

Wideband Multi-Service Automotive Antenna Conformed to a Curved Surface

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ABSTRACT

Vehicles produced in decades past were fitted with very few antennas. In most cases only an AM or FM antenna was required. In contrast to this, today's vehicles are fitted with a plethora of antennas to receive a wide variety of signals at a number of different frequencies. This work presents a wideband radiating structure capable of sending and receiving many of the signals required in a modern vehicle from a single device. The antenna is based on Planar Inverted Cone Antenna geometry. The effect of bending or curving the antenna substrate is investigated at values in the range that may be required for vehicular integration.

INTRODUCTION

Present day automobiles are undergoing rapid development in the areas of communications, entertainment and multimedia. This trend is driving innovation in the provision of wireless services for vehicles. Only a few decades ago, the primary wireless service used in passenger vehicles was AM and FM radio. Today's vehicles however are equipped with a multitude of additional antennas for services including cellular phone signals for voice calls, GPS signals for satellite navigation, Bluetooth for connecting to portable devices, and in North America, SDARS which provides access to hundreds of radio stations via satellite. Future technologies are expected to require even more antennas in vehicles to provide access to services such as WiMAX, Wi-Fi, and Vehicle-to-Vehicle communications.

Many present day automobiles provide dedicated antennas for some of these services. However, each antenna element tends to be only narrowband, capable of receiving signals across a fairly narrow frequency range, requiring multiple antennas to be fitted to a vehicle. The antennas may be placed

in different locations across the vehicle body, or as is increasingly common, they may be housed together under a “shark-fin” style radome. This most recent approach provides an attractively styled exterior component, but can lead to excessive mutual coupling between neighboring antenna elements, distorting their radiation patterns, and may lead to high cabling costs due to the duplication of coaxial transmission lines. External antennas of all kinds, including the shark-fin, suffer from several additional drawbacks. They are prone to damage, whether accidental or intentional, and add to a vehicle's aerodynamic drag and wind noise. An alternative approach to vehicular antenna requirements would ideally decrease the total vehicle weight, reduce vehicle manufacturing costs, and provide an elegant solution to the challenge of fitting antennas for the increasing number of wireless services.

This paper describes an antenna suitable for use in vehicles. Rather than affix a specific antenna to the vehicle body for each narrowband service, we propose the creation of a color-matched radiating aperture that resembles a piece of the vehicle body itself. This aperture could contain a single antenna with a very wide impedance bandwidth, making it capable of providing almost all the necessary wireless capabilities of the vehicle. Such an aim may be realized by including a thin printed antenna geometry in a painted composite polymeric body panel such as Sheet Molding Compound (SMC) [1], which is commonly used for exterior body panels in the automotive industry.

Recent years have seen much research effort expended in creating antennas with very wide impedance bandwidths. This wave of antenna research has been driven primarily by the creation of the FCC UWB scheme, designed for transmission of pulses ranging in frequency from 3.1 to 10.6 GHz. Many wideband antenna designs have been created

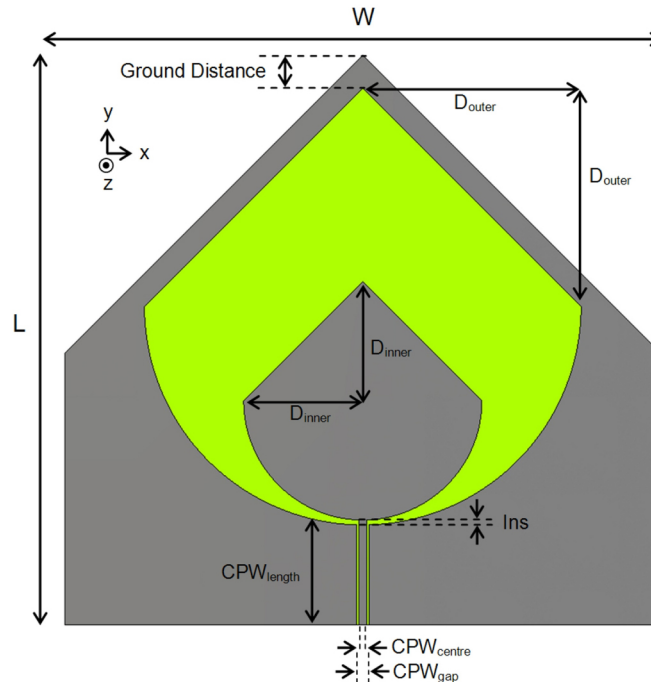


Fig. 1. Geometry of the enlarged uniplanar CPW fed PICA. Parameters: $L = 190\text{mm}$, $W = 200\text{mm}$, $\text{CPWlength} = 33.3\text{mm}$, $\text{CPWcentre} = 2.84\text{mm}$, $\text{CPWgap} = 3.24\text{mm}$, $\text{Douter} = 73.3\text{mm}$, $\text{Dinner} = 40\text{mm}$, $\text{Ins} = 0.67\text{mm}$, $\text{Ground Distance} = 10\text{mm}$, $h = 0.4\text{mm}$.

with each possessing different strengths and weaknesses, or being optimized for a given applications. The Planar Inverted Cone Antenna (PICA) is one of the wideband antennas to arise from this research. Several PICA adaptations have been proposed since its original publication by Suh et al. in 2004 [2]. In a recent paper [3], the authors presented an enlarged uniplanar PICA on a thin substrate for use in vehicular applications. In this paper, we propose further modifications to that antenna with the aim of enhancing the performance of the device in the intended application. We also determine the effect of bending on the PICA antenna, as if conformed to a curved surface, as may be the case in vehicular applications. The effect of bending is investigated by both measurements and simulations.

TRUNCATED PICA ANTENNA GEOMETRY

The proposed antenna (Fig. 1) represents a new stage in the development of the recently presented enlarged uniplanar CPW-fed PICA slot antenna [3]. The prior work presented an understanding of the method of radiation of the antenna, describing the antenna performance in terms of a combination of behaviors from two well known classes of antennas. At the low end of its band, the PICA radiates a low gain broad beamwidth pattern like a traditional Slot Antenna, while at the upper end of the band, the PICA behaves like a Tapered Slot Antenna, creating high gain in the direction of the opening of the slots. However, in the original design, the

presence of a thick ground plane at the end of the slot opening causes an undesirable split in the radiation pattern in the plane of the substrate. Hence, it was decided to truncate the upper portion of ground plane as shown in Fig. 1 (represented by the parameter “Ground Distance”). The dark grey areas of Fig. 1 represent the metalized sections of the antenna, while the light green areas show an absence of conductive metal, revealing the FR-4 substrate on which the antenna is constructed.

Fig. 2 shows the radiation pattern of the antenna both with and without the truncated ground plane. Cartesian coordinates and a thin grey outline of the antenna conductors are drawn to provide orientation. Where the ground plane is kept at the full size, the main beams of radiation can be seen to be split above and below the substrate, with a null in the x-y plane. Removal of a portion of the ground plane in the manner prescribed increases the gain in the plane of the substrate, and results in a decrease in the value of peak gain by approximately 2 dBi. This corresponds with the reduction in directivity due to the broadening of the beamwidth at this frequency. The modification is advantageous for application in vehicles because, if installed horizontally in a section of bonnet, roof or trunk, the antenna with the truncated ground plane will provide higher gain at 5.9 GHz in the direction of the horizon where roadside beacons or other vehicles are likely to be located. Therefore, the truncation of the groundplane enables the electromagnetic energy to be

directed where it is needed at the upper end of the antenna's frequency range.

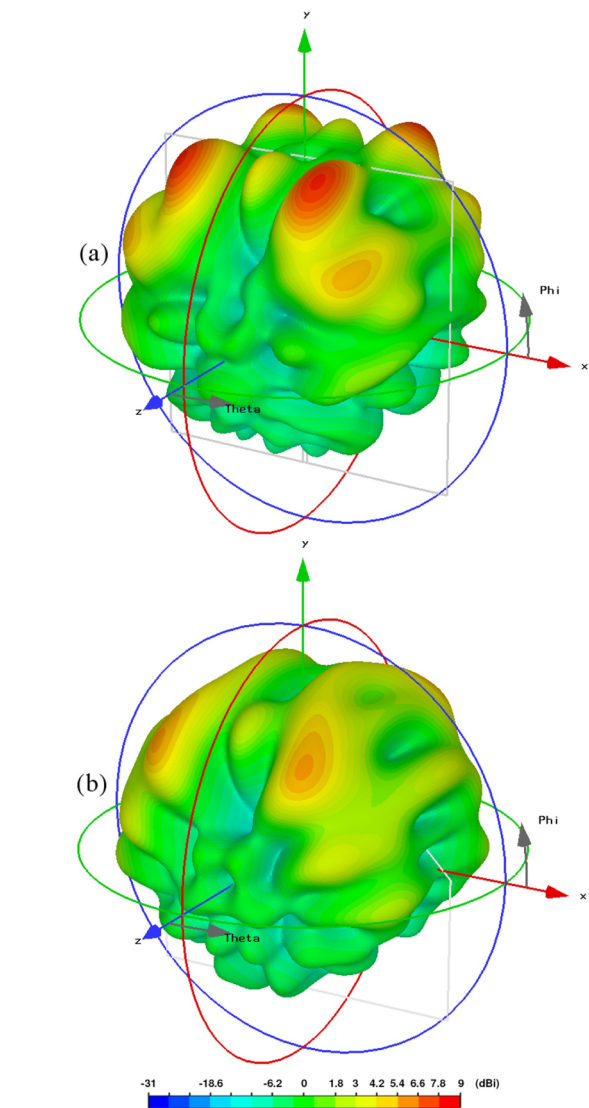


Fig. 2. Radiation pattern of the PICA antenna at 5.9 GHz, (a) with the original ground plane, and (b) with the truncated ground plane.

The Truncated PICA automotive antenna is flat and low-profile, printed on a single side of an industry standard FR-4 printed circuit board material substrate. The fabricated structure is 0.4 mm thick, enabling it to be attached to, or embedded in, polymeric components. It occupies an area of 190 mm by 200 mm and provides a good impedance match to a 50 ohm transmission line at each of the frequencies mentioned in [Table 1](#).

Table 1. Table of Services compatible with Truncated PICA Automotive Antenna.

Service Name	Frequency
Cellular Phone	850 MHz, 900 MHz, 1.8 GHz, 1.9 GHz, 2.1 GHz
GPS	1.575 GHz
SDARS	2.3 GHz
Wi-Fi, Bluetooth	2.4 GHz
WiMAX	3.5 GHz
V2V, VII, DSRC	5.9 GHz

(the reflection coefficient of the Truncated PICA Automotive Antenna is plotted in [Fig. 6](#) and [Fig. 9](#) below)

CURVED ANTENNA INVESTIGATION

Thus far analysis of the Truncated PICA has assumed that the antenna substrate is flat in the installed position on the vehicle body. This is unlikely given the styling trends of modern vehicles. Most vehicles have curved panels, and hence it is important to investigate the effect this curvature might have on antenna performance. The effect of curvature on other types of antennas has been investigated recently [4], yet to the authors' knowledge no such investigation has been performed on the PICA. Many potential antenna host sites, such as the roof or hood display curvature which is only slight, yet it may be desirable to be able to locate the Truncated PICA or other wideband antennas in panels which have curves of relatively tight radius. In order to investigate the effect of such curvature on the antenna two parallel investigations were conducted, using electromagnetic simulation tools and practical measurements in an anechoic chamber.

DEGREES OF BENDING INVESTIGATED

Curvature of the antenna was investigated in four steps of increasing angle: 0°, 22°, 45°, and 90° ([Fig. 3](#)). In order to achieve these angles for the antenna size given, the centre of the antenna is required to be displaced by 0mm, 10mm, 20mm and 40mm respectively. In order to illustrate the correlation between displacement and angle, markups are placed on the 90 degree curvature image of [Fig. 4](#).