# Miniaturized Shark-Fin Rooftop Antenna with Integrated DSRC Communication Module for Connected Vehicles

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## Abstract

This work presents a compact shark-fin rooftop antenna combined with the dedicated short-range communication (DSRC) module for automotive applications. The proposed antenna is constructed by two short tapered monopoles and one cylindrical cavity resonator to achieve small size, light weight and low profile characteristics. Good impedance matching and omni-directional radiating properties of the proposed antenna are verified in the DSRC frequency band. The measured peak gain and efficiency of the antenna mounted on a large metallic plane are 4.5 dBi and 50% at 5.875 GHz. The proposed antenna is connected to the DSRC communication module consisting of transceiver, power amplifier, low-noise amplifier, and single-pole double-throw switch. The holistic DSRC communication system is embedded into the shark-fin radome and mounted on the rooftop of a vehicle to experimentally validate the usefulness of the connected vehicle application.

## 1. Introduction

With the rapid development of the Intelligent Transportation System (ITS), dedicated short-range communication (DSRC) has been widely considered as the leading technology for the communication-based automotive applications in recent years [1]. The importance of this technology, also known as wireless access in vehicular environment (WAVE), was recognized by the United States Department of Transportation (DOT) for improving vehicle safety and traffic efficiency. Hence, the Federal Communications Commission (FCC) in the USA has allocated 75 MHz of licensed spectrum at 5.9 GHz as the DSRC band for ITS services. In Europe, the commission of the European Communities has specified harmonized use of radio spectrum in the 5875-5905 MHz frequency band for safety related applications of ITS. In Japan, the deployment of Electronic Toll Collection (ETC) system has been standardized at the 5.8 GHz spectrum. Many extensive field applications have shown the practicality of such technologies. Major automotive original equipment manufacturers, wireless device developers, research institutions, public agencies, and private enterprises are conducting research on various topics pertaining to Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications. V2V applications include the post-crash warning, vehicle-based road condition warning, and blind spot warning. The highway/rail

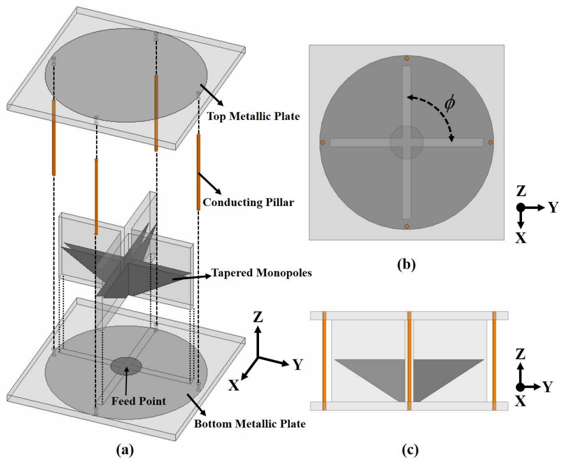


Fig. 1. Geometry of the proposed antenna. (a) Three-dimensional view, (b) top view, and (c) side view.

collision warning, curve speed warning, left turn assistant, and traffic signal violation warning are for V2I applications [2].

DSRC antenna is the key element that can significantly impact the performance and size of transponder modules used in V2V and V2I communications [3]. One of the antenna design challenges for DSRC system is to generate the omni-directional radiation pattern in the azimuth plane without compromising on gain [4]. The available DSRC system indicates that an antenna and a communication module were successfully integrated into an existing car rooftop with a shark-fin radome [5]. Generally, the omni-directional radiation pattern in the azimuth plane is critical in DSRC antenna design for automotive applications. Recently, the DSRC antenna and communication module deployed in the current vehicular models are integrated in a shark-fin radome that is mounted on the vehicle rooftop [6]. Owing to design considerations, the volume within the housing is limited making it challenging to integrate the antenna with the communication modules [7].

In this study, a novel DSRC antenna with full functionality is realized and integrated with a DSRC communication module within a shark-fin radome on the vehicle rooftop and the signal transmission of the holistic DSRC system are measured. The proposed antenna constructed by two tapered monopoles with one cylindrical cavity resonator is investigated based on the circuit and radiation characteristics. Additionally, this monopole-type antenna with a cavity resonator reduces the induced currents on the environment and therefore the

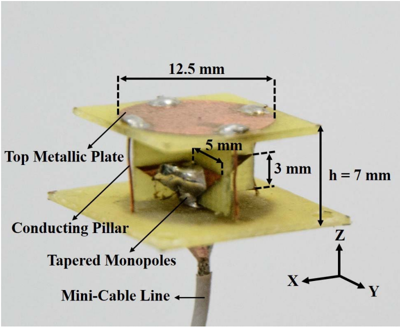

Fig. 2. Photograph of the fabricated antenna in the PCB technology.

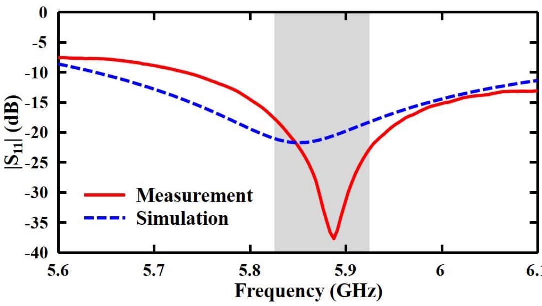

Fig. 3. Simulated and measured reflection coefficient $|S_{11}|$ of the proposed antenna.

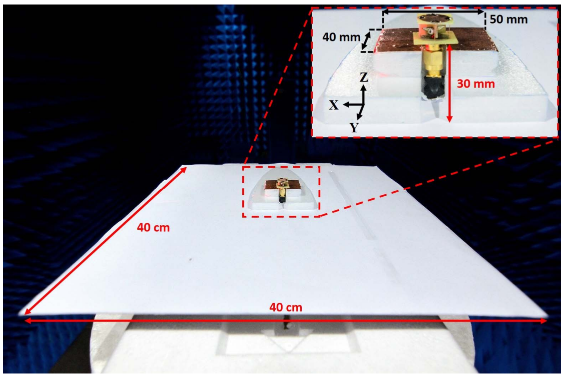

Fig. 4. Photograph of the proposed antenna located on the large metallic plate (40 cm x 40 cm).

antenna performance with omni-directional radiation pattern in the azimuth plane would not be deteriorated by the shark-fin housing. Finally, to further explore the transmitting and receiving characteristics of the signal for connected vehicle applications, this antenna is connected to a DSRC communication module and mounted on the rooftop of a car to measure the received power around the car with different azimuth and elevation angles.

## 2. Antenna Design

To achieve the antenna with low profile and light weight characteristics, a novel antenna structure implemented by one cylindrical cavity resonator and two short monopoles is presented, as shown in Fig. 1. The proposed antenna is realized by two tapered monopoles with an integrated cylindrical cavity resonator, where the cylindrical cavity resonator is constructed by a circular

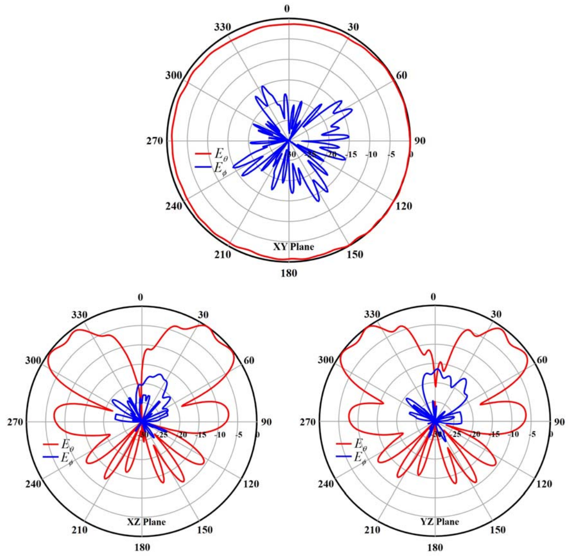

Fig. 5. Measured two-dimensional radiation patterns of the proposed antenna located on the large metallic plate (40 cm x 40 cm).

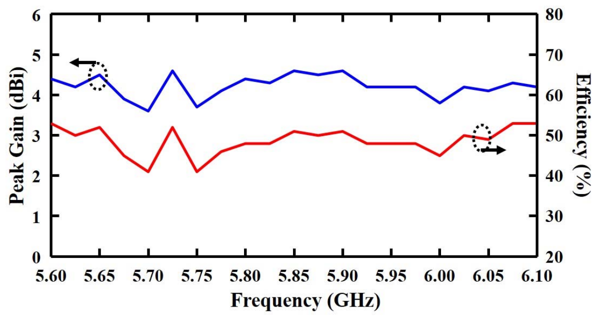

Fig. 6. Measured peak gain and efficiency of the proposed antenna located on a large metallic plate (40 cm x 40 cm).

metallic lid connected to the antenna ground via four pillars. The two short tapered monopoles are combined as the excitation to stimulate the fundamental mode of the proposed cylindrical cavity resonator. The short tapered monopoles within a cylindrical cavity resonator are implemented by using the PCB technology and connected to a mini-cable connector, as shown in Fig. 2. The circuit and radiation performances are measured by using Keysight NS5230A vector network analyzer and NSI near-field system (NSI 2000). Fig. 3 shows a comparison of the simulated and measured reflection coefficients. The measured reflection coefficient is smaller than -10 dB from 5.825 to 5.925 GHz.

To investigate the effect of the vehicle rooftop, the 40 cm x 40 cm metallic plate is placed beneath the proposed antenna as the vehicle rooftop for the radiation pattern measurement, as shown in Fig. 4. The distance between the proposed antenna and the large metallic plate is 30 mm. Fig. 5 shows the measurement of the far-field radiation pattern with a large metallic plate as the vehicle rooftop. Results show that the omni-directional radiation pattern and sidelobes are observed in the horizontal plane by using a large metallic plate. The measured antenna peak gain and efficiency are 4.5 dBi and 50% at 5.875 GHz, as shown in Fig. 6.

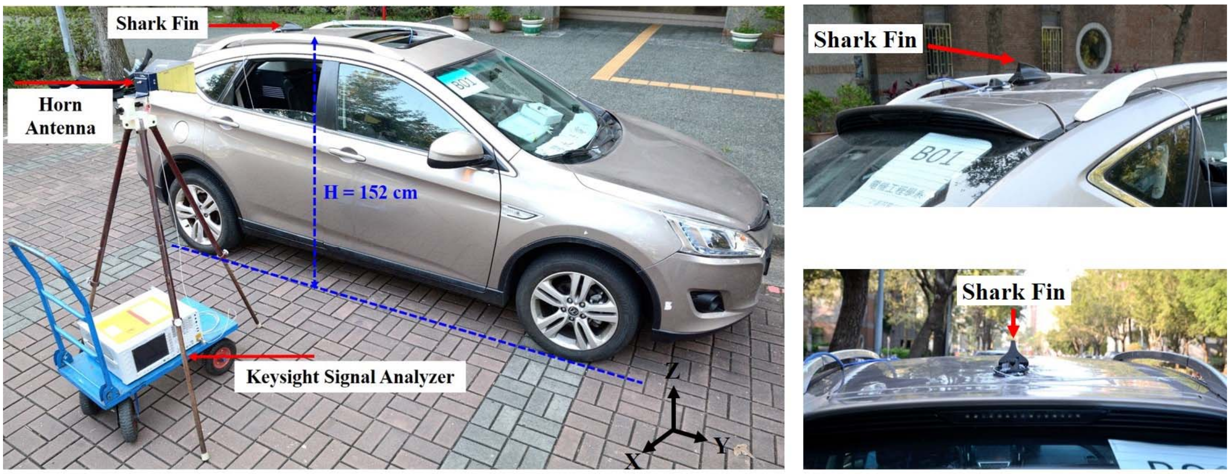


Fig. 7. Experimental setup of the the proposed DSRC system embedded into the shark-fin radome and installed on a vehicle rooftop.

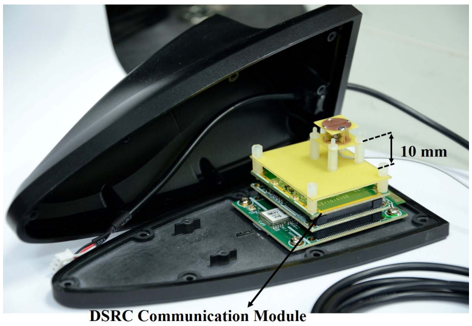


Fig. 8. Photograph of the holistic DSRC system embedded into a shark-fin radome.

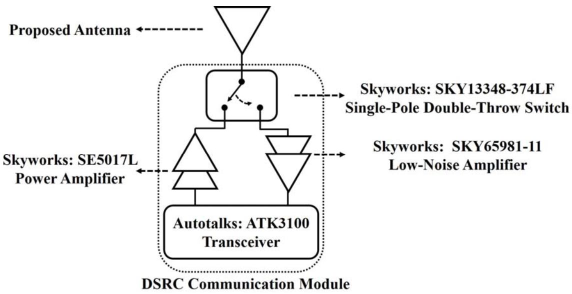


Fig. 9. Function block of the holistic DSRC system.

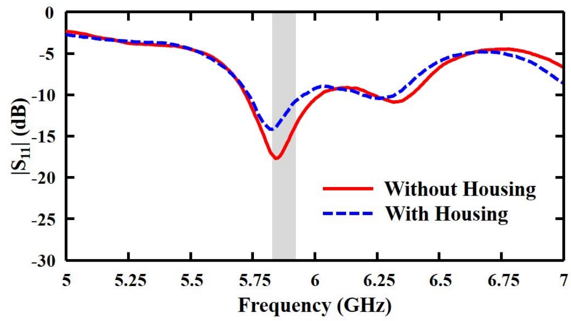


Fig. 10. Measured reflection coefficient $|S_{11}|$ of the proposed antenna with and without shark-fin radome.

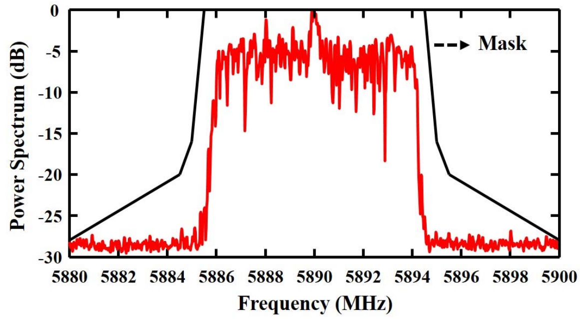


Fig. 11. Measured received power spectrum from the transmitted DSRC sytem in the shark-fin rooftop radome. (Black Line : Spectrum Mask for IEEE 802.11p)

## 3. Application

The proposed antenna is low profile (h = 0.14 $\lambda_0$ at the operating frequency of 5.9 GHz) and compact in size, which would facilitate easier installation on the vehicle rooftop. Thus, to demonstrate the usefulness of proposed antenna in the application of V2V and V2I communications, the proposed antenna and the DSRC communication module are embedded into the shark-fin radome and installed on a vehicle rooftop, as shown in Fig. 7. To validate the practical application of the proposed antenna, this antenna is connected to the DSRC communication module and embedded into a shark-fin radome, as shown in Fig. 8. Fig. 9 depicts the functional block of the DSRC communication module consisting of Autotalks ATK3100 V2X RF transceiver [8], Skyworks SE5017L power amplifier, Skyworks SKY65981-11 low-noise amplifier, and Skyworks SKY13348-374LF single-pole double-throw switch.

Fig. 10 shows that the measured reflection coefficient of the antenna possesses a good impedance matching at the DSRC operating band with and without the shark-fin radome. The DSRC signal is transmitted by Autotalks ATK3100 and Skyworks SE5017L via the proposed antenna in the shark-fin radome. The received signal is analyzed by DRH-0118 ultra-wideband horn antenna and Keysight N9020A MXA signal analyzer. Fig.11 shows the received power spectrum when the output power of the power amplifier fed to the antenna is 18 dBm.

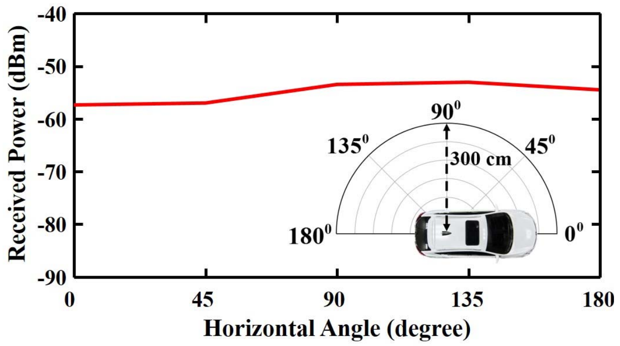


Fig. 12. Measured received power with various horizontal angles at H= 152 cm.

To examine the proposed shark-fin rooftop antenna in the V2V and V2I applications, the receiving terminal is moved surrounding the vehicle to measure the DSRC signal transmitted from the proposed antenna in the shark-fin radome. The receiving horn antenna is located on the various horizontal angles of $0^0$, $45^0$, $90^0$, $135^0$, and $180^0$ at the vertical level of H=152 cm, as shown in Fig. 12. This demonstrates that the received signal strength of proposed antenna mounted on the vehicle rooftop with streamlined shape is approximately omni-directional at the horizontal plane of vertical level H= 152 cm, even though the rooftop of the vehicle is curved and not totally flat. Hence, the usefulness of the proposed antenna is validated and the holistic DSRC system is suitable for V2V and V2I communications.

## 4. Conclusion

This work presents a shark-fin rooftop antenna integrated with the DSRC communication module for V2V and V2I applications. The large metallic plate as the vehicle rooftop, the shake-fin radome, and the DSRC communication module are employed to examine the proposed antenna to achieve the low profile, small size, light weight, and low cost characteristics. The measured antenna peak gain and efficiency are 4.5 dBi and 50 % at 5.875 GHz when the large metallic plate as the vehicle rooftop are located beneath the proposed antenna. To validate the usefulness of the practical application of the proposed antenna, the shark-fin rooftop antenna integrated with the DSRC communication module is installed on a vehicle rooftop as the transmitting system and the DSRC signal is received by a spectrum analyzer. Results demonstrate that the proposed antenna mounted on the vehicle rooftop can transmit DSRC signal successfully and the omni-directional received signal is observed at the azimuth plane. The presented antenna architecture with tunable frequency characteristic can be further applied to the integrated multi-band wireless communication systems for multi-standard V2V and V2I applications.

## 5. References

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