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Design of 5G monopole antenna for vehicle window glass using FEKO simulator to enhance antenna characteristics

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Abstract **:** Design for an on-glass 5G monopole antenna for a vehicle window glass is done which consist of a monopole resonator, an inductive line and a coplanar waveguide (CPW), whichcan adjust the face so that the current ineach resonator is close to in-phase.Therefore, although the vehicle window glass has a high dielectric loss, the proposed monopole with an inductive line can obtain an antenna gain that is suitable for applying to vehicle 5G communication. To verify the antenna characteristics, the reflection coefficient and the radiation pattern are measured. The results demonstrate that the proposed on glass antenna is suitable forapplying a vehicle 5G communication**.**

Keywords: *Antennas, antenna arrays, glass products, glass antennas, 5G antennas, autonomous driving, feko software.*

I INTRODUCTION

Recently, the demand has been progressively increasing for a Vehicle to Everything (V2X) technology to improve the level of autonomous driving technology. A glass antenna technique that prints an antenna pattern on the vehiclewindow has several advantages. V2X typically encompasses several specific technologies such as Vehicle-to-Vehicle (V2V), Vehicle-to-Pedestrian (V2P), vehicle-to-infrastructure (V2I), and vehicle-to network (V2N), which can improve the safety and efficiency of autonomous driving. However, due to limited data throughput and latency issues,previous communication technologies are not suitable for V2X.

Notably, 5G communication systems that use a millimetre wave (mm Wave) have numerous advantages, such as low latency, high speed, and high capacity. Therefore, attempts to apply 5G communication techniques in autonomous vehicles havebeen increasing. To apply 5G techniques toan autonomous vehicle, a high-gain 5G array antenna must be mounted on a small area of the vehicle. To address concerns regarding the appearance and air resistance of the vehicle, a shark-fin is generally used on the roof of the automobile for various vehicle antennas. However, since a number of antennas (e.g., DMB, GPS, and LTE) are already built-in in the shark-fin housing, there is not enough space to insert an additional high-gain 5G array antenna without performance degradation from mutual coupling effect with adjacent antennas. To reduce the mutual coupling characteristics, various techniques such as the use of a cavity wall, a meta-surface, anda resonator have been introduced. The space is still not enough to insert theseisolators in the shark-fin housing.

In comparison, a glass antennatechnique that prints an antenna pattern on the vehicle window has several significant advantages. First, the glass antenna does not require additional mounting space, which can preserve the appearance of the vehicles. Second, printing the antenna on the window glass prevents physical and electrical interferences (blockage or mutual coupling) with other vehicle antennas. Finally, the glass antenna can be easily made within the manufacturing process of the

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vehicle window glass.

For these reasons, a glass antenna can be considered as a noteworthy candidate antenna type for applying in vehicle wireless communications, although thick glass windows with high dielectric loss characteristics does not help the performance of the 5G antenna at all. The previous studies on vehicle window glass antennas are limited in low frequency bands such as AM/FM, DMB, LTE, and 5G sub- 6 band.

Although some studies on glass antennas have been attempted at a high frequency in the mm Wave band, they were conducted on very thin glass, less than 0.5 mm. Similarly, printed 5G antennas of general types such as Vivaldi antennas, slot antennas, and dipole antennas do not consider glass substrates with high dielectric loss characteristics. In reality, the laminated glass for vehicle windshields with electrically very thick thickness has a high dielectric loss in the 5G mm Wave band. Therefore, in-depth research on a 5G antenna design for electrically thick window glass is required. Many studies have investigated the use of conventional antenna structures, i.e., patch antennas, dipole antennas, and dielectric resonator antennas in 5G vehicle antenna designs. In some cases, research has attempted to apply such conventional antennas to actual vehicles using additional structures; for example, the vehicle roof is re-designed and modified to construct a cavity structure for mounting a 5G inverted-F monopole antenna. Although these antennas have shown high antenna performances, the need to modify the vehicle structure or add new structures to the vehicle creates a disadvantage for their adoption as 5G wireless vehicle communication systems. To resolve these problems, a number of antenna designs that directly print the antennas onto the vehicle window glass have been reported, for example, mesh-gridstrip line patterns.

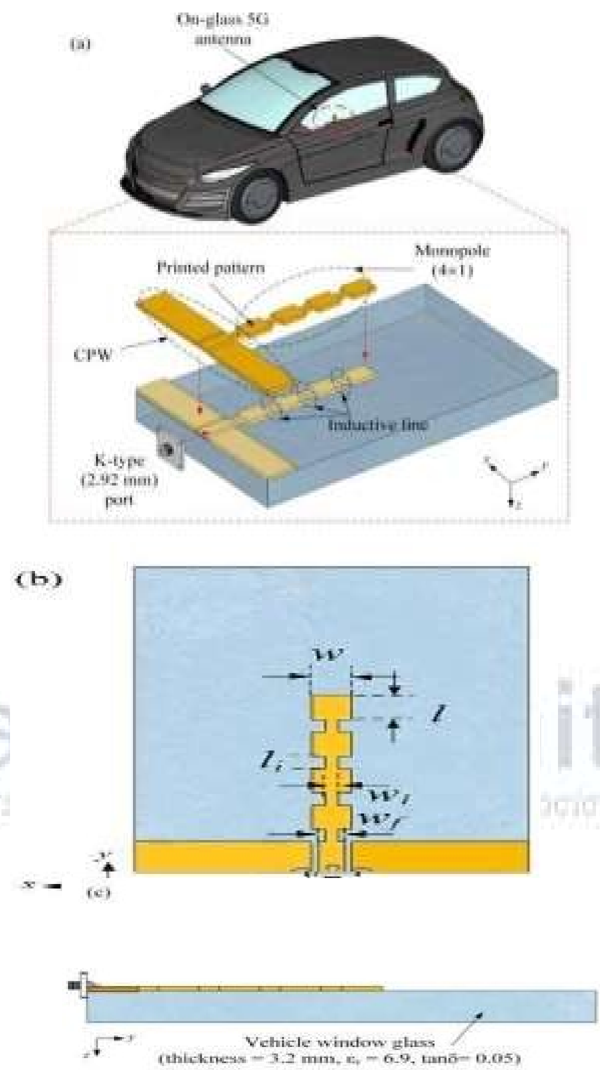

Fig 1 Geometry of the proposed antenna.
(a) Isometric view. (b) Bottom view. (c) Side view

Figure illustrates the geometry of the on-glass 5G monopole antenna for vehicle window glass. The antenna is attached to the side of the vehicle window glass, as shown in Figure 1.1(a). The window glass has a high dielectric loss characteristic (r = 6.95, tan δ = 0.05) with an electrically thick thickness of 3.2 mm. Therefore, it is difficult to obtain a suitable antenna gain with a 1/4 wavelength conventional printed antenna.

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To improve the antenna gain whilesimultaneously considering the high loss characteristics of the vehicle window glass, the proposed antenna consists of 4 × 1 monopole resonators with width and length of w and l. The monopole resonators are connected through the inductive line with width and length of wi and li, respectively.

The inductive line can adjust the phase of each resonator, making the surface current in each resonator close to the in- phase.

The total radiation pattern of the 4 × 1 monopole resonators with the inductive lines can be expressed as follows:

$$X_{4\times1} = \sum_{n=1}^{N} (\theta) ejkd.\sin\theta.\emptyset^{opt}$$

Where, F_n is the radiation pattern of the n^t single resonator (n = 1, 2, 3, 4), k is the wave number, and d is the array spacing. In addition, $\emptyset_{opt}$ is the phase delayby the optimized inductive line that can makes the surface current in each resonatorclose to the in-phase. In an ideal situation, the 4 × 1 monopole resonators with perfectin-phase state for each resonator have ahigher gain of 6 dB than a single monopole resonator. To obtain a higher antenna gain, the 4 × 1 monopole can repeatedly arrange in the x-axis direction. For example, the radiation pattern of the 4 × 4 monopole array expresses as the summation of

$X_{4\times1n}$ as follows:

$$X_{4\times4} = \sum_{n=1}^{N} X_{4\times1n}(\theta)kd.\sin\theta$$

The 4 × 4 monopole array gain is higher of 6 dB than the 4 × 1 monopole array in an ideal situation. Therefore, although a vehicle window has a high dielectric loss characteristic, the proposed antenna can obtain the antenna gain suitable for applying 5G communications.

The proposed antenna is linearly polarized, which is widely employed in vehicle 5G communications because it has some advantages such as ease of an antenna design and fabrication. An input signal is fed to the proposed antenna through the CPW line with a width of wf and a gap of g. Since the monopole resonators and the CPW use only a single layer of vehiclewindow, it can be fabricated through a simple manufacturing process. The detaileddesign parameters for maximizing the bore-sight gain are obtained with the FEKO electromagnetic (EM) simulator. Like all antennas a monopole antenna is used to transmit and receive radio waves.

A monopole antenna consists of a conductor perpendicular to a conducting plane surface or ground plane. In essence it's a half dipole antenna where one half of the dipole is constructed of a conducting metal and theother half is formed by a plane surface.

Since a monopole antenna requires a surface for functioning it's not as commonly used (for outdoor/external) antennas as compared to other types of antennas. In many cases though the earth isused as a ground plane. As well as thesurface of car or an airplane. In these casesmonopole design is quite compact and inexpensive. On the other hand monopole ismost common type of antenna in chips because the chip surface forms a natural physical conductor for monopole to work.

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II METHODOLOGY

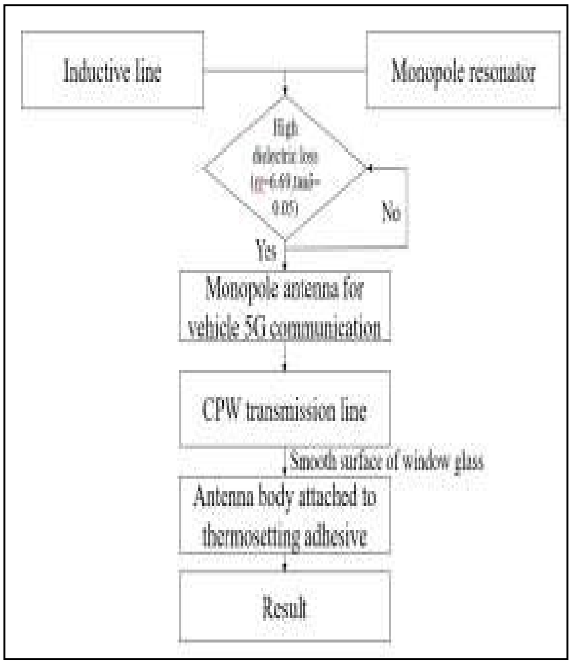

Fig 2 Flow diagram of proposed systemfor vehicle window glass

A design for an on-glass 5G monopole antenna for vehicle window glass consists of a monopole resonator, an inductive line, and a co-planar waveguide (CPW). The inductive line connecting the monopole resonators can adjust the phase so the current in each resonator is close to the in-phase.

Therefore, although the vehicle window glass has a high dielectric loss, theproposed monopole with an inductive line can obtain an antenna gain that is suitable for applying to vehicle 5G communications. The monopole antenna is fed through a CPW transmission line. Herein, the monopole array and the CPW use only a single layer of vehicle window; therefore, it can be fabricated through asimple manufacturing process.

Taking the smooth surface of the vehicle window glass into consideration, the conducting antenna body is attachedusing a thermosetting adhesive. To verify the antenna characteristics, the reflection coefficients and the radiation patterns are measured. The results demonstrate that the proposed on-glass antenna is suitable for applying in vehicle 5G communications.

Inductive line: Imaginary lines within a body marking the direction taken within it by magnetic induction. These are not necessarily parallel to lines of force, but may, in bodies of uniform agglomeration, or in crystalline bodies, take various directions. The inductive line can adjust the phase of each resonator, making the surfacecurrent in each resonator close to the in- phase.

High dielectric loss: Dielectric loss, loss of energy that goes into heating a dielectric material in a varying electric field. The window glass hasa high dielectric loss characteristic (r =6.95, tan δ = 0.05) with an electrically thick thickness of 3.2 mm.

Monopole antenna for 5G communication:A monopole antenna is a class of radio antenna consisting of a straight rod-shapedconductor, often mounted perpendicularly over some type of conductive.

The proposed antenna can obtainthe antenna gain suitable for applying 5G communications. The proposed antenna is linearly polarized, which is widely employed in vehicle 5G communications because it has some advantages such as ease of an antenna design and fabrication.

CPW Transmission line: The Coplanar Waveguide is a planar transmission line. It is widely used for microwave Integrated Circuit design. Cpw gives the smooth surface for vehicle window glass. An input signal is fed to the proposed antenna through the CPW line with a width of wf and a gap of g.

Since the monopole resonators and the CPW use only a single layer of vehicle window, it can be fabricated through a simple manufacturing process.

Antenna body attached to thermosetting adhesive: An input signal is fed to the proposed antenna through the CPW line with a width of wf and a gap of g. Since the monopole resonators and the CPW use only a single layer of vehicle window, it can be fabricated through a simple manufacturing process.

Result: Finally by using this, we found, theantenna characteristics, the reflection coefficients and the radiation patterns are measured using FEKO software. The results demonstrate that the proposed on- glass antenna is suitable for applying invehicle 5G communications.

III IMPLEMENTATION

The proposed antenna is linearly polarized, which is widely employed in vehicle 5G communications because it has some advantages such as ease of an antenna design and fabrication. An input signal is fed to the proposed antenna through the CPW line with a width of wf and a gap of g. The monopole resonators and the CPW use only a single layer of vehicle window. The detailed design parameters for maximizing the bore-sight gain are obtained with the FEKO electromagnetic (EM) simulator.

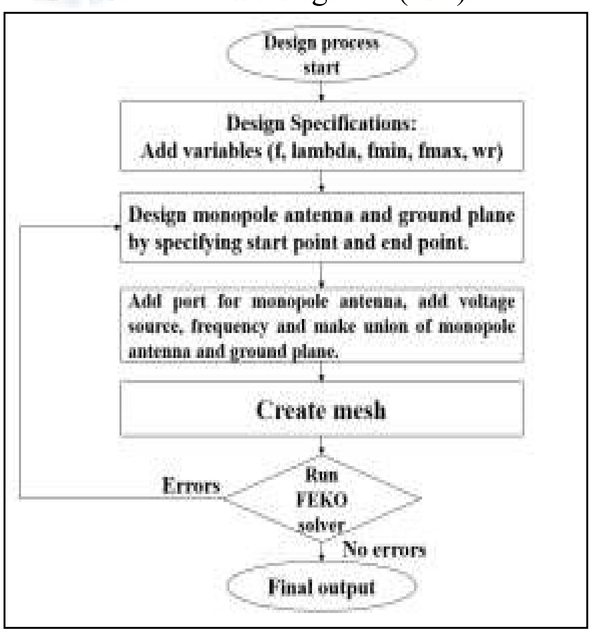

Fig 3. Flow Diagram to Design Monopoleantenna

Table 4.1. Optimized values of proposed antenna

Parameters	Value
w_r	$1.5e^{-3}$ m
f	$2.4e^{9}$ Hz
$fmin$	$2e^{9}$ Hz
$fmax$	$3e^{9}$ Hz
ε_0	$8.85 * e^{-12}$
μ_0	$Pi * 4e^{7}$
C_0	$3 * 10^{8}$

IV RESULT ANALYSIS

Output of 4X1 Monopole Antenna UsingEllipse Ground Plane

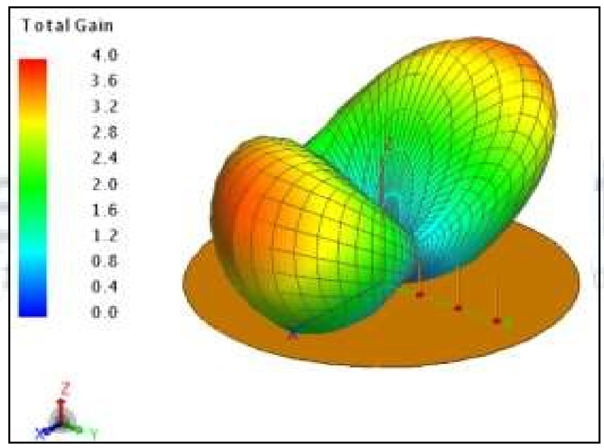

Fig 4 3D view of 4X1 monopole antennausing ellipse ground plane

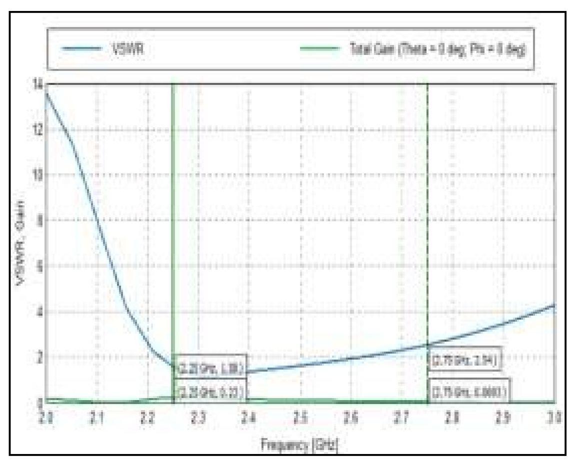

Fig5. Cartesian graph of 4X1 monopoleantenna using ellipse ground plane

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Table 4.2. Cartesian form of 4 X 1 MonopoleAntenna with Ellipse Ground Plane

Frequency (GHz)	Gain (dBi)	Impedance(KΩ)	Reflection Co-efficient	VSWR
2.0	0.2	84.9	0.861	13.5
2.1	0.038	54.7	0.773	8.04
2.2	0.161	30.9	0.416	2.61
2.3	0.229	47.8	0.855	1.20
2.4	0.171	62.1	0.152	1.35
2.5	0.126	71.0	0.237	1.63
2.6	0.097	79.0	0.316	1.93
2.7	0.077	87.6	0.395	2.31
2.8	0.061	98.0	0.475	2.81
2.9	0.048	111	0.551	3.45
3.0	0.037	128	0.621	4.28

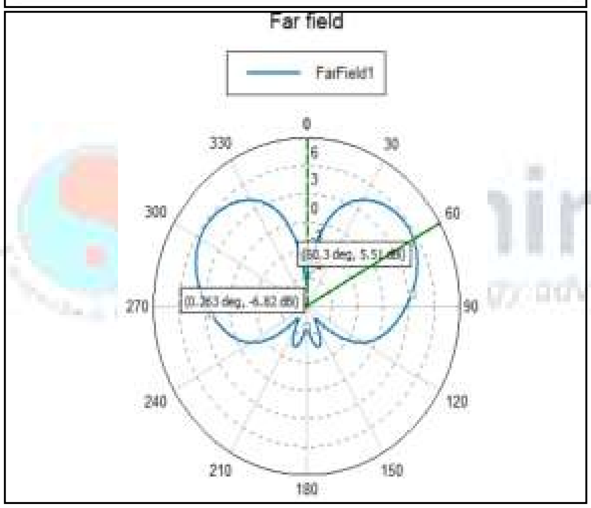


Fig 6. Polar Graph of 4X1 monopoleantenna using ellipse ground plane

Table 4.3. Polar form of 4 X 1 Monopole Antennawith Ellipse Ground Plane

θ in degree	Gain (dBi)
30	4.28
60	5.53
90	2.76
120	-1.24
150	-6.33
180	-6.85

Output of 4*1 Monopole Antenna Using Rectangular Ground Plane

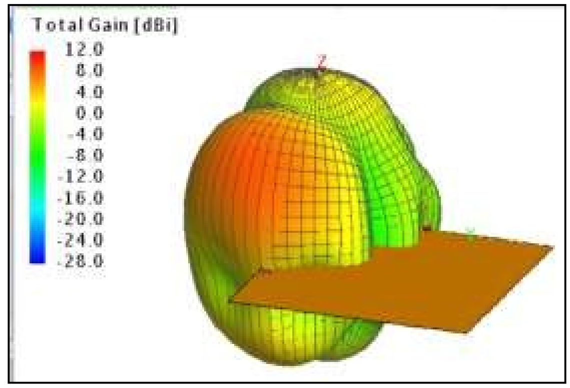
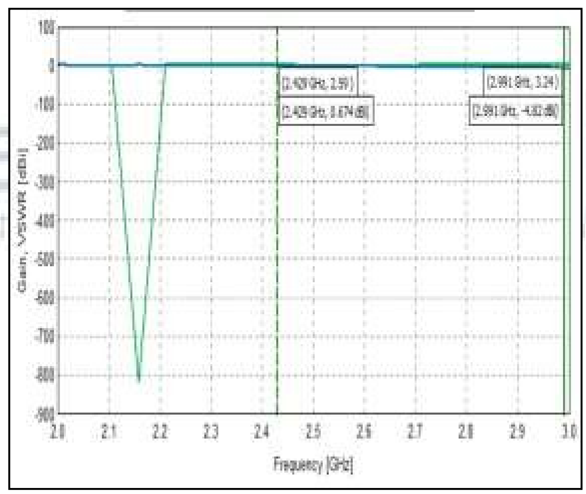


Fig 7. 3D view of 4X1 monopole antennausing rectangular ground plane

Fig 8. Cartesian graph of 4X1 monopoleantenna using rectangular ground plane



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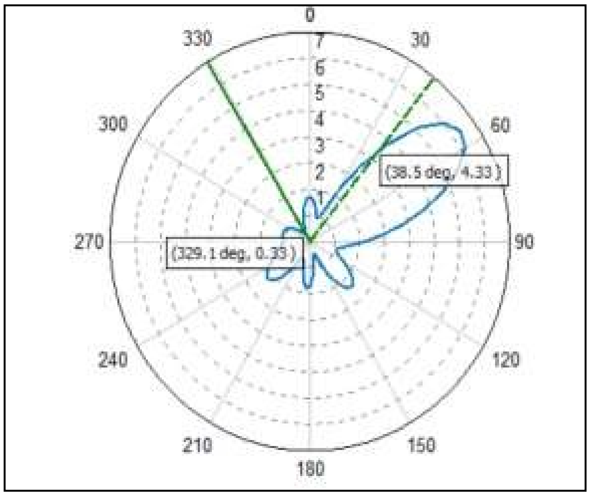

Fig 9. Polar Graph of 4X1 monopoleantenna using rectangular ground plane

Table 4.4. Cartesian form of 4 X 1 MonopoleAntenna with Rectangular Ground Plane

Frequency (GHz)	Gain (dBi)	Impedance (KΩ)	Reflection Co-efficient	VSWR
2.0	2.37	0.087	0.407	2.35
2.1	1.85	0.082	0.25	1.68
2.2	2.01	0.037	0.731	-140
2.3	1.45	0.145	0.572	3.65
2.4	0.86	0.118	0.473	2.81
2.5	0.93	0.102	0.369	2.19
2.6	-0.95	0.1	0.334	2.01
2.7	-2.24	0.112	0.40	2.32
2.8	-3.4	0.129	0.473	2.79
2.9	-4.4	0.141	0.511	3.09
3.0	-4.8	0.144	0.53	3.25

Table 4.5. Polar form of 4 X 1 Monopole Antennawith Rectangular Ground Plane

θ in degree	Gain (dBi)
30	3.40
60	8.56
90	3.57
120	2.06
150	1.67
180	2.31

V THEORITICAL CALCULATIONS

$f = 2.4GHz$

$Impedence = 60.5\Omega$

$Voltage = 1V$ 1

$Current = \frac{\quad}{60} = 0.016A$

$Z = 60.5 + j13.5$

$Magnitude = \sqrt{(60.5)2 + (13.5)2} = 61.9$

$Phase = \tanh\left(\frac{Im(Z)}{Re(Z)}\right) = 12.21°$

$Band\ Width = 100 \times fh - fl/fc$

$Band\ Width = 100 \times \frac{3-2}{2.5} = 40$

$Reflection\ Coefficient(\rho) = 0.15$

$VSWR = \frac{1 + |\rho|}{1 - |\rho|} = 1.35$

$G = KD$

$K = 1, D = 5.51dBi\ at\ 60°$

$Gain = 1 \times 5.51 = 5.51dBi$

VI CONCLUSION

The design of the on-glass 5G monopole antenna for the vehicle window glass. The proposed antenna consisted of the monopole resonator, the inductive line, and the CPW. The inductive line connecting the monopole resonators, could adjust the phase so that the current in each resonator was close to in phase. Therefore, although the vehicle window glass had the high dielectric loss, the proposed monopole with the inductive line could obtain the antenna gain suitable for apply to vehicle 5g communication. To verify the antenna characteristics, the reflection coefficients and the radiation patterns. The measured reflection coefficient remained at less than −10 dB in the 5G mm Wave band. On the other hand, the proposed antenna had the small size but not optically transparent. To enhance the visibility, transparent conductors or mesh structures can be applied to 5G glass antenna in future work.

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