Combined LTE and IEEE 802.11p Antenna for Vehicular Applications

Edith Condo Neira[1], Jan Carlsson[1], Kristian Karlsson[1], Erik G. Ström[2]
[1] SP Technical Research Institute of Sweden, Borås, Sweden, edith.condoneira@sp.se
[2] Chalmers University of Technology, Gothenburg, Sweden

***Abstract*—Vehicles may contain multiple antennas for different applications. Among all of them, Vehicle-to-Vehicle and Vehicle-to-Infrastructure (V2X) is one of the most recent applications. This new technology focuses on traffic safety and traffic efficiency. In this paper we present a new compact antenna module suitable for vehicular applications. This module could be easily integrated into the rear-spoiler on a vehicle. The module consists of two identical monopoles for V2X applications based on the IEEE 802.11p standard and two identical printed inverted F-antennas for Long-Term Evolution (LTE) communications. The evaluation of the proposed module is done by analyzing the simulated and measured antenna S-parameters, antenna efficiencies, radiation patterns, as well as by calculating the diversity performance. The results show that the antennas are well matched and well isolated for both LTE and V2X and exhibits a radiation pattern close to the desired omnidirectional in the horizontal plane for V2X. The two LTE antennas have radiation patterns that complement each other ensuring an omnidirectional coverage by combination. Furthermore the module presents good radiation efficiency for both LTE and V2X.**

***Index Terms—Antenna Module; LTE and V2X* antennas; *LTE and 802.11p* antennas; Vehicular Antennas.**

I. Introduction

In the last few years, the automotive industry has increased its interest in wireless technologies significantly. It is well known that antennas are key components to assure a reliable wireless communications link. Modern vehicles may contain multiple antennas covering different frequency bands for different wireless applications. In addition to the existing applications, modern vehicles will include Long-Term Evolution (LTE) and Vehicle-to-Vehicle and Vehicle-to-Infrastructure (V2X) technologies. LTE will provide high data rates for several applications such as Internet connectivity. V2X, which is currently based on IEEE 802.11p, will allow vehicles to communicate with each other and with the road infrastructure improving traffic safety and traffic efficiency. In Europe, IEEE 802.11p is used as basis for the ITS-G5 standard which is standardized by European Telecommunications Standard Institute (ETSI) with a bandwidth allocation of 30 MHz at 5.9 GHz (i.e., from 5875 MHz to 5905 MHz) [1]. The increasing number of antennas and the restricted space due to aesthetic aspects requires the development of multiband antennas integrated in a single compact module that preferably should be placed hidden in some part (e.g., a spoiler) of the vehicle.

Therefore, a lot of research is conducted on designing antennas capable of covering different frequency bands and fitted in the same module [2-4]. Most of them have focused on some specific technology. For example the design and performance of LTE antennas were presented in [5] while [6] proposed a module including antennas for V2V communications. In [7], a module including V2V as well as LTE antennas was published. All of these modules have been proposed for a roof-top mounting position. To the authors' best knowledge there is no published information about other mounting positions regarding antennas for LTE and V2X technologies.

This paper describes the design and performance evaluation of a compact module consisting of diversity antennas for LTE and V2X technologies. The module is proposed to be mounted inside the rear-spoiler and it consists of two identical LTE antennas covering the frequency bands specified in Table I, and two identical V2X antennas for 5.9 GHz. The LTE antennas are based on a printed inverted F-antenna (PIFA) design [8], to which a slot has been added to increase the bandwidth and to achieve good performance in the lowest LTE band specified in Table I. The V2X antennas are quarter-wave monopoles. For the evaluation, we measure the S-parameters, the radiation efficiency as well as the total radiation efficiency, and the radiation patterns.

We also investigate diversity taking into account the multipath environment to which vehicles are exposed. This is done by using the radiation patterns and a statistical method [9] which is based on simulations in VIRM-Lab, a computer code for analyzing the performance of multiport antennas in multipath environments [10]. The multipath environment is generated by a number of incident waves with a specific angle of arrival distribution, defined by the user. The incident waves will generate a voltage at the antenna ports. By generating several sets of waves and studying the received power at 1% Cumulative Distribution Function (CDF)-level and by applying diversity techniques we are able to characterize the performance of the antenna module.

The paper is organized as follows: In Section II the design for LTE and V2X antennas is described as well as the antenna module design. In Section III, the evaluation of the antenna module is presented. This includes the antenna S−parameters, antenna efficiencies, radiation patterns as well as the received power at 1% CDF-level when using selection diversity combination. Finally, the conclusions are given in Section IV.

II. MULTI-FUNCTION ANTENNA

The multi-function antenna module is designed to be within the dimensions of 300 mm length, 50 mm width and 20 mm height. This is considering the available space inside the rear-spoiler on a vehicle, e.g., a crossover vehicle.

A. Antenna Design

Fig. 1 shows the geometry of the proposed antennas for LTE as well as for V2X communications. As mentioned before the LTE antenna is based on a PIFA design [8]. The antenna consists of a radiating element, a shorting strip, a feeding element, and a ground plane. The radiating element is shorted to the ground plane by the shorting strip as in any conventional PIFA design. The height between the ground plane and the radiating element is 5 mm. In order to allow a better current distribution a wide feeding element is used. As shown in Table I, the lowest frequency band is between 698 MHz to 716 MHz. At these frequencies the ground plane is the main contributor to the radiation, which means that the size of the ground plane should be in the order of half wavelength, i.e., in the order of 200 mm, for good radiation performance. Thus, we need to make the ground plane sufficiently large electrically and at the same time keep the physical length small due to the limited available space. We achieve this by inserting three slots in the ground plane. Two of the slots are placed under the radiating element followed by the third one that is placed further out on the ground plane. The slots have a length of 5 mm and a width of 26 mm. The dimensions of the PIFA are given in Table II.

For V2X communications a quarter-wave length monopole antenna is used. The antenna resonates at 5.9 GHz and it is mounted on the PIFA ground plane as shown in Fig. 1.

Table I. Frequency Bands for LTE

LTE Frequency Bands	
Uplink	***Downlink***
698 – 716 *MHz*	925 - 960 *MHz*
1710 - 1785 *MHz*	2110 - 2170 *MHz*
2500 - 2570 *MHz*	2620 - 2690 *MHz*

Table II. Dimensions of PIFA for LTE Communications

Description	***Dimensions***
Radiating element	Length = 25 mm; Width = 40 mm; Thickness = 1 mm
Feeding element	Height = 4 mm; Width = 17 mm; Thickness = 1 mm
Shorting strip	Height = 5 mm; Width = 1 mm; Thickness = 1 mm
Ground Plane	Length = 120 mm; Width = 40 mm; Thickness = 0.1 mm

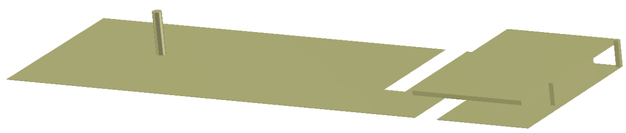


Figure 1. PIFA antenna for LTE Communications including a quarter-wave length monopole.

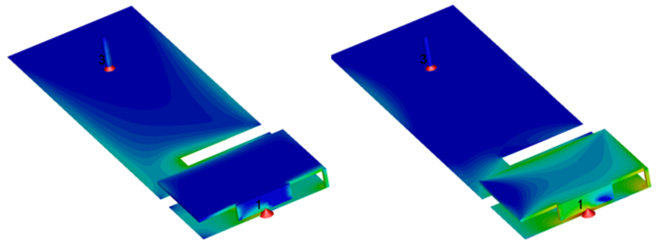


Figure 2. Current distribution at 698 MHz (left) and 2690 MHz (right).

Fig. 2 shows the surface current at 698 MHz and 2690 MHz which are the lowest and highest frequencies for LTE, see Table I. It is shown that at lower frequencies the main contributor to radiation is the ground plane while at higher frequencies the main contributor is the radiating element.

B. Final Antenna Module Design

Two identical LTE and two identical V2X antennas are used in the antenna module. The LTE antennas are printed on FR4 substrate with permittivity of 4.3, loss tangent of 0.025, and thickness of 1.6 mm, and each of them has its own ground plane, which are spatially separated by 50 mm. This is done to achieve a good isolation between the antennas as well as to have enough space for future GPS antenna integration. For V2X, the antennas are mounted on the ground plane of each LTE antenna and the separation between them is 90 mm. The design and optimization of the antenna module is done in CST Microwave Studio [11]. The complete module has a length of 290 mm, width of 40 mm, and a height of 7.6 mm. The final antenna module prototype is shown in Fig. 3. For the measurements, the feeding of the antennas is made through a 50 Ω SMA connector. The manufactured antenna module is shown in Fig. 4.

III. EVALUATION OF THE ANTENNA MODULE

The antenna module has been both simulated and measured. For convenience the antennas are referred to as antenna 1 and 2 for LTE and antenna 3 and 4 for V2X as shown in Fig. 3.

A. Analysis of S-parameters

The simulations were done in CST Microwave Studio and for the measurements a vector network analyzer was used.

In Fig. 5 and Fig. 6, the simulated and measured return losses ($-S_{ii}$) of the antenna module are shown. As can be seen in Fig. 5, the return loss for LTE antennas is better than 6 dB in all relevant frequency bands specified in Table I. The difference between the simulated and measured LTE antennas as well as the difference between both measured LTE antennas is attributed to factors such as manual soldering and manufacturing tolerances. For V2X, the antennas are well matched at 5.9 GHz. Both the simulated and measured return loss is better than 13 dB, see Fig. 6.

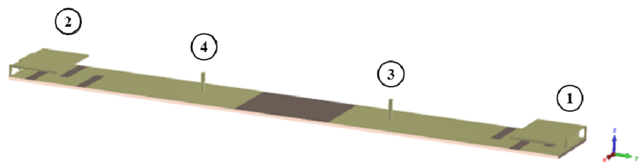


Figure 3. Antenna module for LTE and V2X communications.

Figure 4. Fabricated prototype of the antenna module

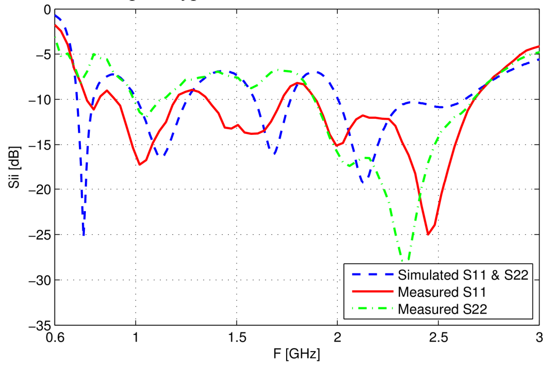


Figure 5. Simulated and measured return loss of the antenna module for LTE antennas.

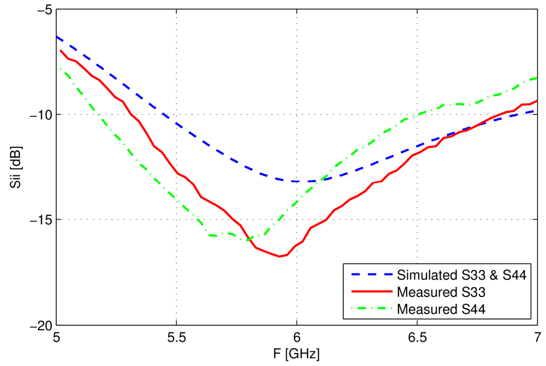


Figure 6. Simulated and measured return loss of the antenna module for V2X antennas.

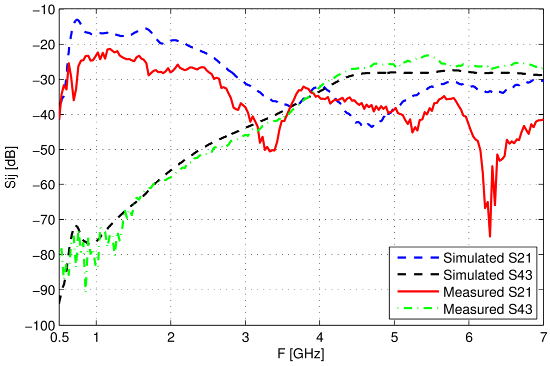


Figure 7. Simulated and measured mutual coupling between antenna 1 and 2 (LTE antennas) and between antenna 3 and 4 (V2X antennas).

As mentioned before the distance between the antennas were optimized to achieve good isolation. The resulting isolation is shown in Fig. 7 and Fig. 8. In Fig. 7, the mutual coupling between the LTE antennas (S21) is less than −15 dB at the lower bands and less than −20 dB at the highest band specified in Table I. For V2X the mutual coupling between the antennas (S43) is less than −26 dB. The mutual coupling between the LTE antenna 1 and V2X antenna 3 (S31) is less than −20 dB and less than −30 dB between LTE antenna 2 and V2X antenna 3, as shown in Fig. 8.

The measured radiation efficiency as well as the total radiation efficiency for LTE antennas is shown in Fig. 9. As can be seen the total radiation efficiency is better at the highest band in comparison to the lower bands. This is due to the antenna is better matched at higher frequencies. For V2X, the difference between the radiation efficiency and the total radiation efficiency is less than 0.2 dB, see Fig. 10. This is because the antennas are well matched.

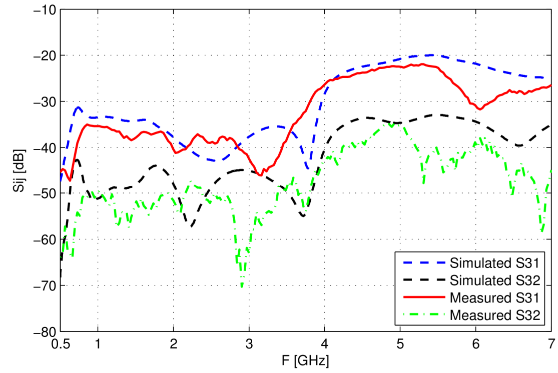


Figure 8. Simulated and measured mutual coupling between antenna 1 (LTE) and 3 (V2X) and between antenna 2 (LTE) and 3 (V2X).

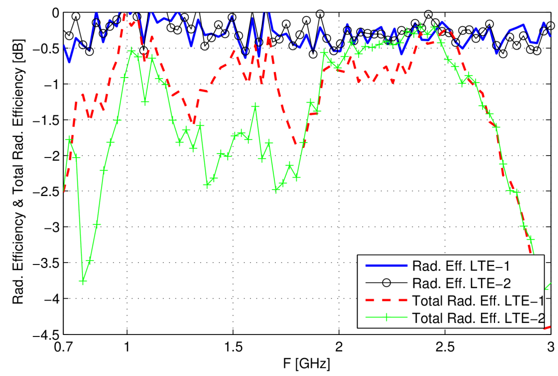


Figure 9. Measured radiation efficiency and total radiation efficiency for the LTE antennas.

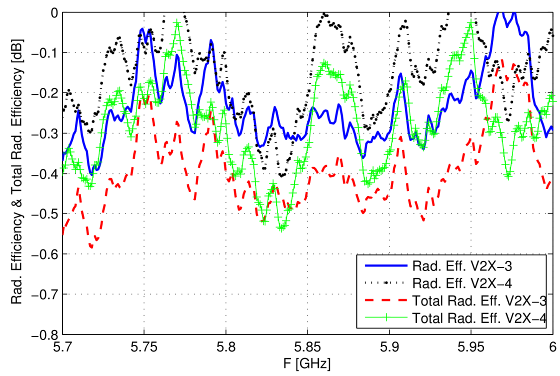
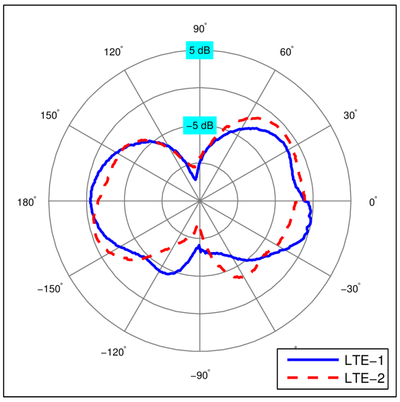


Figure 10. Measured radiation efficiency and total radiation efficiency for the V2X antennas.

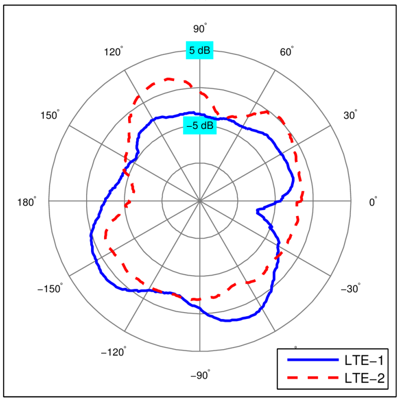
B. *Analysis of Radiation Patterns*

The radiation pattern measurements were done in an anechoic chamber.

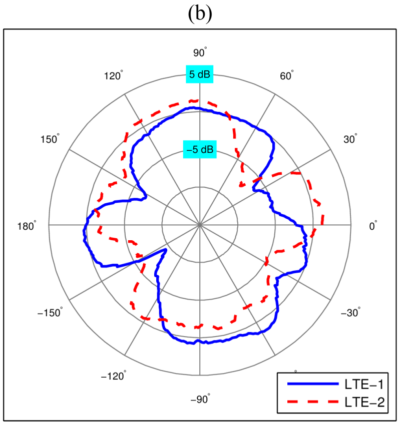
The measured radiation patterns at three different frequencies of 829 MHz, 1940 MHz, and 2590 MHz are shown in Fig. 11. These frequencies are the center frequencies of the LTE bands specified in Table I. As can be seen, the two LTE antennas have radiation patterns that complement each other, at least for the higher frequency bands. Thus, combined, they are close to omnidirectional in the azimuth plane. Fig. 12 shows the measured radiation pattern at 5.9 GHz. As expected, the radiation pattern is close to omnidirectional in the azimuth plane.



(a)



(b)



(c)

Figure 11. Measured radiation patterns (total gain) for LTE in the azimuth plane. (a) 830 MHz, (b) 1940 MHz, (c) 2590 MHz.

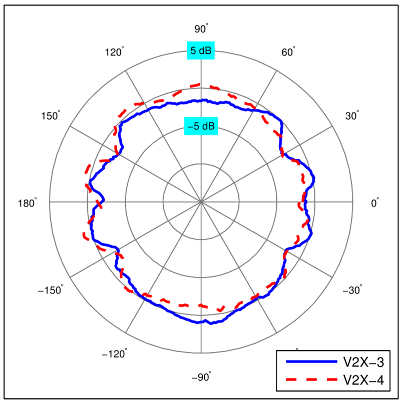


Figure 12. Measured radiation pattern (total gain) for V2X in the azimuth plane.

C. *Received Power at 1% CDF-level*

As was done in [9], we here assume the multipath phenomena for V2X communications to be located mostly in the horizontal plane. Thus, the incident waves will come within a limited range of angles in elevation and from arbitrary directions in azimuth. The incident waves are uniformly distributed in both elevation and azimuth.

For the simulations, we generate the multipath environment by a number of incident waves, defined by their angle of arrival and polarization. In order to resemble reality, a large number of realizations are generated to simulate a changing environment when computing the received power at 1% CDF-level. Each realization consists of a number of statistically distributed incident plane waves, which are distributed on the radiation patterns of the receiving antennas. These incident waves generate a voltage at the antenna ports.

In the figures to follow, we have used 10^5 realizations and each realization contains two to twenty incident plane waves. The incident waves are uniformly distributed between 0° to 360° in azimuth and −5° to 15° in elevation. The phase of the incident waves are uniformly distributed between 0 and 2π radians and the amplitude is Rayleigh distributed. In order to give a feeling for the performance of our antennas, an ideal half-wave vertical dipole is used for comparison.

For LTE, we have used linearly polarized incident waves with random polarization since the antennas for LTE base stations are dual-polarized. Fig. 13 shows the results for LTE at three different frequencies. As can be seen, the LTE antennas are better than the dipole antenna for all the studied frequencies. It is also shown in the graphs that the signal quality can be improved by applying diversity selection combining. The signal quality at 829 MHz, 1940 MHz and 2590 MHz improves around 3.1 dB, 4.5 dB and 5 dB, respectively.

In Fig. 14, the results for V2X are shown. Here, we have only used vertically polarized incident waves. This is because the manufactured V2X antennas are vertically polarized and we assume the opposite side of the link to have the same polarization. As expected, the received power at

1% CDF-level is better than the dipole antenna. Applying diversity selection combining improves signal quality around 2.4 dB.

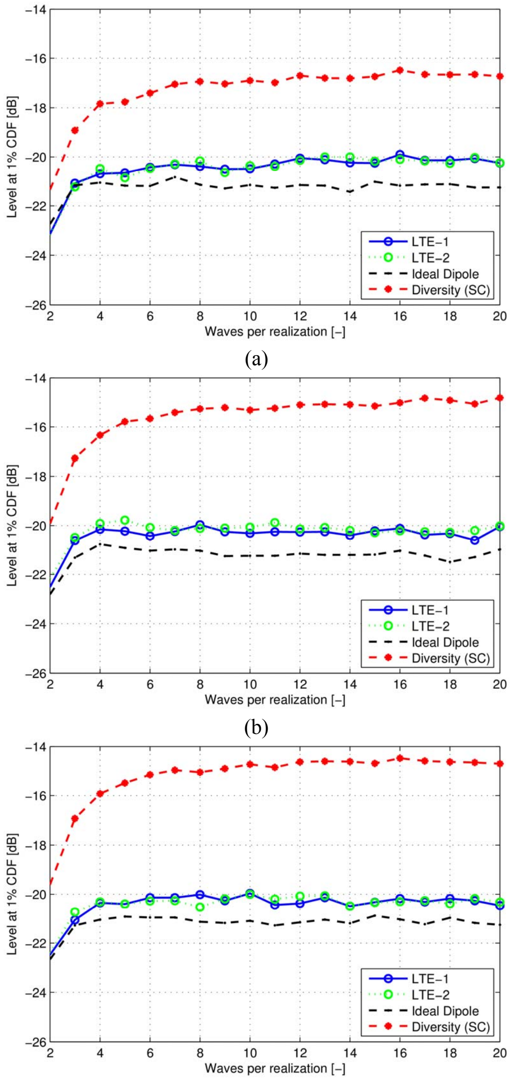


Figure 13. Received power at 1% CDF-level as a function of linearly polarized incident waves for LTE at three different frequencies. (a) 830 MHz, (b) 1940 MHz, (c) 2590 MHz. Diversity selection combining is also shown in the graph.

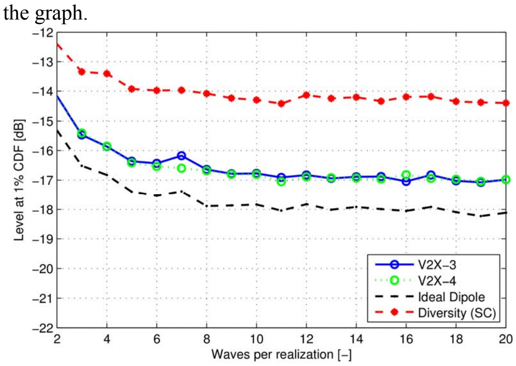


Figure 14. Received power at 1% CDF-level as a function of vertical polarized incident waves for V2X, i.e., 5.9 GHz. Diversity selection combining is also shown in the graph.

IV. CONCLUSION

We have presented a compact module consisting of two identical LTE and two identical V2X antennas. The overall size of the module is 290 x 40 x 7.6 mm^3 and it is suitable for a rear-spoiler mounting position. Simulations and measurements results performed on the module show that the antennas are well matched and well isolated for the three different studied LTE frequency bands as well as for V2X communications. Moreover the module presents a total radiation efficiency of −1.5 dB at the lowest band, −1.2 dB at the middle band and −0.8 dB at the highest band for LTE and −0.5 dB for V2X.

ACKNOWLEDGMENT

This work has been supported by The Swedish Governmental Agency for Innovation Systems (VINNOVA) within the VINN Excellent Center Chase.

REFERENCES

[1] E. G. Ström, "On Medium Access and Physical Layer Standards for Cooperative Intelligent Transport Systems in Europe " *Proceedings of the IEEE,* vol. 99, no. 7, pp. 1183-1188, July 2011.

[2] B. Sanz-Izqierdo and R. Leelaratne, "Evaluation of Wideband LTE Antenna Configurations for Vehicular Applications," *Loughborough Antennas & Propagations Conference (LAPC)*, Loughborough, UK, Nov. 2013.

[3] E. Gschwendtner and W. Wiesbeck, "Ultra-Broadband Car Antennas for Comunications and Navigation Applications," *IEEE Transactions on Antennas and Propagation,* vol. 51, pp. 2020-2027, Aug. 2003.

[4] R. Leelaratne and R. Langley, "Multiband PIFA Vehicle Telematics Antennas " *IEEE Transactions on Vehicular Technology,* vol. 54, pp. 477-485, March 2005.

[5] A. Thiel, L. Ekiz, O. Klemp, and M. Schutz, "Automotive Grade MIMO Antenna Setup and Performance Evaluation for LTE-Communications," *International Workshop on Antenna Technology (iWAT)*, Karlsruhe, Germany, March 2013.

[6] M. Gallo, S. Bruni, and D. Zamberlan, "Design and Measurement of Automotive Antennas for C2C Applications," *Antennas and Propagation (EuCAP) Proceedings of the 6th European Conference*, Prague, Czech Republic, March 2012.

[7] M. Gallo, S. Bruni, M. Pannozzo, and D. Zamberlan, "Performance Evaluation of C2C Antennas on Car Body," *Antennas and Propagation (EuCAP) Proceedings of the 7th European Conference*, Gothenburg, Sweden, April 2013.

[8] R. Gomez-Villanueva, R. Linares-y-Miranda, J.A. Tirado-Mendez, and H. Jardon-Aguilar, "Ultra-Wideband Planar Inverted-F Antenna (PIFA) for Mobile Phone Frequencies and Ultra-Wideband Applications," *Progress In Electromagnetics Research C,* vol. 43, pp. 109-120, 2013.

[9] E. Condo Neira, U. Carlberg, J. Carlsson, K. Karlsson, and E. G. Ström, "Evaluation of V2X Antenna Performance Using a Multipath Simulation Tool," *Antennas and Propagation (EuCAP) Proceedings of the 8th European Conference*, The Hague, The Netherlands, April 2014.

[10] U. Carlberg, J. Carlsson, A. Hussain, and P. S. Kildal, "Ray Based Multipath Simulation Tool for Studying Convergence and Estimating Ergodic Capacity and Diversity for Antennas with Given Far-Field Functions," *in 20th Internat. Conf. on Applied Electromagnetics and Communications (ICECom)* Dubrovnik, Croatia, Sept. 2010.

[11] *CST Microwave Studio*. Available: https://www.cst.com/