MULTIFUNCTIONAL CONFORMAL ANTENNAS FOR AUTOMOBILE APPLICATIONS

Dejan S. Filipovic(1), John L. Volakis(2)

(1) University of Michigan, EECS Dept., 1301 Beal Ave., Ann Arbor, MI 48109-2122, USA, dejan@umich.edu
(2) As (1) above, but E-mail: volakis@umich.edu

ABSTRACT

Two new conformal, shallow and cavity-backed, slot spiral antennas with multi-band properties are presented for specific automotive applications. The first is a 2\textsuperscript{nd} mode circularly polarized slot spiral excited to operate as a broadband (return loss) / dual-band (pattern) antenna. The second is a dual-mode antenna comprised of a circularly polarized slot spiral occupying the inner (center) section and a vertically polarized annular slot occupying the outer section. Both antennas are intended for simultaneous reception of the Digital Audio Broadcasting and Satellite Digital Audio Radio Services systems in an automobile based receiver.

INTRODUCTION

Future automobiles will incorporate several antennas for a variety of communications and connectivity needs in the 800-2500MHz band. Among these are antennas for the Global Positioning System (GPS: 1.5744-1.5746GHz), Personal Communication Systems (0.824-0.896GHz and 1.85-1.99GHz), as well as antennas for Satellite Digital Audio Radio Services (SDARS: 2.3225-2.345GHz) system, Digital Audio Broadcasting (DAB: 1.452-1.492GHz) services and Bluetooth (2.4-2.4835GHz) [1]. It is desired to integrate as many of these under a single multifunctional configuration that is small and conformal. The varying requirements of these antennas in terms of gain, pattern and polarization makes their integration under a single aperture a rather challenging task. Moreover, these requirements must be satisfied in the presence of the platform rather than in isolation, thus further complicating their design.

The goal of this paper is to present new design approaches for integrating several service functionalities under a single aperture subject to given constraints. Evaluation of the antennas on the platform (with simulations and measurements) is also included. More specifically, we present new antenna designs which integrate three functionalities (SDARS, DAB and possibly Bluetooth) under a single aperture. The conformal slot spiral is used in a multimode [2] configuration, and a general design approach is presented utilizing multiple feeds and loading across the slot for band isolation. A new antenna paradigm for combining two electrically different antennas into the same physical aperture (combo-antenna) is also introduced [3]. A particular challenge addressed here is the design for concurrent radiation of circularly polarized and linearly polarized functionalities, each having different pattern and gain requirements. Good and often pre-specified over the horizon gain is also an issue for completely conformal antenna designs which account for platform interactions. We believe that this is the first time where the full design of a complex antenna was guided by full wave simulators which accounted for sections of the structure.

DUAL-BAND 2\textsuperscript{nd} MODE TWO-ARM SLOT SPIRAL

Typically excited to operate in the 1\textsuperscript{st} mode [4], the proposed two-arm slot spiral is redesigned to efficiently operate in a hybrid 1st/2nd mode for better functionality. The design is accomplished using full wave finite element-boundary integral simulations [5] and is verified with measurements. To obtain the 2\textsuperscript{nd} mode of operation the following idea was considered: If the excited traveling wave (within the slot) changes sign at the spiral center, the antenna could have a 2\textsuperscript{nd} mode-like pattern. Indeed, by offsetting the infinite balun feed from the spiral center the required conditions can be created for the slot electric field (magnetic current) to change sign as it crosses the center. With this approach, the slot spiral aperture will have a single feed for each system and an appropriate coax to slot line transitions will be utilized on the opposite arms. To find the optimal feed position, a number of feed locations at spiral radii 0.5cm≤r≤3cm were tested utilizing the finite element-boundary integral simulator until the 2\textsuperscript{nd} mode-like pattern was obtained. Further, to reduce coupling between DAB and SDARS channels, the length of the corresponding feed cables must be carefully chosen. For example, if the DAB input amplifier has small input impedance at the SDARS frequency, then the DAB cable length should be an integer multiple of odd \lambda/4, where \lambda is the guided wavelength in the coaxial cable at SDARS frequency. Thus, the feeding cable represents a quarter wavelength transformer at 2.339GHz and the traveling wave excited at the SDARS feed "sees" large impedance, implying lower coupling. If the input impedance of the input DAB amplifier is high, the length of the feeding cable should be an integer multiple of half guided wavelength at SDARS.
Of particular importance is the introduction of a design methodology for optimizing the multifunctional slot spiral performance for the pre-specified design criteria. The procedure allows for optimization of the spiral growth, arm termination, cavity size and loading, and feed location to achieve the concurrent 1st and 2nd mode operation. The resulting design combines several features, including new feeding systems (one per radiation system, thus avoiding use of filters/amplifiers), a suitable mix of spiral growth rates and a low-loss spiral arm termination, as shown in Fig.1.

As shown in Fig.2 and Fig.3, better than 4dBic for SDARS and 1.5dBic for DAB are demonstrated. Also, axial ratios of less than 3dB and gain variations in the horizontal plane that are smaller than 2.5dB were achieved. Return loss was less than -10dB for broad frequency ranges at both feeds.
An interesting property of this antenna is shown in Fig.4, where measured co-polar patterns of the antenna for a set of frequencies are taken in the same vertical plane. Antenna features frequency scanned radiation pattern while broadband impedance matching remains. This behavior is due to the hybrid 1st/2nd modes simultaneously excited due to the offset feed.

DUAL-MODE SPIRAL/ANNULAR SLOT â€œCOMBO ANTENNA

Instead of using a single multifunctional spiral and a single cavity, an alternative is to employ multiple cavities to accommodate the different bands and thus allow for more degrees of freedom in the design process. This alternative was pursued to allow for more flexibility in achieving the pattern performance at each band. In the context of this modified concept, the bands requiring circularly polarized performance are radiated by a spiral section of the aperture, whereas those restricted to vertical polarization are configured to radiate from a different section and cavity, see Fig.5. The radiation elements in the different cavities are then designed to achieve the required pattern and gain performance without adversely affecting coupling among the bands. In comparison to commercially available antennas this combo-antenna concept is unique in being small, conformal and integrated.

The combo-antenna was measured in isolation and after integration on a vehicle platform. As shown in Fig.6 gains better than 0dBic and axial ratios less than 4dB were obtained with the interior, circularly polarized 2nd mode slot spiral antenna inside the coverage cone of 30° > θ > 70°. The interior slot spiral antenna was backed by a shallow λSDARS/10 deep circular cavity. It has variable growth rate, and is more tightly wound in the 2nd mode radiating ring region. It is optimized to use only one resistor per arm, and the narrow-band feeding technique utilizing symmetrically offset dual feed system [2] is implemented. For the exterior annular slot antenna gains of better that 2dBi with nearly omnidirectional horizontal coverage (ΔG > 1dB) inside 40° > θ > 90° and across the DAB were measured, as shown in Fig.7. The exterior annular slot antenna was realized over a λSDARS/26 deep coaxial cavity. It is optimized for the minimum gain variation in the horizontal plane where maximum gain is obtained. It is much simpler and approximately 3-8 times thinner than similar designs [6]. The isolation between the interior and exterior antenna is better than 25dB.
SUMMARY

We presented novel slot spiral antenna designs for a dual-mode CP/CP or VP/CP operation in an automobile-based receiver. Realized antennas are thin (less than 1.3cm), small (diameter less than 15cm), simple and can be easily mounted on a vehicle. It was shown that their performance can satisfy stringent requirements for simultaneous reception of terrestrial (DAB) and satellite (SDARS) digital radios.

REFERENCES