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Bandwidth Enhancement of a Monopolar Patch Antenna with V-shaped Slot for Car-to-Car and WLAN Communications

Hang Wong, *Senior Member*, *IEEE*, Kwok Kan So, *Senior Member*, *IEEE*, and Xia Gao

***Abstract*—A monopolar patch antenna with a V-shaped slot for Car-to-Car (C2C) and WLAN communications is presented in this paper. To widen the impedance bandwidth of the antenna, techniques of adding shorting pin and a V-shaped slot are applied to an equilateral triangular patch. By properly placing the shorting pins on an equilateral triangular patch, two operating modes, TM_{10} and TM_{20}, are obtained. The presence of the V-shaped slot can generate an additional TM_{11} mode. These three resonances found in the operating frequency bandwidth resulted in a wideband characteristic. The proposed antenna can operate from 4.82 to 6.67 GHz for the reflection coefficient ≤ -10 dB with the gain of around 5.0 dBi. In addition, an omnidirectional radiation pattern is yielded by a coaxial centred-fed probe excitation. The antenna has a thickness of $0.09\lambda_g$ (at the centre frequency of 5.5 GHz), which is easily hidden on the roof of a vehicle for C2C communication. This proposed design can also be used as indoor base station antennas for WLAN communication.**

***Index Terms*—V-shaped slot, Car-to-Car, WLAN, shorting pins, triangular patch, omnidirectional radiation pattern.**

I. Introduction

WIRELESS services are popularly used in our daily life. Mobiles bring convenience to people-to-people communications. Global Positioning System (GPS) assists us in reaching designated destinations. WiFi allows us fast-speed internet access. After several decades of wireless system developments, people now focus on the Car-to-Car (C2C) communication which can be integrated into telemetric platform to provide driver with real-time information so as to avoid traffic accidents. In July 2010, IEEE amended the 802.11 standard with 802.11p in vehicle environments and dedicated short range communications (DSRC) [1] which include C2C and Car-to-Infrastructure (C2I) communications among other potential applications [2]. In Europe and the United States, the frequency bands of the C2C communication allocate from 5.85 to 5.925 GHz [3]–[11]. On the other hand, wireless local area network (WLAN) access in transportations became popular. Users can enjoy their WLAN online services on trains, buses, ships and even private vehicles. One of the operating frequency bands of WLAN is 5.15 to 5.752 GHz [12]–[14]. Forecast of new vehicles may include the C2C system for safe driving control and WLAN system for internet access anytime and anywhere. These enforceable requirements post challenges to antenna designs in vehicles. Particularly, it is important to devote antenna technologies with low-profile structure and wideband characteristics to C2C and WLAN applications.

Lots of work has suggested low-profile antenna arrays [3]–[5] for the C2C applications. These examples [3]–[5] are practical and easy to implement but their operating bandwidths are narrow. It is preferred to use wideband antennas [15]–[17] for vehicular communications. The wideband antennas [15]–[17] can operate at a designated frequency regardless of environmental factors, e.g. temperature change. In addition, dual-band or multi-band antennas [18]–[19] are frequently used for the vehicular communications. The antenna with multiple operating bands can have a compact form factor that is easy to integrate with other components and systems in a vehicle. Recently, wireless access in vehicular environments (WAVE) referring to the standard of IEEE 802.11p is proposed. A number of low-profile antennas operating at 2.4 GHz and 5.8 GHz [8]–[11], [20] have been demonstrated; nonetheless, their operating bandwidths are narrow and the fabrication costs may be high.

In this paper, we propose a low profile and wideband antenna for both applications of C2C and WLAN communications. The proposed antenna technology uses shorting pins and a V-shaped slot to excite three resonant modes at a triangular patch antenna. This antenna has two sets of shorting pins connected from the triangular patch to the ground plane. The antenna has a wider impedance bandwidth than that of the antennas without the shorting pins [21]. With this proposed design, the shorting pins are effective to adjust the resistance and the reactance of the antenna for both TM_{10} and TM_{20} modes while the V-shaped slot are used to generate the TM_{11} mode of the patch. As a result, the antenna can obtain TM_{10}, TM_{20}, and TM_{11} modes across the operating bandwidth with a good impedance matching. In addition, the antenna is centred-fed by a coaxial probe such that an omnidirectional radiation pattern can be achieved. The antenna has an impedance bandwidth of 32.20% (Reflection coefficient ≤ -10 dB) from 4.82 to 6.67

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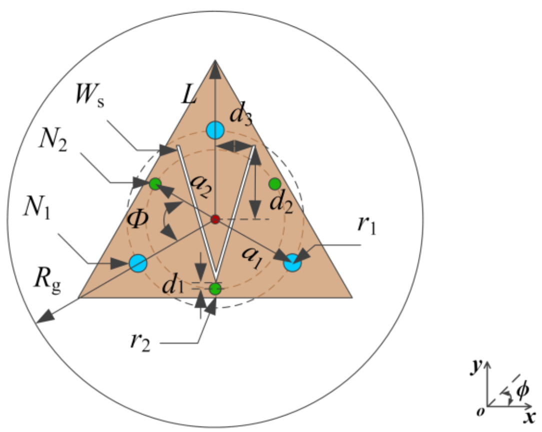
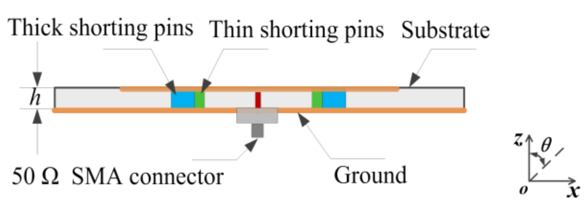
GHz, and a maximum gain of 6.50 dBi. The proposed antenna mounted on the car roof will be studied and discussed.

II. Antenna Design

Fig. 1 shows the geometry of proposed antenna. The antenna is composed of an equilateral triangular patch with a V-shaped slot and six shorting pins. It is known that triangular patch antenna can provide different modes and can enhance bandwidths comparing with a circular patch [22]. To further increase the bandwidth, we introduce two sets of shorting pins to the triangular patch so that the TM_{10} and TM_{20} modes of the patch can be adjusted to obtain a good impedance matching. The first set of shorting pins are placed in a circular arrangement and located at the position defined by a_1 as shown in Fig. 1(a). The first set of shorting pins has radius r_1 = 1.25 mm. Then, the second set of shorting pins is also arranged in the circular form and located at the position defined by a_2. This set of shorting pins has radius r_2 = 0.25 mm which is used for adjusting the impedance of the TM_{10} mode on the triangular patch. The proposed technique of non-uniform (or bi-radii) shorting pins in dual-circular arrangements is effective in merging the two modes of TM_{10} and TM_{20} on the equilateral triangular patch to obtain wide impedance bandwidth. Note that the number of shorting pins is defined by N_1 and N_2 for those pins with the radii of r_1 and r_2, respectively. Both N_1 and N_2 are equal to three, which are the minimum number of shorting pins to guarantee the wideband operation. Totally, six shorting pins are used; the value of Φ is set to 60^{o} for even angular separations between all pins, where Φ is a parameter to determine the shorting pin separations.



(a) Top view



(b) Side view

Fig. 1 Geometry of proposed antenna.

TABLE I
Detailed Dimensions of Proposed Antenna with V-shaped Slot

Parameters	R_g	L_1	r_1	r_2	a_1	a_2
value/mm	32	21.5	1.25	0.25	13.2	10.25
λ_g	0.96	0.64	0.04	0.007	0.39	0.31
Parameters	h	W_s	d_1	d_2	d_3	
value/mm	3.0	0.3	0.2	9.0	5.0	
λ_g	0.09	0.009	0.006	0.27	0.15	
Parameters	N_1	N_2	Φ			
values	3	3	60^{o}			

In order to further widen the impedance bandwidth, the V-shaped slot on the patch is etched to the antenna [23]–[25]. It changes the current path and develops a new resonant mode of TM_{11}. The location and length of V-shaped slot, d_1, d_2, and d_3, are related to both of the impedance match and the resonant frequency at low frequency band, while the slot width, W_s mainly affects the impedance matching. The analysis of antenna will be discussed in next section. This antenna is proposed to fabricate by a conventional printed-circuit-board (PCB) technology which is low cost. The substrate of the antenna has a dielectric constant of 2.65 and a thickness of 3.0 mm. A coaxial centred-fed probe excites this antenna with 50 Ω SMA connector, realizing conical radiation pattern at the vertical plane and omni-directional radiation pattern at the horizontal plane. This antenna is simple, wideband, and low cost. The detailed dimensions of proposed antenna with the V-shaped slot are shown in Table I. (λ_g is the guided wavelength at 5.5 GHz.).

III. Antenna Analysis

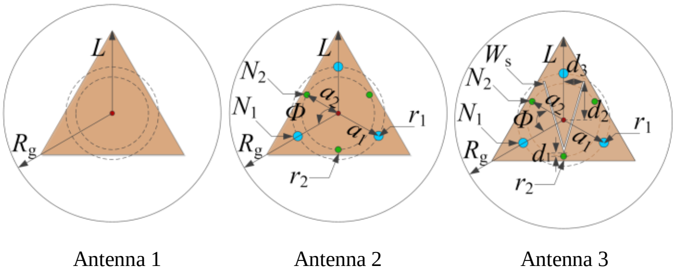
As stated above, the position of the shorting pins might influence the input impedance of proposed antenna. The V-shaped slot develops a new resonant mode of TM_{11}. A parametric study for the change in input impedance, parameters of V-shaped slot, and a current distribution are going to carry out and discuss as follows.

A. Change in Input Impedance

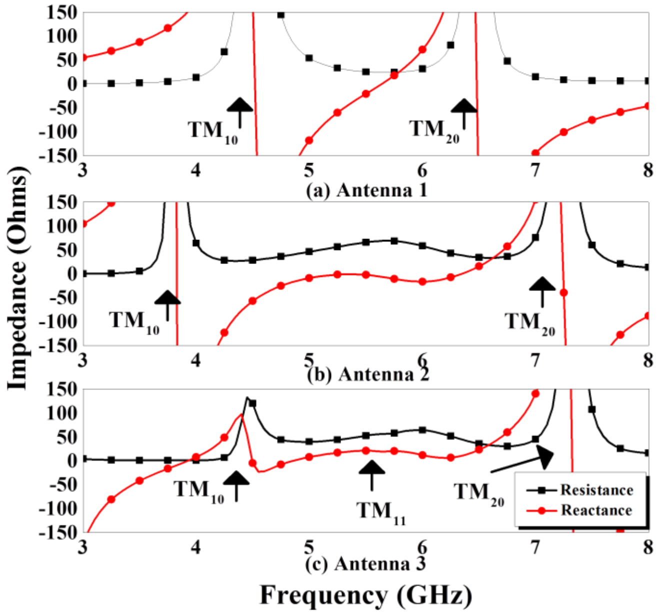
Fig. 2(a) shows the top views of Antenna 1, 2, and 3. Antenna 1 is without shorting pins and V-shaped slot, Antenna 2 is without V-shaped slot, and Antenna 3 is with shorting pins and V-shaped slot. In Fig. 2(b), it reports input impedance of three antennas. It is found that TM_{10} and TM_{20} modes are found from three investigating antennas. The impedance value is very high for Antenna 1 that causes a poor impedance matching. However, adding shorting pins can reduce the resistance and the reactance of the input impedance of the antenna between both modes, such that the impedance becomes stable across the operating bandwidth. Then the V-shaped slot introduces the TM_{11} mode to achieve a wider bandwidth. As a result, the proposed antenna (Antenna 3) can obtain three resonant modes with reasonable impedance values across the operating bandwidth.

B. Study on Parameters of V-Shaped Slot

Firstly, the V-shaped slot width, Ws is studied. Reflection coefficients versus frequency with different Ws are given in Fig. 3. It is found that W_s increases, the impedance bandwidth becomes narrower and the reflection coefficient at low



(a) Top view of Antenna 1, 2, and 3



(b) Input impedances of Antenna 1, 2, and 3

Fig. 2 Top views and input impedances of Antenna 1, 2, and 3.

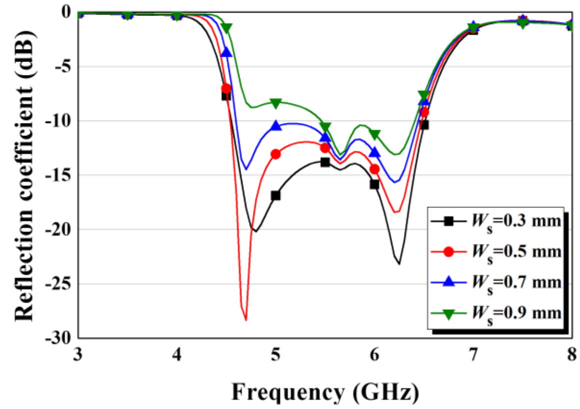


Fig. 3 Reflection coefficients versus frequency with different W_s.

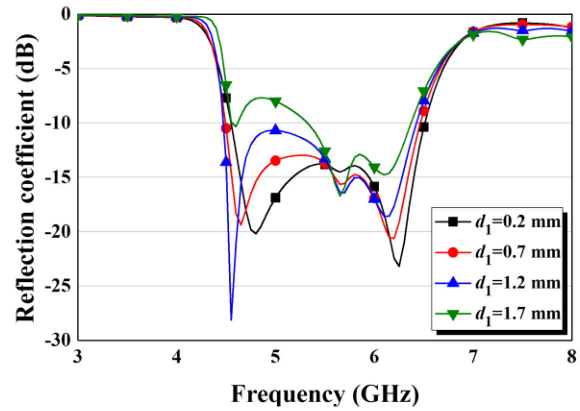


Fig. 4 Reflection coefficients versus frequency with different d_1.

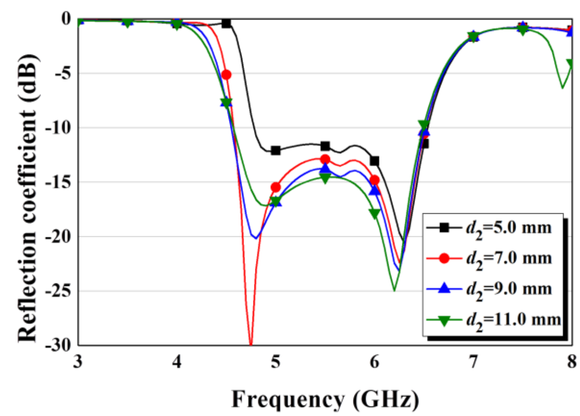


Fig. 5 Reflection coefficients versus frequency with different d_2.

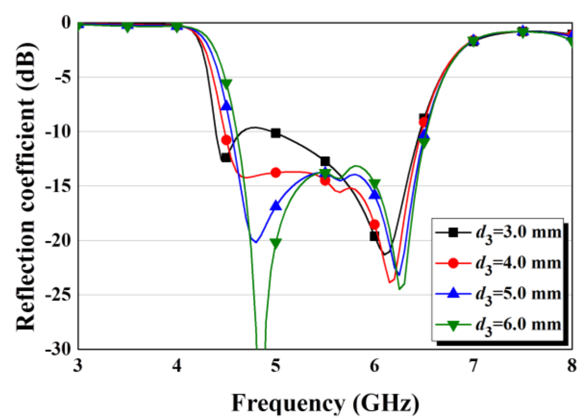


Fig. 6 Reflection coefficients versus frequency with different d_3.

frequency band becomes worse. *W*s = 0.5 mm is chosen for an easy fabrication and a reasonable wideband characteristic.

Reflection coefficients versus frequency with other different parameters of V-shaped slot are given in Figs. 4–6, respectively. The location and lengths of V-shaped slot have greater influence on the reflection coefficients at low frequency band. The reflection coefficient is deteriorated when the distance between the V-shaped slot and the thin shorting pin, d_1 is increased. To realize the fabrication, we set the value of $d_1 = 0.2$ mm. In addition, the reflection coefficient can be improved with the increase of values of d_2 and d_3. If the length of V-shaped slot can be properly designed, the antenna might produce a new resonant frequency of 5.65 GHz shown in this example to expand the impedance bandwidth.

C. Change in Current Distribution

Simulated current distributions with / without V-shaped slot at 5.65 GHz is shown in Fig. 7. It is seen that the currents in Fig. 7(a) are concentrated in six shorting pins and the feeding point. The current of thick shorting pins are stronger than the current of thin shorting pins. However, the V-shaped slot changes the current distribution on the equilateral triangular patch and introduces a new resonant frequency of 5.65 GHz. As shown in Figs. 7(b), the current strength at the bottom of the equilateral triangular patch becomes stronger.

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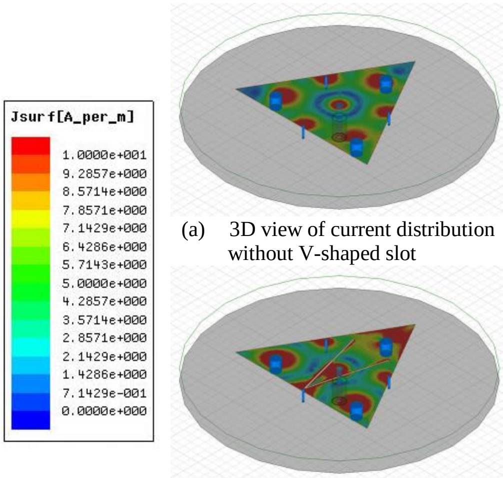

(a) 3D view of current distribution without V-shaped slot

(b) 3D view of current distribution with V-shaped slot

Fig. 7 Simulated current distribution with/without V-shaped slot at 5.65 GHz.

IV. Simulated and Measured Results

The antenna with V-shaped slot has been fabricated based on a conventional PCB technology to verify simulation. Measurements were carried out by using Agilent Technologies E5071C network analyzer and Satimo StarLab antenna measurement system for verifying the reflection coefficient, radiation pattern, and gain. The photograph of the fabricated prototype is shown in Fig. 8.

Fig. 9 depicts simulated and measured reflection coefficients versus frequency. It can be found that the fabricated antenna has the impedance bandwidth of 32.20% for the reflection coefficient ≤ -10 dB from 4.82 to 6.67 GHz.

For radiation characteristics, the simulated and measured antenna gains versus frequency are given in Fig. 10. The simulated gain varies relatively less over the operating frequency band, ranging from 4.21 to 5.44 dBi (except the frequency at 5.64 GHz). The important reason is that there is strong radiation around the new resonance frequency produced by the V-shaped slot. Compared with the simulation, the measured results slightly shift to high frequencies. The measured gain of the antenna varies from 3.17 to 6.50 dBi over the entire frequency range from 4.82 to 6.67 GHz. The gain difference between simulated and measured results is around 1 dBi due to fabrication errors.

Fig. 11 shows the measured efficiency of proposed antenna. As seen in the figure, the efficiency ranges from 0.83 to 0.93 over the whole frequency band ranged from 4.82 to 6.67 GHz. It is indicated that this antenna can provide good radiation properties for C2C and WLAN communications.

Fig. 12 shows the simulated and measured radiation patterns at 4.8, 5.5, and 6.2 GHz. Both of the simulated and measured patterns agree well in the plane perpendicular to the antenna. As shown in the horizontal plane ($\theta = 90^{o}$), the radiation pattern is omnidirectional. Measured out of roundness is less than 2.48 dBi, comparing with the simulated results of 2.46 dBi. Moreover, in the vertical plane ($\phi = 0^{o}$ or 90^{o}), the measured cross polarizations are less than -11.62 dB over the operating frequency bandwidth. The range of simulated 3-dB beamwidth goes from 22^{o} to 32^{o}, while the measured 3-dB beamwidth ranges from 23^{o} to 37^{o}. As the radiation patterns are conical, the simulated peak gains are found at the angle from 38^{o} to 42^{o} or 324^{o} to 326^{o}; while the corresponding measured values are 37^{o} to 49^{o} or 317^{o} to 332^{o}. The detail values of proposed antenna with V-shaped slot are shown in Table II.

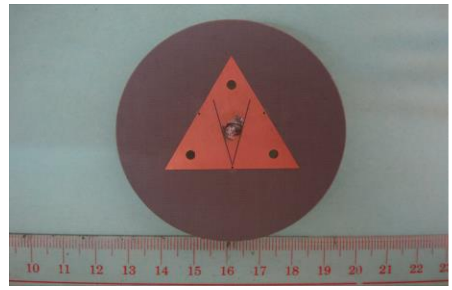
Fig.8 Photograph of fabricated prototypes.

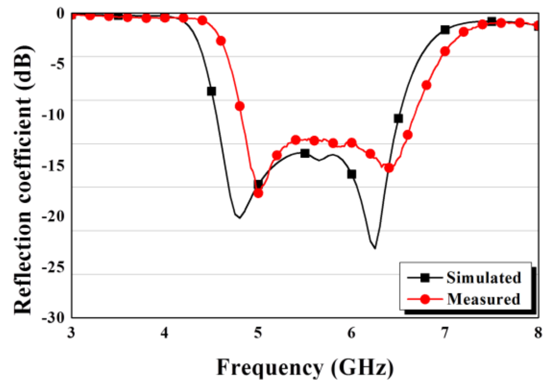

Fig. 9 Simulated and measured reflection coefficients versus frequency.

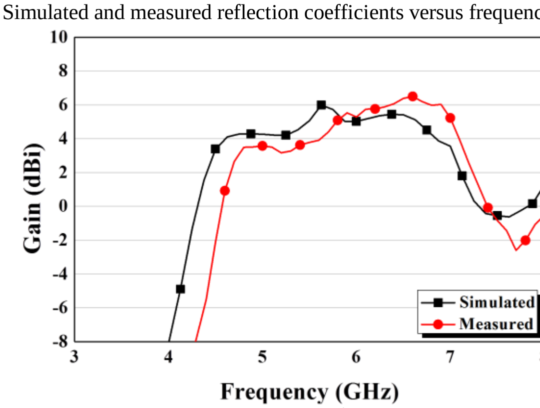

Fig. 10 Simulated and measured gains versus frequency.

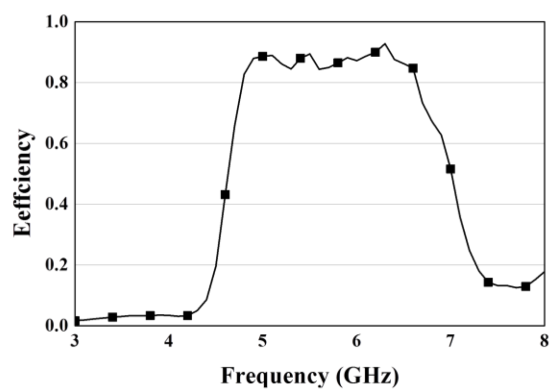

Fig.11 Measured efficiency of proposed antenna.

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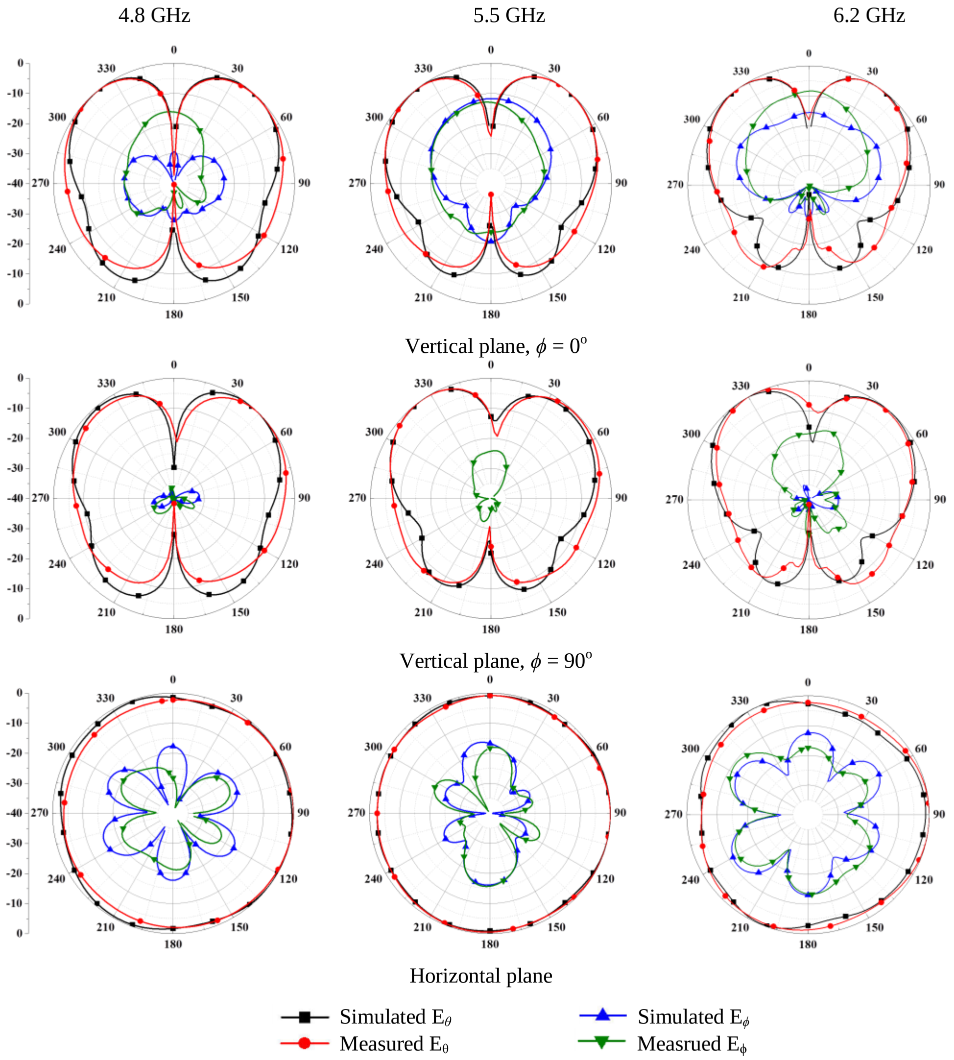

Fig. 12 Simulated and measured radiation patterns at 4.8, 5.5, and 6.2 GHz.

TABLE II
THE SIMULATED AND MEASURED PATTERNS OF PROPOSED ANTENNA

		Simulated results			Measured results		
Frequency(GHz)		4.8	5.5	6.2	4.8	5.5	6.2
3-dB beamwidth (degree)	Vertical plane, ϕ = 0°	30	32	28	37	33	26
Angle of peak gain (degree)		40	38	324	317	37	328
Cross polarization (dB)		-23.75	-14.31	-13.93	-20.68	-18.30	-11.62
3dB beamwidth (degree)	Vertical plane, ϕ = 90°	30	22	24	37	27	23
Angle of peak gain (degree)		42	326	326	49	326	332
Cross polarization (dB)		-33.06	-50.19	-34.77	-37.16	-29.11	-19.62
Cross polarization (dB)	Horizontal plane	-15.35	-16.12	-11.21	-19.50	-15.64	-10.65
Out of roundness (dB)		1.57	1.29	2.46	1.93	1.28	2.48

V. DISCUSSION

The proposed antenna is low profile, h = 3 mm ($0.09\lambda_g$), which would be facilitated easier installation on the car roof. Fig. 13 gives the proposed antenna mounted on the car roof with the radius of R_f and thickness of H. The value of H is 3 mm. With the presence of the car roof, the reflection coefficient of proposed antenna is changed as shown in Fig. 14.When R_f varied from 40 mm to 190 mm, the reflection coefficient would become poor if R_f is as large as 190 mm.

An example of fine tuning for parameters of the shorting pins, a_1 and a_2 to obtain a better impedance performance for the antenna placed above the car roof is shown in Fig. 15. The antenna can have good impedance bandwidth of 26.56% (4.67 to 6.10 GHz) after fine tuning.

As for the radiation patterns shown in Fig. 16, more sidelobes occur with larger car roof at the operating frequency of 5.5 GHz and the peak gain is about 6.5 dBi at the θ = 60° in the vertical plane in Fig. 16, which is still suitable for C2C and WLAN communications.

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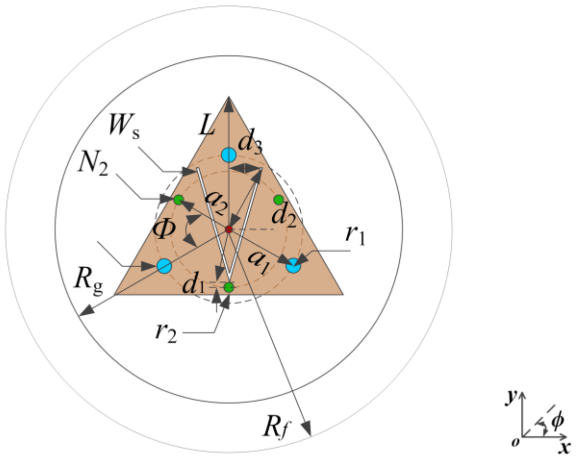
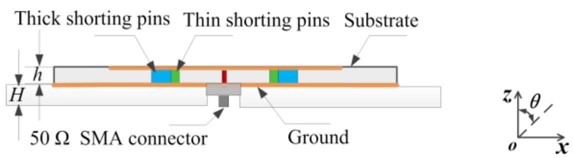


(a) Top view



(b) Side view

Fig. 13 Proposed antenna mounted on the car roof.

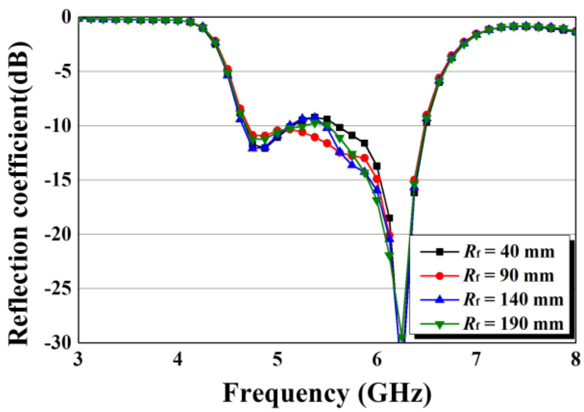


Fig. 14 Reflection coefficients versus frequency of antenna mounted on the car roof with different R_f.

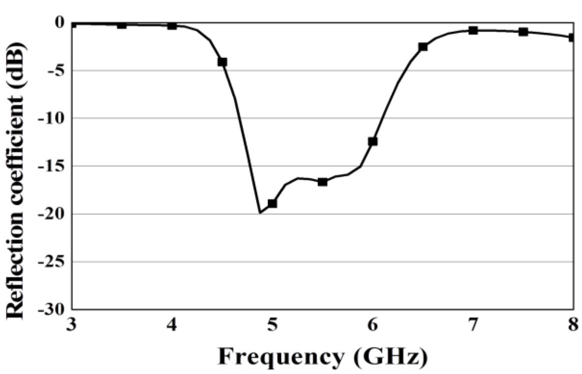


Fig. 15 Reflection coefficient of antenna mounted on the car roof with R_f = 190 mm.

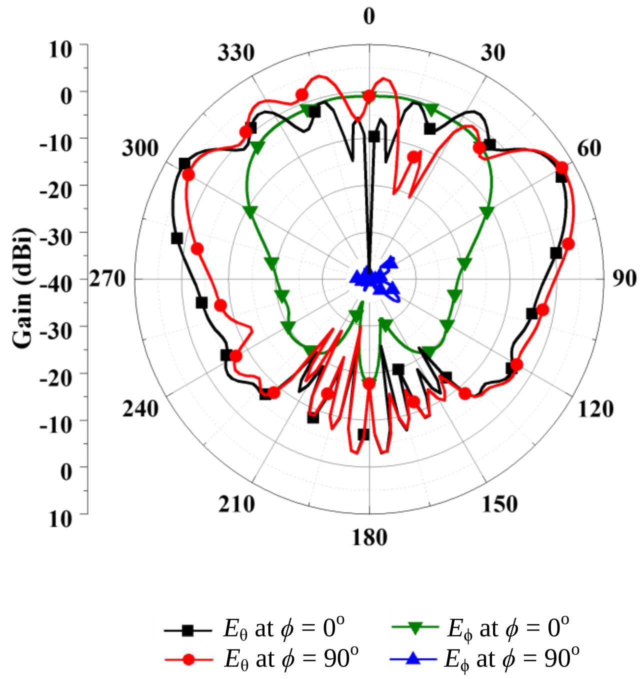


Fig. 16 Radiation pattern of antenna mounted on the car roof with R_f = 190

VI. Conclusion

An antenna with vertical polarization for Car-to-Car and WLAN communications is proposed and analyzed. Firstly, an equilateral triangular patch with certain shorting pins can effectively reduce the resistance and the reactance of input impedance. Then a new resonant frequency of TM_{11} can be produced if the V-shaped slot is added to the patch antenna. The V-shaped slot is simply equivalent to a capacitance loading to reduce the resistance and the reactance of the antenna which contributes a wider impedance bandwidth.

The measured results show that the proposed antenna has the impedance bandwidth of 32.20%, with the peak gain of 6.50 dBi. In the vertical plane, for both $\phi = 0^o$, 90^o planes, cross polarizations are less than -12.07 dB over the operating bandwidth. The 3-dB beamwidth ranges from 27^o to 35^o. In the horizontal plane, the radiation pattern is omnidirectional with the out of roundness of 2.48 dB. The proposed antenna is simple, low cost, and can be mounted on the car roof. With these characteristics, the proposed antenna is suitable for C2C and WLAN communications.

Acknowledgment

The useful comments of the reviewers are gratefully appreciated.

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