S-Band Circularly Polarized Crossed Dipole Antenna for Automotive Applications

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***Abstract*- This paper presents a circularly polarized crossed dipole antenna mounted on a 1-m circular ground plane for reception of satellite digital radio signals within the S-band in automotive applications. The main radiator consists of a pair of dipole antennas connected to separate nonresonant lines of unequal length to achieve the current are in phase quadrature and right hand circular polarization (RHCP). A two-ray model utilized to provide a fast estimation method to analyze the radiation pattern characteristic of the proposed antenna. The simulation results show the ground plane influences on the radiation pattern of the antenna at specific elevation angles for satellite broadcasting system.**

Keywords*- *corssed dipole, automotive, right hand circular polarization (RHCP), satellite broadcasting

I. INTRODUCTION

Nowadays, the satellite broadcasting system for automotive applications are rapidly spreading in America and Europe. One of the important reasons is that the drivers of long-distance commuting already tired of hearing a lot of noise and poor quality of audio and video contents through traditional radio stations. This situation could be improved by using the satellite broadcasting system for broadcasting the high quality video and audio channels. The vehicle manufacturers in manufacturing process of the initial stage to the satellite radio equipment installed on the interior of the vehicle, satellite radio service provider can provide what kind of content has also became the major sticking point to attract customers.

ONDAS Media is the largest supplier of satellite broadcasting services in the Europe. It provides customers with hundreds of channels of digital radio, such as music, news, traffic, sports and data programming all over the Europe [1]. The system mainly operate in the Highly Elliptical Orbit (HEO) based on three satellites which receive the signal within 8-hours each one to achieve the purpose of the signal is not interrupted, different from traditional satellites in geosynchronous orbit (GEO) signal is likely to be blocked. It will provide high-quality service of digital entertainment to 240 million vehicles and 600 million European inhabitants a day in the future. Due to the ONDAS system has many advantages to listen to the radio, this system is subject to the attention of many vehicle manufacturers which have invested in technology of ONDAS satellite radio receiver embedded in the interior of the vehicle. ONDAS system is pursuing frequencies in S-band and L-band, respectively. The S-band comprises two portion of 30 MHz in the 1980 ~ 2010 MHz for the transmit (Tx) band and 2170 ~ 2200 MHz for the receive (Rx) band, allocated by the International Telecommunications Union (ITU) basis to the Mobile Satellite Service (MSS).

Since the receiving antenna design of the ONDAS satellite broadcasting system is not very common in the currently academic literature, the investigation of the Satellite Digital Audio Radio Service (SDARS) is another popular type of Digital Audio Radio Service (DARS) provider operating in the American in this paper, such as the Sirius satellite radio and XM satellite radio. Each satellite broadcasting provider uses different satellite and antenna requirements but their common features of the antenna like omnidirectional radiation pattern characteristics of the antenna at certain range of the elevation angle, especially at low elevation angles, reflections and shadowing effects will significantly change the antenna radiation pattern [2], simple structure, production of low-cost, to allow antennas to be incorporated onto a vehicle roof.

Table I shows the specifications and targets desired of the SDARS and ONDAS antennas for use with mobile satellite communication services, it is observed that the target minimum gain of the antenna is set to +2 dBic for Sirius satellite radio applications at elevation angles between 25^0~90^0 and for XM satellite radio applications at elevation angles between 20^0~60^0, both of them designed with the characteristics of the left hand circular polarization(LHCP), but the demand for gain values at high and low elevation angles of the ONDAS antennas different from the SDARS antennas, the minimum average gain of +4 dBic is required at elevation angle 90^0, +5 dBic is required at elevation angle between 45^0~75^0, and a value of +3 dBic is required at elevation angle 30^0, according to the comparison of the ONDAS antenna and SDARS antenna specifications, the overall required gain of the ONDAS antennas is more stringent than the SDARS antennas. Therefore, the choice of appropriate antenna structure is very important to receive satellite signals for ONDAS satellite broadcasting system. The next section will explore different types of the antennas for satellite broadcasting systems.

TABLE I
SPECIFICATIONS ON THE ANTENNA FOR SDARS AND ONDAS APPLICATIONS

Parameters	SIRIUS	XM	ONDAS
Frequency band (MHz)	2320~2332.5	2332.5~2345	2170~2200
Antenna polarization	LHCP	LHCP	RHCP or LHCP
Antenna gain (dBic)	+2~+4 (EA 90^0-25^0)	+2~+4 (EA 60^0-20^0)	+4 (EA 90^0)
			+5 (EA 75^0-45^0)
			+3 (EA 30^0)

*Note：The antenna is placed on the center of a 1-m diameter ground plane.

Many kinds of antenna have been proposed for satellite mobile communication in pervious literatures. In [3-5], an integrated antenna solution for GPS and SDARS services was proposed, the main radiating elements commonly used patch antennas, stacked in the form of design to reduce the size. The patch antenna is a very promising candidate for satellite broadcasting system due to the structure is easy to fabrication, low profile, low cost, maximum gain in the zenith direction and conformability to vehicle surfaces. Quadrifilar helical antenna also widely used for satellite communication [6-7], it has a good circular polarization characteristic, wide beamwidth and low back-lobe radiation characteristic allows it to be operated with or without a ground plane, especially in vehicles application is a very important property. In [8-9], a circularly polarized beam steering patch array antenna for mobile satellite communications is proposed, the design provides stable beam switching and generates beams that can cover the azimuth angles to achieve average gain and low circular polarization demand, but this way will increase an additional circuit area and cost.

This paper presents a circularly polarized crossed dipole antenna mounted on a 1-m circular ground plane for reception of satellite signals within the S-band (2170 ~ 2200 MHz) in automotive applications. The crossed dipole antenna structure is very suitable for satellite communications owing to it has good circular polarization characteristics, easy to fabrication and a hemispherical quasi-isotropic circularly polarized radiation pattern which can improve antenna gain at low elevation angles, especially mounted onto a vehicle roof will significantly reduce the radiation performance of low elevation angles [10]. The main radiator consists of a pair of dipole antennas connected to separate non-resonant lines of unequal length to achieve the current are in phase quadrature and right hand circular polarization (RHCP). A two-ray model utilized to provide a fast estimation method to analyze the radiation pattern characteristic of the proposed antenna. The simulation results show the ground plane influences on the radiation pattern of the antenna at specific elevation angle for satellite broadcasting system.

II. CIRCULARLY POLARIZED CROSSED DIPOLE ANTENNA STRUCRURE

The geometry of the proposed crossed dipole antenna structure for ONDAS satellite broadcasting system application operation in the S-band (2170 ~ 2200 MHz) is shown in Fig. 1. The proposed antenna consists of a pair of dipole antennas connected to separate nonresonant lines of unequal length of dipole arm *A* and arm *B*, fabricated by copper of wifth 0.8 mm and conductivity 5.8×10^7 (S/m), and fed by a 50-Ω coaxial cable with its dimension of 2.2×60 mm^2, to achieve the current are in phase quadrature and RHCP. In addition, because the crossed dipole is center fed directly from the coaxial cable, it will make the outer conductor of the coaxial cable to be a part of the radiating system. Thus, a sleeve balun which apply to proposed structure with its total length of a quarter wavelength of the center frequency 2185 MHz is required. The total length of dipole arm *A* and arm *B* is about 69.6 mm and 58 mm, respectively.

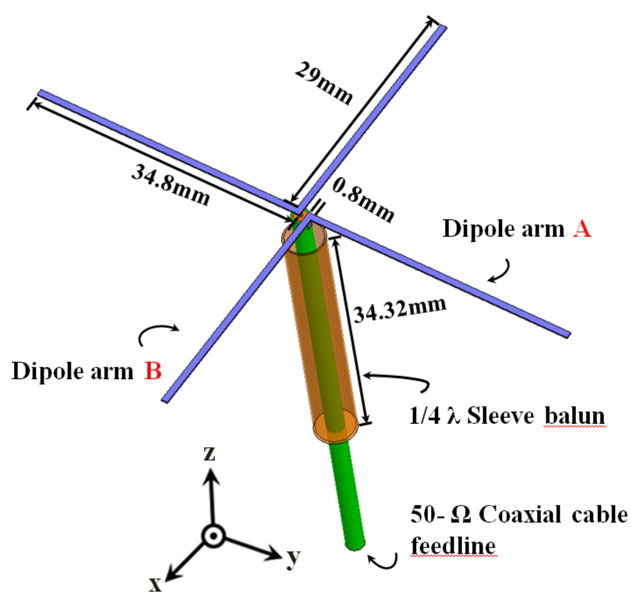

Fig. 1. Geometry of the crossed dipole antenna

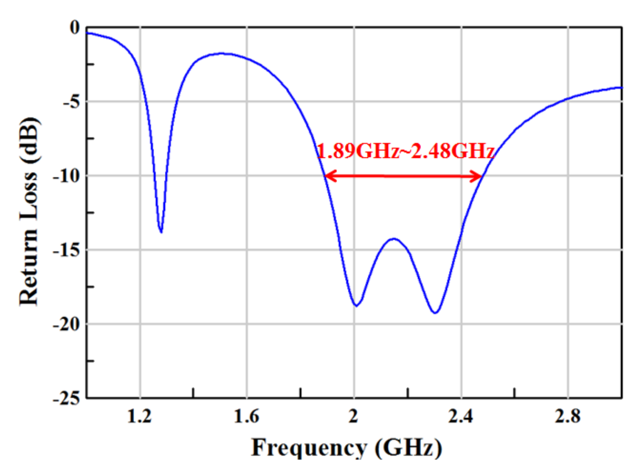

Fig. 2. Simulated return loss for the proposed antenna

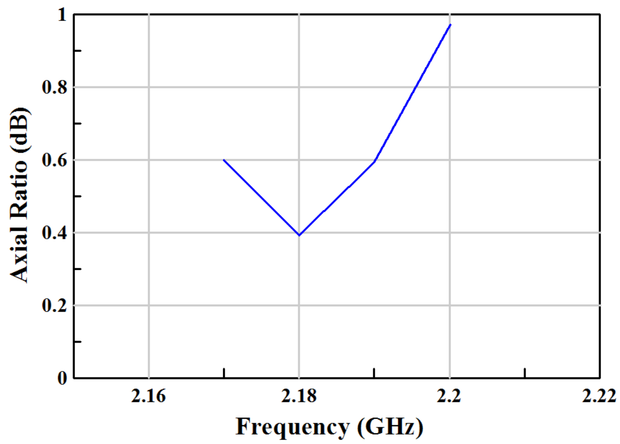

Fig. 3. Simulated axial ratio for the proposed antenna

Fig. 2 shows the simulated return loss for the constructed prototype with dimensions given in Fig. 1. The simulated bandwidth is 1890 ~ 2480 MHz (590 MHz) based on 2:1 VSWR, the impedance bandwidth shows a good impedance matching and could completely operate in S-band for ONDAS satellite broadcasting system. Fig. 3 represents the Axial Ratio (AR) at S-band in the zenith direction (+z direction), it is observed that the AR bands in S-band are lower than 1 dB, thus the proposed antenna has good circular polarization characteristics. The commercial program high frequency structure simulator (HFSS) based on the finite-element method (FEM) is used for analyzing the behavior of proposed model and determining suitable values of parameters [11]. The simulated radiation patterns at 2185 MHz in the x-z and y-z planes are shown in Fig. 4. The pattern are mainly RHCP for +z direction corresponding to the requirement of ONDAS antennas, and LHCP for –z direction, this radiation pattern characteristics can help to design of the antenna mounted on a ground plane in next section.

III. CP Crossed Dipole Antenna Monted on a Ground

The integration of various automobile communication services of antenna is a serious challenge for engineers. One of the most important factors is the mounting environment will significantly affect the properties of the antenna, especially for satellite communications, the average gain of antennas may be defined strictly. Consequently, the antenna mounted on a circular or square ground plane extensively used to examine the radiation performance of the antenna, and the measurement results will be adopted [2]. Fig. 5 shows the crossed dipole antenna mounted on the center of a 1-m circular ground plane as a vehicle roof, where *h* is the height between the horizontal crossed dipole antenna and the ground plane, due to the presence of the ground, the far field radiation pattern is the resultant of a direct wave and a wave reflected from the ground plane. To acquire the radiation pattern of the far field, it is convenient to simplify and create an equivalent model to analysis of the performance of radiation pattern.

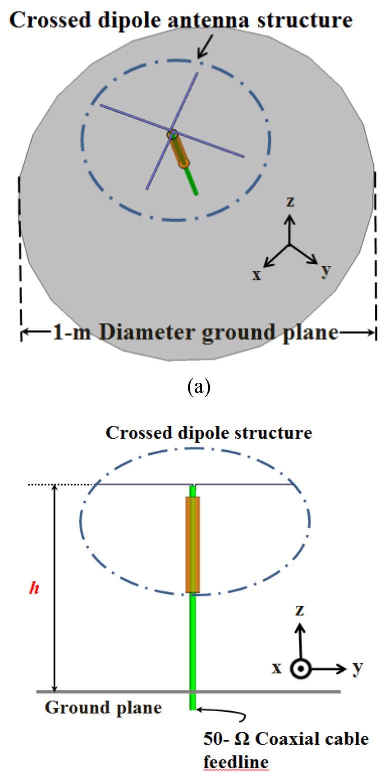

Fig. 5. Geometry of the crossed dipole antenna mounted on the center of a 1-m circular ground plane (a) full view and (b) side view

In Fig. 6, the equivalent two-ray model of antenna mounted above an infinite ground plane is proposed. Herein, it is assumed that the ground plane is perfectly conducting and the tangential electric field should be zero at the surface of ground plane. Therefore, the reflected wave must have a phase reversal of 180° at the reflection point to satisfy the boundary condition. The direct and reflected waves are toward the point *G* at far filed region. In this model, the ground plane can be replaced by an image of antenna element at the same distance *h* below the ground plane on the basis of image theory [10]. The current distribution on the antenna and image one are equal in magnitude but opposite phase. Hence the tangential electric field must be zero along the entire ground plane which is the reason that the ground plane can be replaced by image element. To obtain the total field at point *G*, the overall antenna structure consisting of the antenna and image one should be considered to be in the form of the end-fire array, therefore, the radiation pattern characteristic will be affected by the array factor and pattern factor, as shown in Fig. 7. The gain in field intensity of the antenna can be calculated in following expressions：

$$G_f(\theta) = |2\sin(h_\alpha \cos\theta)| \qquad (1)$$

Fig. 7 and Fig. 8 show the comparison of calculated and simulated radiation pattern by varying the height *h* to operate at the 2185 MHz, respectively. The simulated results show a good agreement with the calculated results to verify this model is feasible. From the results, if the height h was about 0.25λ or less, the maximum radiation is always in the zenith direction (elevation angle 90^0), as the height increases to 0.3λ, 0.4λ, 0.5λ or 1λ, the maximum radiation is in elevation angle between 0^0-90^0. Fig. 9 show the comparison of the average gain of specific elevation angles by varying the height h between the antenna and the ground plane, if h varies from 0.25λ to 1λ, the average gain of high elevation angle 90^0 will be decreased significantly, furthermore, as the height is nearly 0.5λ or higher, the radiation pattern in certain directions may generate additional null points, this result for ONDAS antenna requirements is not a good situation for reception of satellite signals. If the height selected about 0.25λ or less, the average gain of low elevation angles between 45^0-30^0 cannot meet the specifications of ONDAS antenna. Therefore, the best height of h should be between 0.25λ and 0.5λ, finally, the height is fine tuned to h=0.36λ.

IV. Conclusions

A circularly polarized crossed dipole antenna mounted on a 1-m circular ground plane for reception of satellite digital radio signals within the S-band (2170 ~ 2200 MHz) for ONDAS satellite broadcasting system is proposed. The crossed dipole antenna structure is very suitable for satellite communications owing to it has good circular polarization characteristic and a hemispherical radiation pattern to achieve a stable signal reception. In this paper, a two-ray model utilized to provide a fast estimation method to obtain the desired radiation pattern for satellite broadcasting system applications, the simulated results show a good agreement with the calculated results, and a good performance in the radiation efficiency can be reached, thence, the proposed antenna structure can be a very promising candidate for ONDAS satellite broadcasting system.

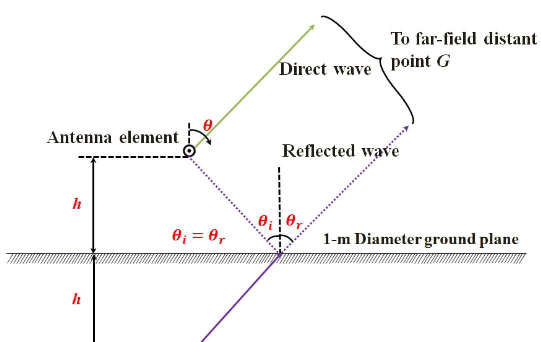

Fig. 6. The two-ray model of antenna above the ground with image element

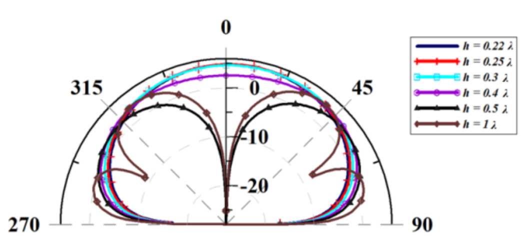

Fig. 7. Calculated radiation pattern for various height of h at vertical-plane

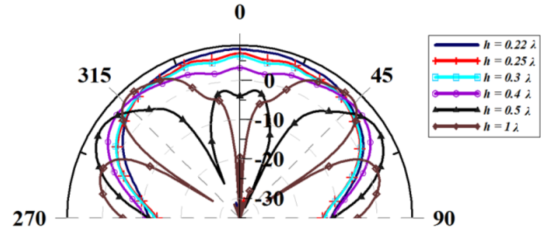

Fig. 8. Simulated radiation pattern for various height of h at vertical-plane

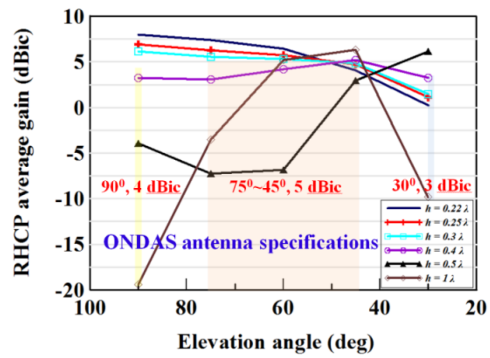

Fig. 9. Simulated RHCP average gain at specific elevation angles

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