Versatile automobile antenna unit for roadside communication

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***Abstract—* The main goal for the CVIS (Cooperative Vehicle-Infrastructure System) project is to create a wireless network between vehicle and roadside infrastructure. CVIS includes implementation of technology components, to develop a multi-channel terminal. This terminal will be installed in a vehicle, and in this paper we report on the development of the Rooftop Antenna Unit. The antenna unit contains 5 individual antennas, including two WLAN antennas. The WLAN antenna is a broadband double-fed printed monopole antenna designed and optimized within the CVIS project. It covers the frequency band 2.0-6.7 GHz, a bandwidth of 128%. The Rooftop Antenna Unit will be used for the CVIS field trials, taking place at six different test sites throughout Europe.**

I. INTRODUCTION

The main goal for the CVIS project is to create a wireless network between vehicle and roadside infrastructure, and to use this network to share available traffic information to improve efficiency and safety within ITS (Intelligent Transport Systems) CVIS is based on the emerging CALM (Continuous Air Interface for Long and Medium Range) standards for communications between vehicles and infrastructure. CVIS includes implementation of technology components, to develop a multi-channel terminal capable of connecting with a range of potential carriers supported by the set of CALM standards. The development of the CVIS multi-channel terminal includes the design and integration of a group of antennas, leading to the Rooftop Antenna Unit. The Rooftop Antenna Unit contains five individual antennas, a DSRC (Dedicated Short Range Communication) system, a GPS antenna, a broadband GSM/UMTS antenna (named CALM 2G/3G in CVIS) and two broadband WLAN antennas (named CALM M5 in CVIS). The DSRC system and GPS antenna are commercially available components which are integrated into the Rooftop Antenna Unit. Both the GSM/UMTS and WLAN antennas are double-fed printed monopole antennas designed and optimized within the CVIS project. In this paper we report in detail on the double-fed printed monopole design for the WLAN antenna. The WLAN antenna is a broadband antenna design, covering the frequency band 2.0-6.7 GHz, a bandwidth of 128%. The antenna is manufactured in PCB involving low cost printed technology. The antenna is vertically polarized and maintains good cross-polarization discrimination throughout the frequency band. Both simulated and measured results for the WLAN antenna design are presented.

II. THE ROOFTOP ANTENNA UNIT

Table 1 contains a summary of the electrical specifications of the individual antennas of the Rooftop Antenna Unit. The CALM M5 and the CALM 2G/3G antennas must both cover many frequency bands, and it was recommended to obtain the multi-band coverage with a broadband antenna design. The Rooftop Antenna Unit will be placed on the roof of a vehicle, and omni-directional coverage in azimuth is required for both antennas, since these antennas will communicate with base stations, roadside infrastructure and other vehicles with antennas not much elevated from the ground level.

TABLE I ELECTRICAL SPECIFICATIONS FOR THE INDIVIDUAL ANTENNAS OF THE ROOFTOP ANTENNA UNIT IN THE CVIS PROJECT

Antenna	**Required frequency band coverage**	**Recommended design goals**
CALM M5 (2 ant)	2.4-2.484 GHz 5.15-5.35 GHz 5.47-5.725 GHz 5.725-5.95 GHz	S11 < -10 dB Frequency: 2.2 – 6.1 GHz (BW=107 %) Polarization: Vertical Coverage: Azimuth Omni-directional
CALM 2G/3G	875-960 MHz 1710-1880 MHz 1850-1990 MHz 1900-2170 MHz	S11 < -10 dB Frequency: 0.85 –2.25 GHz (BW=101%) Polarization: Vertical Coverage: Azimuth Omni-directional
GPS	1.575 GHz (RHCP)	COTS
CEN DSRC	5.8 GHz (LHCP) BW:5 MHz	COTS (modified version)

The CALM M5 standard opens for use of either linear vertical or circular polarization. Linear vertical polarization is chosen for our antenna designs, as vertical polarization is best suited for car roof mounted antennas. There are three reasons for choosing linear vertical over circular polarization; 1) the metallic car roof will short-circuit the horizontal component of the electromagnetic field in pointing directions along the car roof surface, resulting in a strongly elliptic polarized signal in azimuth, 2) linear vertical polarization is easier to obtain over broad bandwidth than circular polarization and 3) vertical polarization is greatly preserved in typical user environments, where radio channel measurements in [1] show that the cross polar discrimination (XPD) is typical 8 to 13 dB.

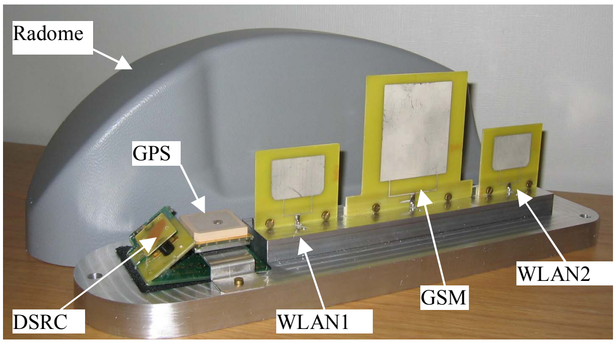

Fig. 1 A 3D illustration of the Rooftop Antenna Unit with its radome removed. The radome is shown in the background.

The Rooftop Antenna Unit also includes a GPS antenna to record position data for each vehicle, to be used for applications and safety messages where vehicle position is essential. A commercially available ceramic GPS antenna with LNA and filter is integrated into the Rooftop Antenna Unit. The CEN DSRC system is typically used for payment systems, like road tolling. The vehicle part of the DSRC system is normally fixed to the windscreen of the vehicle and it is activated when it is driven through a DSRC gateway entry. In CVIS, the commercially available DSRC system component is modified such that the antenna points in the direction of the gateway entry when it is mounted on the roof of a vehicle.

The individual antennas are integrated into an antenna base of size: 80 x 290 x 120 mm, and protected by an aerodynamically shaped radome cover. Fig. 1 shows the prototyped Rooftop Antenna Unit and the relative placement of the antennas. The aerodynamically shaped radome cover is also shown in the background of Fig. 1. The Rooftop Antenna Unit will be manufactured with a magnet base, suitable for mounting to the roof of a vehicle.

III. THE DOUBLE-FED PRINTED MONOPOLE

The basic monopole antenna has gone through various transformations to make it more wideband while keeping its radiation properties intact. It is well known that the bandwidth is increased by increasing the diameter of a wire monopole. This is extended to planar designs, where the width of the dipole is increased to obtain broad bandwidth. Planar monopoles of different shapes have been suggested, such as rectangular, square, elliptical and circular. The square monopole is either fed directly at one, two or three feed points [2], or fed by microstrip lines [3], or is electromagnetically fed [4]. The introduction of additional feed points gives an additional broadening of the bandwidth of the monopole. In this paper we introduce a rectangular monopole double-fed by a microstrip line. The design specifications for the WLAN antenna are given in Table 1 (CALM M5).

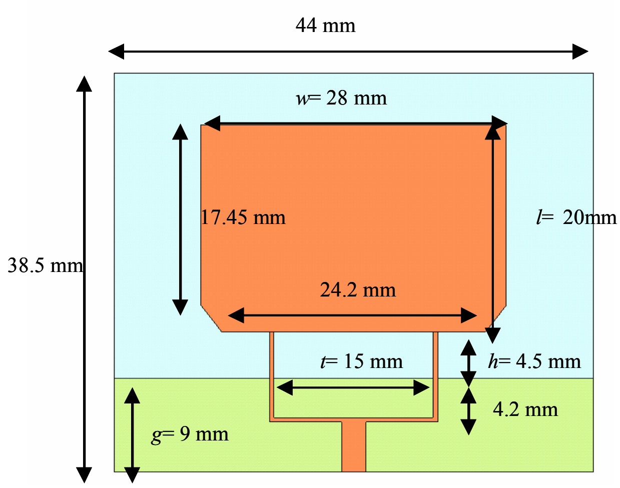

Fig. 2 Double-fed printed rectangular monopole model with trimming

Fig. 2 illustrates the planar rectangular monopole antenna double-fed by microstrip lines, together with its optimized dimensions. The low cost FR4 substrate with a relative permittivity of 4.4 and loss tangent of 0.02 was used. The thickness of the substrate and the copper layers are 1.55 mm and 35 µm, respectively. During the initial phase of designing, the broader microstrip feed line is 3 mm wide and is branched into two narrower feed lines of 0.7 mm wide. This results in a port impedance of 50 Ω. However, in the final stage this feed structure is re-configured to form a quarter-wave transformer between the monopole and the 50 Ω-SMA cable connector, thus further improving the return loss. The outer dimensions of the PCB are 44 x 38.5 mm. The parameters ***h***, ***l***, ***t***, ***w*** and ***g*** denote the distance between the upper edge of the ground and the lower edge of the monopole, length of the monopole, the distance between the feed points, width of the monopole and the height of the ground plane, respectively (Fig. 2). The height of the ground plane supporting the microstrip lines is 9 mm. In addition, in the antenna modeling phase, the antenna is placed on a metal pedestal which is 32 mm deep, 44 mm wide and 10 mm high. The dimensions of the pedestal affect the bandwidth properties of the antenna design. In an earlier stage of the project the height of the pedestal was varied, and the chosen pedestal height of 10 mm was found to contribute positively to an overall broadband antenna design. In addition the pedestal provides necessary space for connecting the antenna to a SMA connector. This antenna pedestal is mounted onto an aluminum antenna base, which is 80 mm wide, 290 mm long and 15 mm high. The antenna base houses four more antennas as shown in Fig 1. The effect of the antenna base and the other antennas are not included in the analysis model.

Ansoft HFSS version 10 was used to analyze and optimize the antenna design. In order to understand the response of the current monopole antenna to the change in dimensions, the design optimization was performed systematically changing one parameter at a time and denoting its effect on the return loss over the operating bandwidth (i.e. 2.4 GHz-6.0GHz).

Based on these analyses, an optimized design that meets our requirements was found.

In order to save the space and to highlight the effect, return loss for changing two dominant parameters simultaneously is illustrated in Fig. 3 and Fig. 4 in Smith chart. Fig. 3 shows how the simultaneous decrease of ***t*** and increase of ***h*** make the impedance response shrink to occupy a smaller area, implying that the bandwidth has increased. The decrease of ***t***, the distance between the two feed points, alone gives a significant broadening of the bandwidth in the lower frequency band. An even more compact impedance response is obtained by decreasing the length and width of the monopole by 2 mm each, as shown in Fig. 4. However the resulting impedance response is not matched to 50 ohm, as it lies away from the centre of the Smith chart where the impedance plot of an ideally match antenna would be. In order to move the impedance pattern closer the centre of the Smith chart without degrading its compactness, the widths of the feed lines are adjusted so that the feed line section represents a quarter-wave transformer between the monopole and the 50 Ω-SMA cable connector. A final improvement of the bandwidth was obtained by trimming the lower corners of the rectangular monopole. Details of the trimming can be found in Fig. 2. Fig. 5 and Fig. 6 show how the introduction of the quarter-wave transformer solution and the trimming of the monopole improve the impedance response, when being matched to a 50 ohm system.

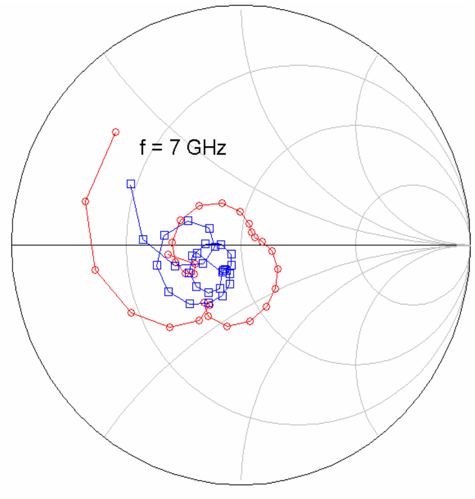

Fig. 3 Simulated return loss as a function of frequency (from 1.4 GHz to 7 GHz) when only *h* and *t* is varied. The red curve corresponds to parameter values *t* = 16.4 mm and *h* = 3 mm whereas the blue curve corresponds to *t* = 15 mm and *h* = 4.5 mm. Other parameters are fixed at *l* = 22 mm, *w*= 30 mm and *g* = 9 mm for both designs.

During measurements the antenna is mounted on a base placed on circular ground plane with 60 cm diameter. The simulated and measured return loss for the optimized antenna is illustrated in Fig. 7. The simulated and measured results for standalone antenna agree fairly well. The discrepancies are caused by the differences in analysis model and actual geometry used for measurements. For example, the antenna base is not included in the simulation model and the width of the prototyped pedestal differs from the analysis model. However, the measured response is more than acceptable within the specified frequency band, with a return loss better than 10 dB over the band 2-6.7 GHz, corresponding to a bandwidth of 128 %. Fig. 7 also shows the measured return loss when the antenna mounted on the final base with other antennas present (Fig. 1). This response is well within our original specifications.

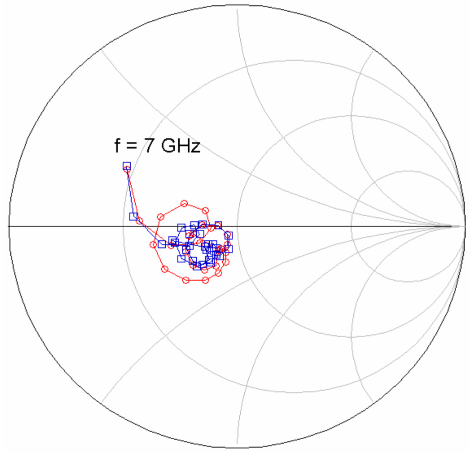

Fig. 4 Simulated return loss as a function of frequency (from 1.4 GHz to 7 GHz) when only *l* and *w* is varied. The red curve corresponds to parameter values *l* = 22 mm and *w* = 30 mm whereas the blue curve corresponds to *l* = 20 mm and *w* = 28 mm. Other parameters are fixed at *t* = 15 mm, *h*= 4.5 mm and *g* = 9 mm for both designs.

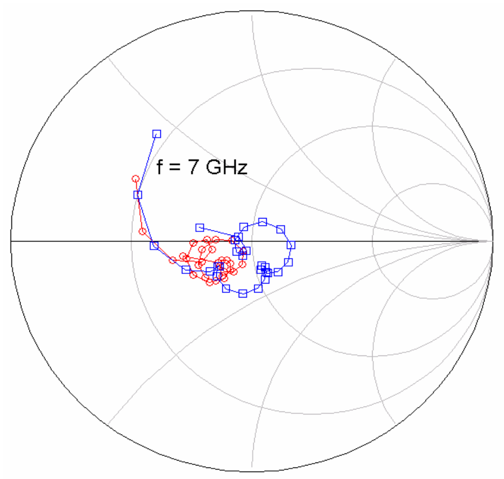

Fig. 5 Simulated return loss as a function of frequency (from 1.4 GHz to 7 GHz) with and without the quarter wave transfomer plus the trimming of the monopole. The red curve corresponds to a WLAN antenna without the quarter wave transfomer and the trimming whereas the blue curve corresponds to a WLAN antenna with the quarter wave transfomer and the trimming. Other dimensions are fixed at t = 15 mm, h = 4.5 mm, *l* = 20 mm, *w*= 28 mm and *g* = 9 mm for both designs.

Both co polar radiation patterns and cross polar radiation patterns are measured in the azimuth plane in an anechoic chamber. These radiation patterns at the frequencies of 2.45 GHz and 5.85 GHz are shown in Fig. 8 and Fig. 9, respectively. The selected frequency points are approximately equal to the centre frequencies of the outer bands listed in Table 1 (for CALM 5). The co-polar radiation patterns are nearly isotropic on the azimuth plane. The antenna is vertically polarized and maintains a good cross-polarization discrimination throughout the frequency band.

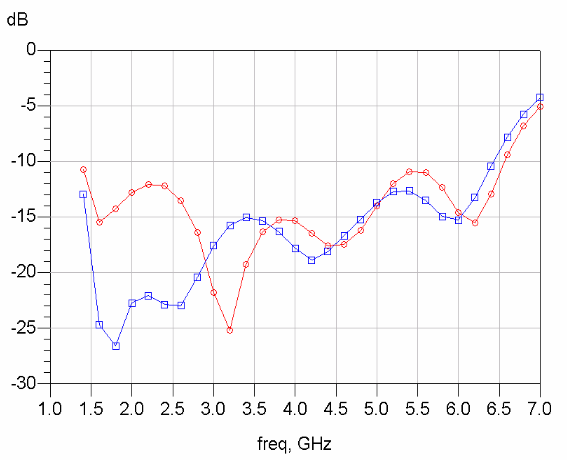

Fig. 6 Simulated return loss (in dB) as a function of frequency with and without the quarter wave transfomer plus the trimming of the monopole. The red curve corresponds to a WLAN antenna without the quarter wave transfomer and the trimming whereas the blue curve corresponds to a WLAN antenna with the quarter wave transfomer and the trimming. Other dimensions are fixed at t = 15 mm, h = 4.5 mm, *l* = 20 mm, *w*= 28 mm and *g* = 9 mm for both designs.

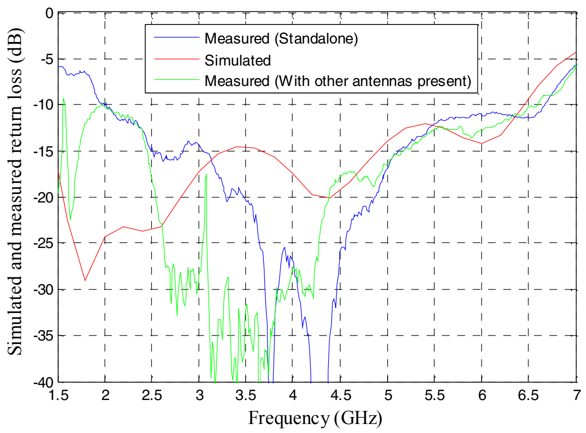

Fig. 7 Simulated (red) and measured (blue & green) return losses of the optimized antenna with t = 15 mm, h = 4.5 mm, *l* = 20 mm, *w*= 28 mm and *g* = 9 mm

IV. CONCLUSIONS

The CVIS Rooftop Antenna Unit contains a DSRC system, a GPS antenna, a broadband GSM/UMTS antenna (CALM 2G/3G) and two broadband WLAN antennas (CALM M5). Both the broadband antennas are double-fed printed monopole antennas designed and optimized within the CVIS project. We reported in detail on the double-fed printed monopole design for the WLAN antenna. The WLAN antenna is a broadband antenna design, covering the frequency band 2.0-6.7 GHz, a bandwidth of 128%. The antenna is manufactured in PCB involving low cost printed technology. The antenna is vertically polarized and maintains good cross-polarization discrimination throughout the frequency band. Both simulated and measured results for the WLAN antenna design are presented. This Rooftop Antenna Unit will be used for the CVIS field trials, taking place at six different test sites throughout Europe.

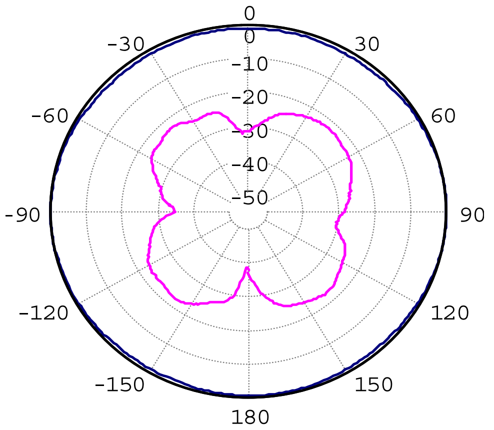

Fig. 8 Measured co (blue) and cross (magenta) polar radiation patterns on the azimuth plane at 2.45 GHz (Amplitude is in dB)

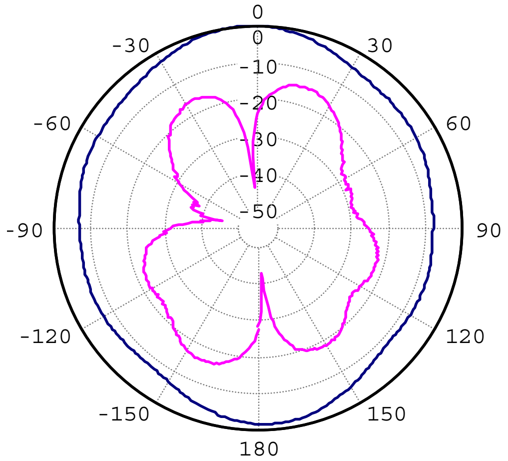

Fig. 9 Measured co (blue) and cross (magenta) polar radiation patterns on the azimuth plane at 5.85 GHz (Amplitude is in dB)

ACKNOWLEDGMENT

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