

Characterization of Plug-in Antennas for Telematic Control Unit

E. Toniolo⁽¹⁾, A. Michel⁽²⁾, and P. Nepa⁽²⁾

(1) MTA Antenne, Isola Vicentina, Italy (enrico.toniolo@mta.it)

(2) Dept. Information Engineering, University of Pisa, Italy (andrea.michel@unipi.it, paolo.nepa@unipi.it)

Abstract

Compact antenna modules for Long Term Evolution (LTE) and 5G technology, WIFI 7, V2X, high-precision GNSS and SDARS are presented in this paper as extension of telematics control unit (TCU). The idea is that antenna modules and TCU follow independent production path and, at the end, they are assembled together with some mechanical tolerance. Easy and RF-reliable way of connecting them by means of contact-springs is proposed. Proposed antenna assembly operates at a wide frequency range from 617 MHz to 7500 MHz. Antenna prototype is fabricated and measured under a dedicated hole in the roof of a commercial vehicle. Results are shown in the paper in terms of Return Loss and realized gain.

1 Introduction

To make a vehicle as “smart” and autonomous as possible, in automotive industry the number of wireless services is significantly increasing, that consequently leads to a higher number of embedded radiating elements, complex electronic systems, networks and architectures. Nevertheless, multiple antennas are used to improve the throughput of a LTE or 5G cellular systems by implementing Multiple Input Multiple Output (MIMO) wireless technology.

Vehicular antennas are typically integrated together under plastic covers, named shark-fin. However, the integration of antennas is challenging in those cases where multiple antennas are present because antenna compactness and isolation requirements are difficult to be fulfilled. The size of the antenna is limited by the available volume under the cover and by the presence of other antennas placed in a close proximity.

To accommodate all the radiating elements while preserving satisfactory performance of the antenna, new locations on the vehicle have been investigated [1], [2], [3], [4], [5]. For example, cellular antennas have also been integrated into windshield, rear glass [2], dashboard [3] as well as into new spaces carved out from the car’s roof [4], [5]. The latter represents an interesting evolution of the shark-fin covers, since the cavity created on the car roof can be large enough to accommodate both radiating elements and electronic circuitry of multiple wireless services. In this context, low-profile connectivity modules are designed to be

placed under the car roof, while guaranteeing compliance with human safety regulations [6].

In this paper, an innovative solution for the production and integration of antennas in a Telematic Control Unit (TCU) is proposed [7]. Specifically, the here described assembly consists of four main parts, that are a main-board (the TCU, with RF front-ends and transceivers) and three extension-modules with the radiating elements. The three antenna-modules are connected to the main-board by means of spring contacts, making the overall system versatile, easy to upgrade and scalable. The proposed assembly offers good performances for various wireless applications: cellular LTE 5G systems (617–5000 MHz), WIFI 7 (2400–2500, 5100–5910 and 6125–7125 MHz), V2X (5825–5910 MHz), GNSS high-precision (L1, 1559–1610 MHz, L2L5, 1150–1254 MHz, bands) and SDARS (2320–2345 MHz).

2 Proposed Solution

The proposed antennas assembly layout is shown in Fig. 1. There are three antenna modules. Two smaller for LTE and V2X and one bigger for two WIFI, active GNSS high-precision and SDARS.

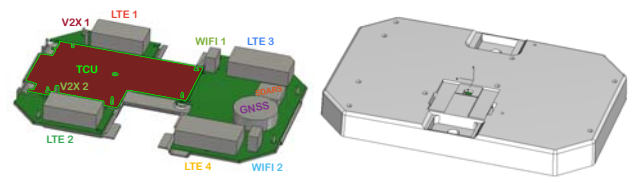


Figure 1. TCU and plugin-antenna modules proposed layout (left) and the plastic cover for protecting the whole assembly (right).

The three antenna modules are positioned onto a metallic base. Then the TCU is placed above overlapping the three modules periferically and all is pressed together by fixing the top plastic cover. The electrical RF-contact between the antennas’ ground and feed-lines to the TCU is provided by Alps Alpine spring-contacts [8] as shown by the simulated CST [9] model in Fig. 2. This type of contacts provide reliable RF-connection in situations like this where the alignment between antenna modules and TCU is subjected to some mechanical tolerance.

In the final prototype, shown in Fig.3, the TCU has been replaced by a PCB containing the spring-contact,

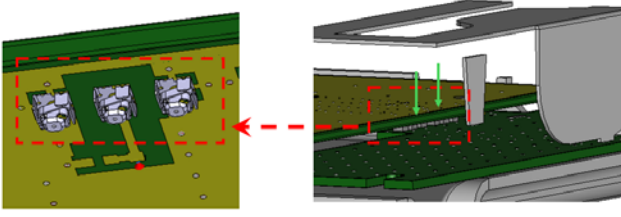


Figure 2. Detail view of the spring-contacts (left). The electrical contact is provided by pressing down TCU to antenna modules (green arrows on right).

feed-lines and output RF-connectors, for testing purposes. The whole size is $255 \text{ mm} \times 175 \text{ mm} \times 25 \text{ mm}$. Four compact ($50 \text{ mm} \times 20 \text{ mm} \times 15 \text{ mm}$) LTE 5G are made of metal sheets to increase the radiation efficiency at high frequencies [10]. A matching network was necessary for the LTE 617–960 MHz band.

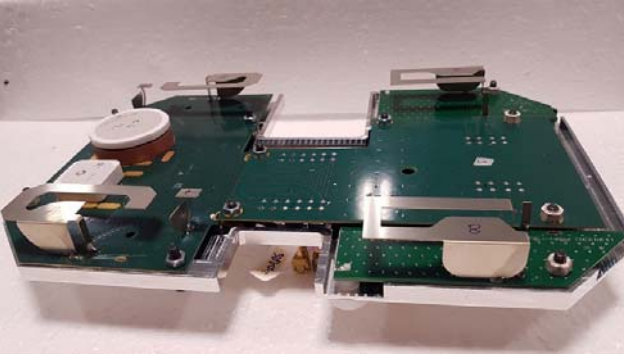


Figure 3. Prototype tested assembly.

3 Measurement setup

To test the input impedance and the radiation pattern, the antenna assembly has been placed under a dedicated hole of $300 \text{ mm} \times 215 \text{ mm}$ on the roof of a vehicle used for tests. This location is representative of the final location in real world where, the hole in the metal roof, would be closed by fiber-glass surface. A prototype of such surface has been made by using FR4 substrates of size $340 \text{ mm} \times 250 \text{ mm} \times 6 \text{ mm}$ connected to plastic clips for supporting the antenna assembly as shown in Fig. 4.

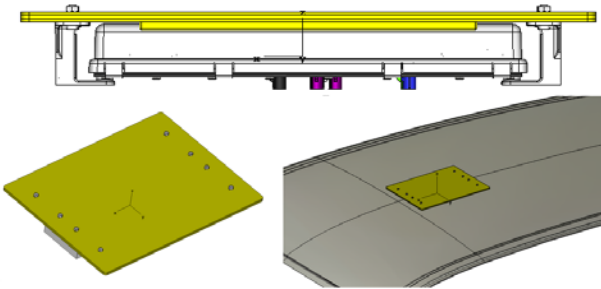


Figure 4. Fiberglass-FR4 covering support of the antenna assembly.

The antenna on the vehicle has been centered in the near-field facility as shown in Fig. 5 for the measurement of the

radiation pattern. The S-Parameters have been measured in similar condition.

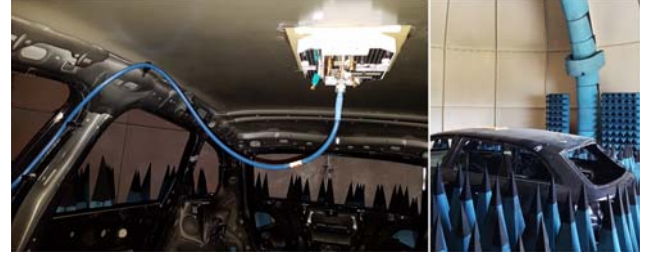


Figure 5. Setup for the measurement of the radiation pattern in MTA's near-field stargate system MVG SG 3000F [11].

4 Antenna Performances

The measured Return Loss, $-20 \log_{10} |S_{nn}|$, and linear average realized gain, LAG, are shown in Fig. 6–10. Return Loss is typically above 10 dB and LAG value from -3 dBi to 0 dBi and more. This is quite good for automotive market.

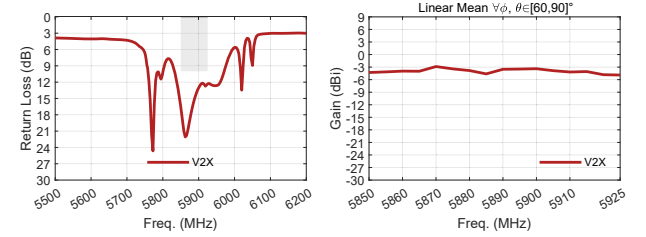


Figure 6. Return Loss and LAG of V2X monopole antenna.

Both SDARS's satellite and terrestrial Sirius-XM requirements [12] are satisfied (Fig. 7).

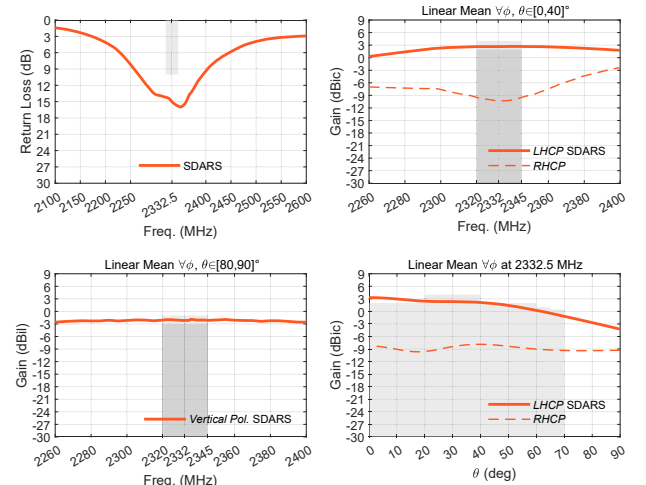


Figure 7. Return Loss and LAG of SDARS ceramic patch antenna. Sirius-XM requirements are represented in gray areas.

Axial-ratio is typically from 2 to 4 dB for GNSS (Fig. 8).

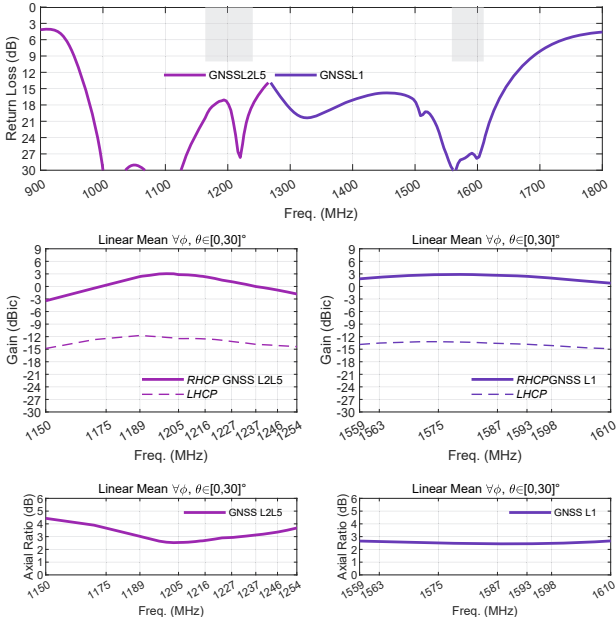


Figure 8. Return Loss, LAG and Axial Ratio of GNSS stacked ceramic patch antennas.

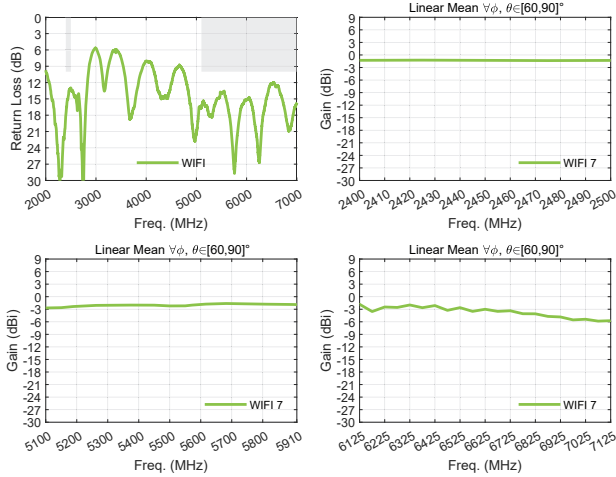


Figure 9. Return Loss and LAG of WIFI double monopole antenna.

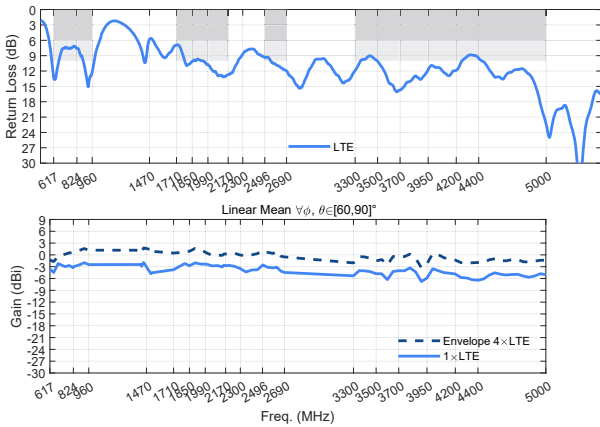


Figure 10. Return Loss and LAG of LTE single PIFA antenna activator compared with Envelope.

LTE's radiation pattern is focused outward (Fig. 11) especially at lower frequencies. MIMO Envelope 4×LTE (max among all LTEs), will compensate for this, increasing the LAG of about 3 dB with respect the single 1×LTE (Fig. 10).

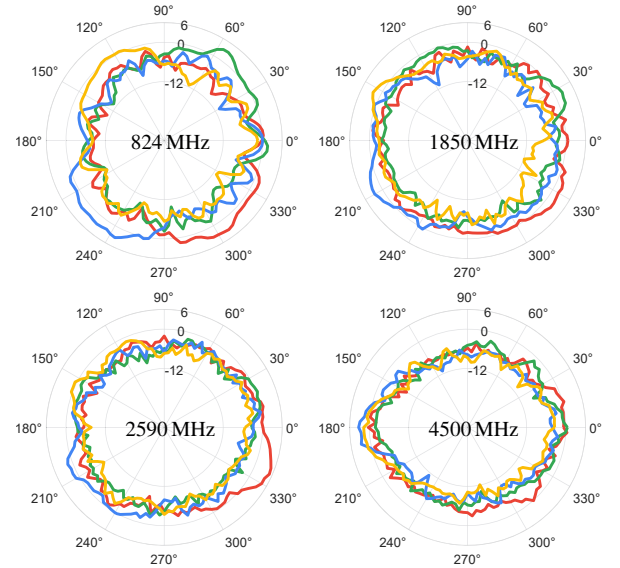


Figure 11. LAG polar pattern for $\theta \in [60,90]^\circ$ in dBi vs. azimuth- ϕ for **LTE1**, **LTE2**, **LTE4** and **LTE3**.

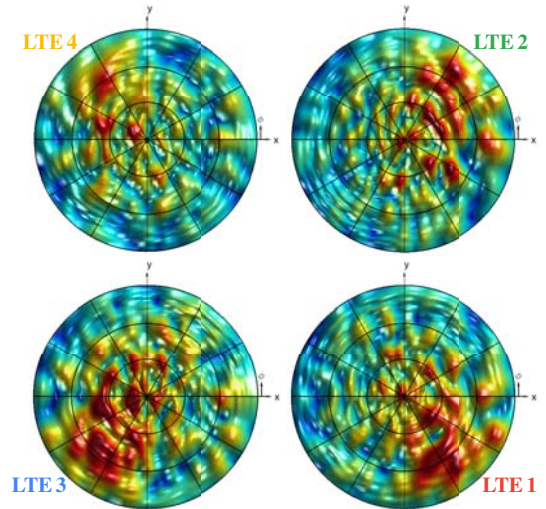


Figure 12. LTEs' polar pattern at 824 MHz from -30 dBi (blue) to 6 dBi (red) vs. azimuth ϕ and co-elevation θ (radial axis).

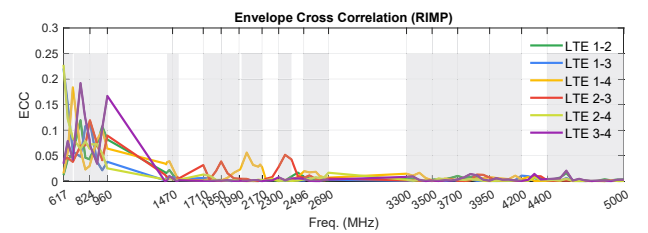


Figure 13. Envelope Cross Correlation (RIMP) among LTEs' elements.

Considering the whole LTEs' patterns (e.g., Fig. 12), the Envelope Cross Correlation in Rich Isotropic Multipath condition [13] results below 25% (Fig. 13).¹

Coupling between antenna elements is typically below -15 dB (Fig. 14). This is important because low coupling between elements means low mutual interference and higher efficiency.² In fact, the total efficiency of the n -th antenna element $e_{\text{tot},n} = e_{\text{rad},n} \cdot e_{s,n}$, where $e_{\text{rad},n}$ depends on the n -th antenna element itself, while $e_{s,n}$ depends on its mismatch loss, $1 - |S_{nn}|^2$, and the couplings with the others, S_{mn} ($m \neq n$): $e_{s,n} = 1 - \sum |S_{mn}|^2$.

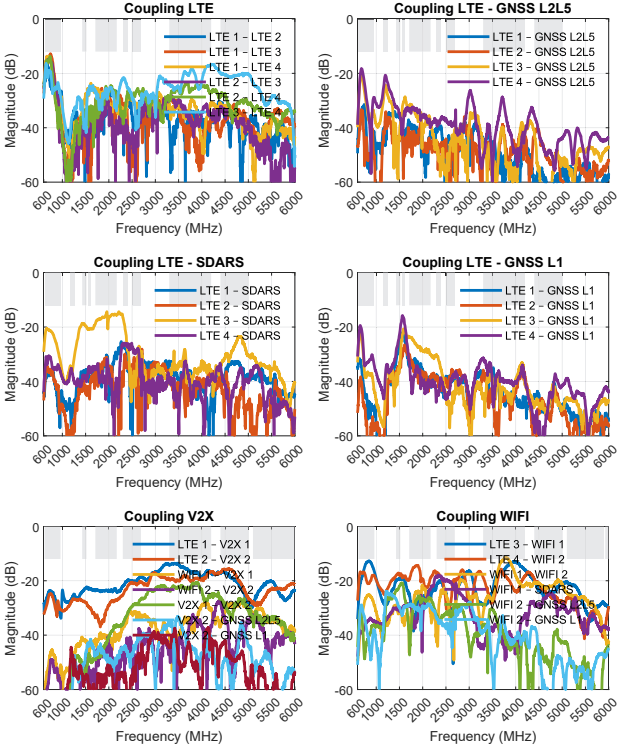


Figure 14. Coupling between antenna elements. Closer the elements, greater the coupling.

5 Conclusions

A novel module for wireless services (LTE 5G, V2X, WIFI 7, GNSS and SDARS) is proposed to be placed below a roof aperture. Spring contacts are used to connect extension-modules (containing the radiating elements) to the Telematic Control Unit, where RF front-ends and transceivers are placed.

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¹ $ECC_{mn} = |\sigma_{mn}|^2 / (\sigma_{mm}\sigma_{nn})$ with $\sigma_{mn} = \iint_{4\pi} (E_{m\theta} E_{n\theta}^* + E_{m\phi} E_{n\phi}^*) dS$.

²Total efficiency of the antenna measured in free-space, with MVG Starlab [11], is about 50% for V2X, 80% SDARS, 50–70% GNSS, 60–70% WIFI and 40–60% LTE, calculated by full pattern integration: $e_{\text{tot}} = P_{\text{rad}}/P_{\text{in}} = \iint_{4\pi} dP_{\text{rad}}/P_{\text{in}} = \frac{1}{4\pi} \iint_{4\pi} G dS$.