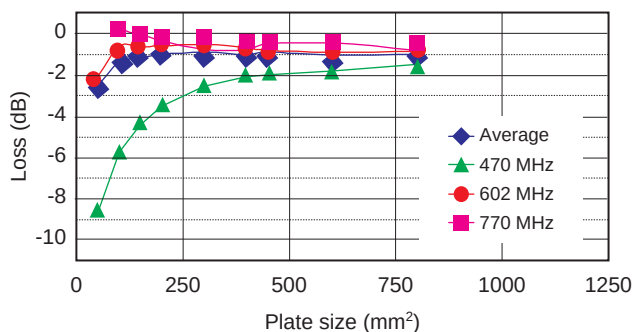


Fig. 6 Relationship of plate size and gain loss

3. Experiments and Results

3.1. Antenna Standalone Simulation

Standalone antenna design was performed by electromagnetic field simulation using the moment method. Figure 7 shows the return loss calculation results. By providing two resonance points at 515 MHz and 710 MHz, a return loss of -5 dB or less was obtained over the digital terrestrial TV band (470 to 770 MHz).

Figure 8 shows the directivity calculation results obtained by simulation. These results show that uniform directivity was obtained with no depression over the front 180° range.

Next, the electromagnetic field of the overall vehicle body with the antenna installed at the top of the front windshield glass was simulated. Figure 9 shows the

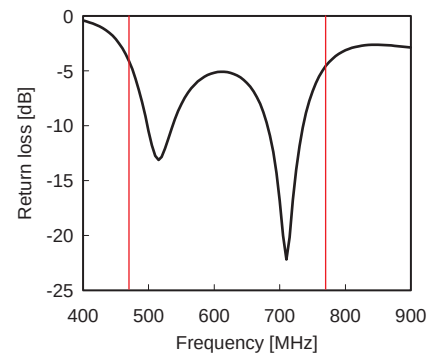


Fig. 7 Return loss

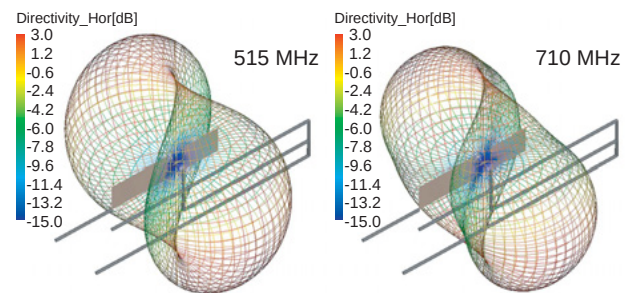


Fig. 8 Antenna directivity of horizontal polarization

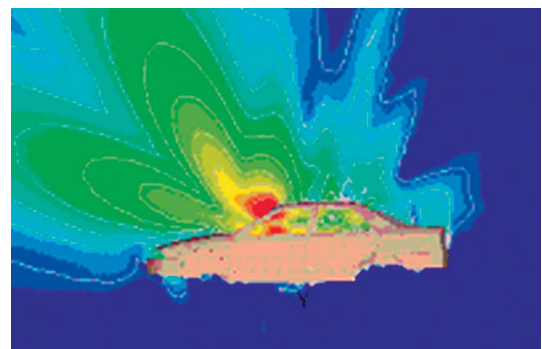


Fig. 9 Electric field at 575 MHz

electric field at 575 MHz. This shows that good radiation properties were obtained in the vehicle front direction.

3.2. On-vehicle Antenna Measurement Results

The developed antenna has diversity from the windshield glass antennas at both the front and back of the vehicle, and the front windshield glass antenna has a reception area of 180° in the vehicle front direction. Figure 10 shows directivity of the on-vehicle copper thin film antenna at 617 MHz. Uniform directivity with no depression could be obtained over the front 180° range. In addition, the measurement results closely matched the simulation.

Figure 11 shows the frequency - gain characteristics of the antenna. A fairly flat frequency response was obtained over the bandwidth from 470 to 770 MHz.

3.3. Reliability when Mounting the Amplifier on the Windshield Glass

The front windshield glass deicer terminal has conventionally been soldered using a terminal on the inner surface of the outer glass. This development is the first to use a method that fixes the connection terminal and the base plate to the terminal on the inner glass surface by soldering, so the thermal stress generated on the glass

surface at this time was simulated. Figure 12 shows the temperature and thermal stress when a heat spot 6 mm in diameter, which is the soldering standard, is heated for 5 s at 300°C , with an initial glass surface temperature of 10°C . The maximum generated thermal stress was confirmed to be 17 MPa, which is sufficiently less than the permissible stress of the glass of 30 MPa. In addition, Fig. 13 shows a simulation of how the glass temperature at the center point of the heat spot and the generated thermal stress change with the heating time. This shows that the glass temperature rises gradually and reaches 235°C after approximately 30 s, but the maximum thermal stress peaks around 5 s and then decreases thereafter. Actual soldering tests were also performed, confirming that there are also no soldering issues present.

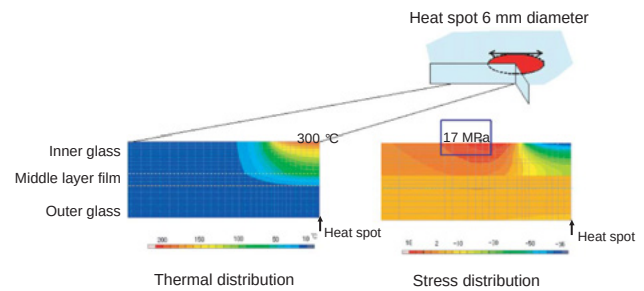


Fig. 12 Simulation of thermal stress in windshield glass

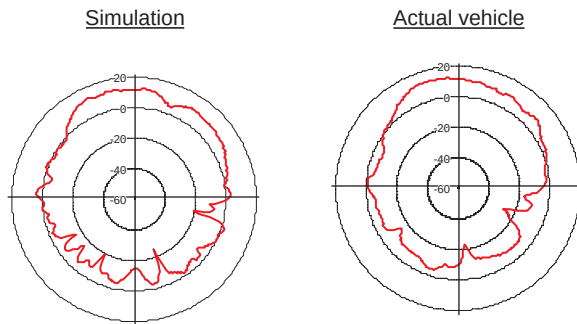


Fig. 10 Antenna gain directivity at 617 MHz

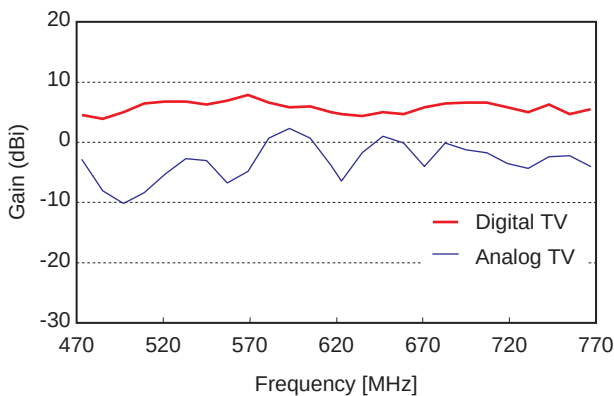


Fig. 11 Average antenna gain in front 180 deg direction

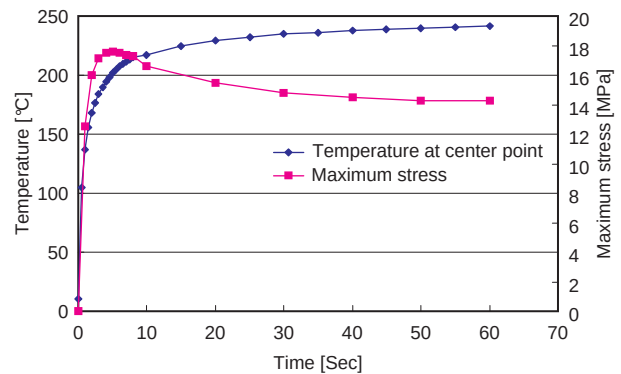


Fig. 13 Relationship of glass temperature and stress force

4. Conclusion

A front laminated windshield glass antenna for digital terrestrial TV reception was developed that provides good receiving performance and reliability.

- (1) A 300 MHz bandwidth was realized by using a $1/4 \lambda$ to $3/4 \lambda$ element.
- (2) Visual unpleasantness in the forward field of view was reduced by clasping a copper thin film antenna with a

- line width of 0.25 mm inside laminated windshield glass.
- (3) A non-contact terminal that uses the capacity coupling method with the glass as the dielectrics enabled the amplifier to be mounted directly below the antenna.
 - (4) The maximum thermal stress when soldering to the terminal on the inner glass surface was verified to be within the permissible range in both simulations and experiments.

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