A Superdirective and Reconfigurable Array Antennas for Internet of Vehicles (IoV)

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Abstract. This paper presents a prototype design of antenna for Internet of Vehicle (IoV). Presented antennas is an array of 4 quarter-wavelength monopoles set in form of lozenge and on an infinite ground plan confused to vehicle's roof. Monopoles are 2 by 2 linearly associated and are excited properly in magnitude and phase. Uzkov's theory is first used to calculated appropriate excitation coefficients and after that Non-Foster circuit theory for determining an impedance-matched with a Z_{load}. Ansys HFSS is used for simulations and results show a good bandwidth and particulary a superdirectivity in order of 8.2 dB reconfigurable in a desired and useful direction.

Keywords: Superdirectivity · End-fire · Impedance active · IoV

1 Introduction

Internet of Things (loT) is a world-wide network connecting all the smart objects together. It is the way in which all things are enabled to talk with each other. Whenever those smart things being connected over internet are restricted to only vehicles, then it is called as Internet of Vehicles (loV). According to recent predictions, 25 billion things will be connected to the Internet by 2020, of which vehicles will constitute a significant portion. In other words, IoV is the largest communication network between vehicles, vehicles owners and some third parties like servers ect. So we establish:

- A communication between the vehicles and the vehicle owners for:
  - security alert about the vehicle,
  - damage alert about the vehicle,
  - the attributes like proximity, tyre pressure and vehicle lock ect.

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- A communication between vehicles defining
  - Proximity between the vehicles,
  - The immediate surroundings of a vehicle through onboard cameras,
  - Speed of vehicles within a particular radius of the vehicle under consideration,
  - Tyre burst related accidental information.
- A communication between vehicles and a centralized server which stores and analyzes datas for the suitable solution
- A communication between server and third parties like police patrol, ambulance, fire-engine, etc.

By that way, detected and been capable to react either to a security inside and outside the vehicle or a human proximity or a thief in a seconde need absolutely an array antennas able to respond to that high need of permanent and directive connectivity.

In that paper, we present an array of 4 quater-wavelength monopoles antennas superdirective with radiation pattern reconfigurable in a desired direction. This array antenna maximize directivity as never obtained before for the least latence but allow to cover all 360 deg azimutal plane with radiation pattern reconfigurability in a desired direction.

2 Antenna Design

Our design is a 4 quarter-wavelength monopoles 0.1λ spaced. Antennas are made cooper and set on an electrically perfect ground plane considered as infinite as a vehicle's roof; we consider for that case a circular ground plane with a radius of 250 mm. We work it in a test simulation at 5.9 GHz resonant frequency with simulator Ansys HFSS.

2.1 Theorical Study

Theorical works on the design of materials giving a high directivity with moderate dimensions has since ever undergo a lot of research. Osseen has been the first most prolific one to state in his old works that it is theorically possible to have a directivity as high as desired with an antenna of arbitrarily small dimensions. Later, Harrington showed so far that a directivity in order of $N^2 + N$ can be obtained with a single antenna, with N representing the highest mode [1]. However, the most significant works for a large number of associating radiators is from Uzkov [2], who states in 1946 the possibility to make a superdirectivity, meaning a directivity in order of N^2, by linearly associating a larger number N of closely spaced radiating elements. Then, he showed from Eqs. (1) and (2) defined below that this directivity can be in a desired direction (θ, ϕ) when radiating elements are properly excited.

$$a_{0n} = {H_{mn}^*}^{-1} . e^{-jkr_0.r_m} . f_m^*(\theta_0, \phi_0) . f_n(\theta_0, \phi_0) \tag{1}$$

$$H_{mn} = \frac{\langle \frac{1}{4\pi} \rangle \int_0^{2\pi} \int_0^{\pi} f_m(\theta,\phi).f_n^*(\theta,\phi) e^{jk\overrightarrow{r}.(r_m - r_n)}}{\sin\theta \partial\theta\partial\phi} \tag{2}$$

where

$f(\theta, \phi)$ is the far field in the (θ, ϕ) direction.
$f(\theta_0, \phi_0)$ is the far field in the (θ_0, ϕ_0) direction.
$\overrightarrow{r}$ is the far field vector in the (θ, ϕ) direction.
$\overrightarrow{r_0}$ is the far field vector in the (θ_0, ϕ_0) direction.
(θ_0, ϕ_0) is the direction (θ, ϕ) where the maximum directivity of the system can be attained.

Matrix a_{0n} are so far currents excitation coefficients which allow to properly excite antennas in magnitude and phase in order to maximize directivity in a desired direction (θ_0, ϕ_0).

Since ever then multiples works have been done theorically and in practice, proving that properly excited in magnitude and phase array antennas closely spaced can provide superdirectivity.

Altshuler et al. show in multiples and significants works with two quarter-wavelength monopoles 0.5λ spaced and excited by currents equal in magnitude but specifically different in phase, that a directivity of about 7.5 dB in the end-fire direction can be reached. This directivity slowly increases as the spacing is decreased and approach values of 9.8 dB and 10.5 dB for respectively distance of 0.2λ and 0.1λ between monopoles [3–5]. In an other way, in some others works, Donnell et al. shows that a similar gain of about 10 dB can be approximately reached when one of two elements 0.145λ spaced is excited and the other one shorted as a "parasitic" element [4]. Best et al. confirm this late possibility in 2 straight-wire monopoles by matching one of his this by an impedance [7].

However, since we state in our previous works that it is more benefit in term of mutual coupling for a two linearly associated monopoles to match antenna with Non-Foster circuit [11], we calculated appropriate Z_{load} (R, L and C) as defined below by Eqs. (3) and (4) to charge one antenna and to excite the other one by unity. For that, first is calculated the impedance matrix H_{mn} used it secondly to determine the current excitation coefficients a_{0n}. All calculations and simulations are done with Ansys HFSS, mostly for far fields determination in all values of (θ, ϕ).

$$Z_{active} = \frac{V(n)}{I(n)} = Z_{nn} + \sum_{\substack{m=1 \\ m \neq n}}^{N} Z_{mn} I_m \tag{3}$$

$$Z_{load} = -Z_{active} \tag{4}$$

Matrix Z_{mn} calculated give a Z_{load} with 37.191Ω resistance and $13.4485nF$ capacitor in a parallel circuit. So, as shown in Fig. 1, a design of 4 monopoles 2 by 2 linear is proposed. Monopoles are each others 0.1λ spaced in form of lozenge. The ones in the x-axis are 0.245λ length and excited by a unit power but the others in y-axis are 0.24λ length and charged with Z_{load}. So the principle

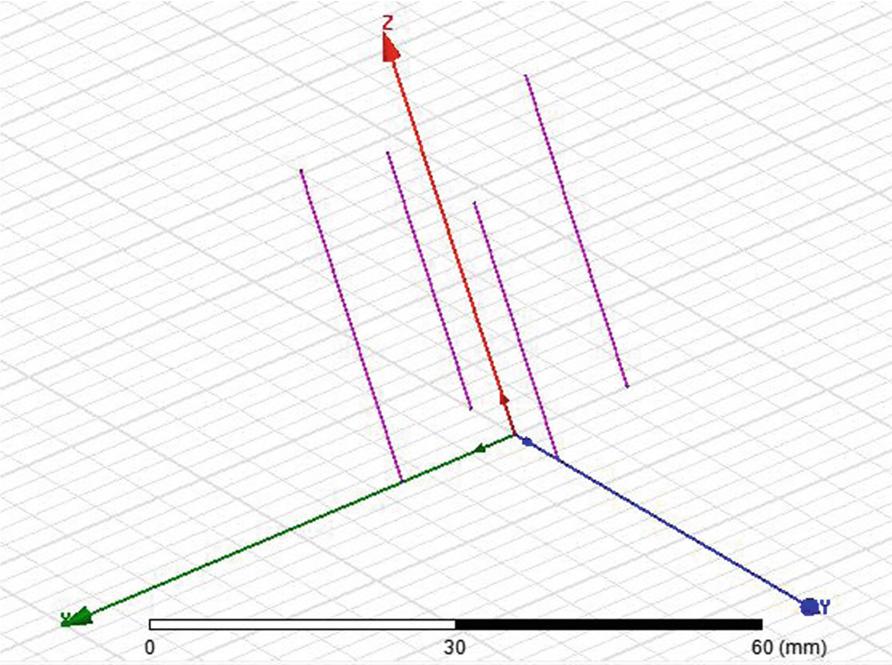

Fig. 1. Antennas geometry

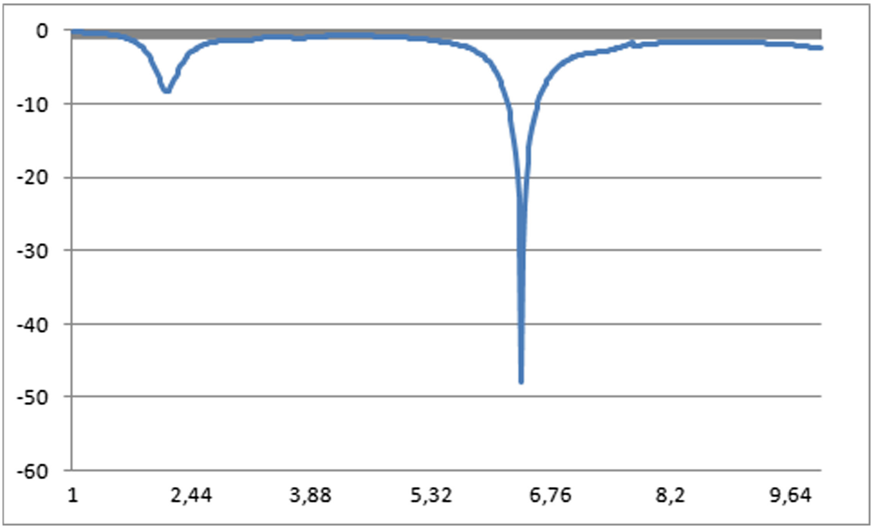

Fig. 2. S-Parameters

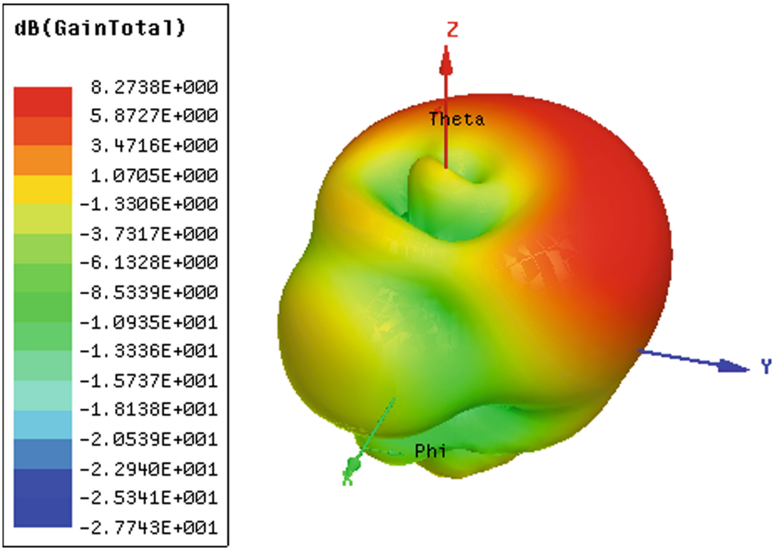

Fig. 3. Situation 1: 3D radiation pattern

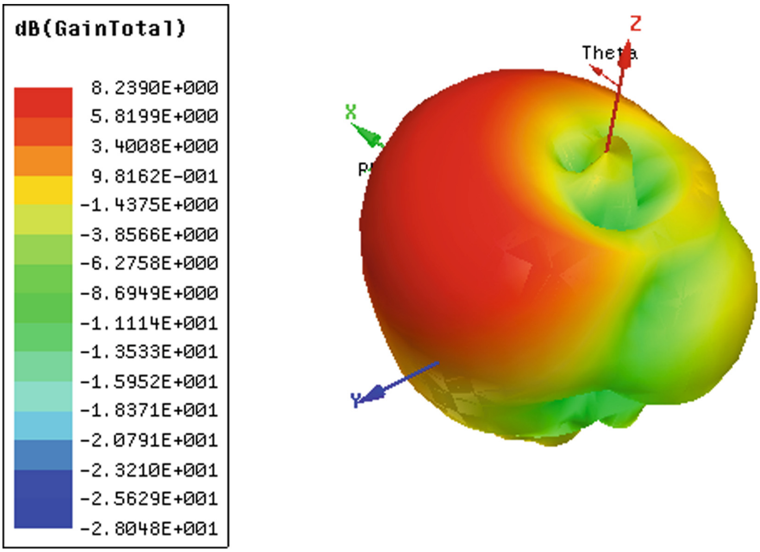

Fig. 4. Situation 2: 3D radiation pattern

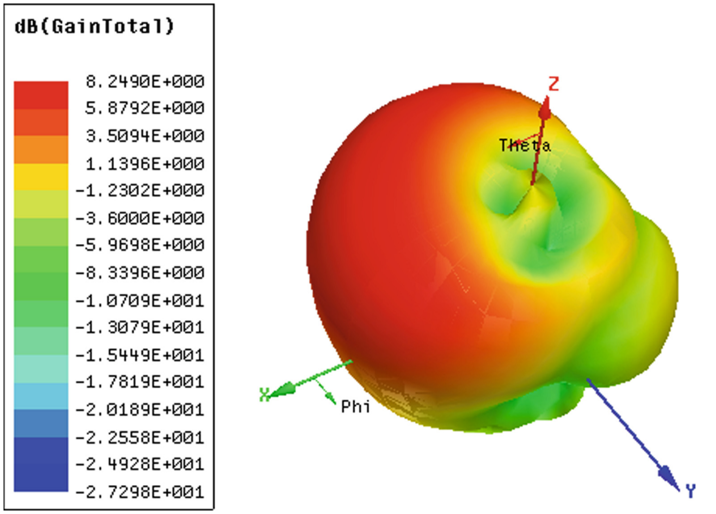

Fig. 5. Situation 3: 3D radiation pattern

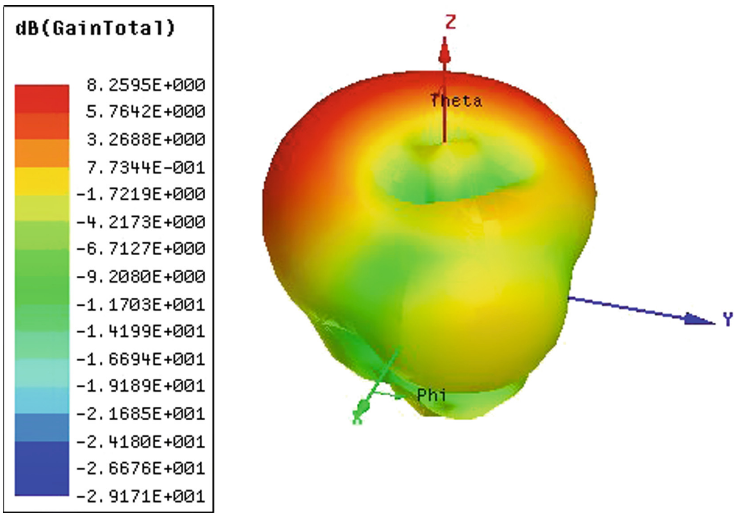

Fig. 6. Situation 4: 3D radiation pattern

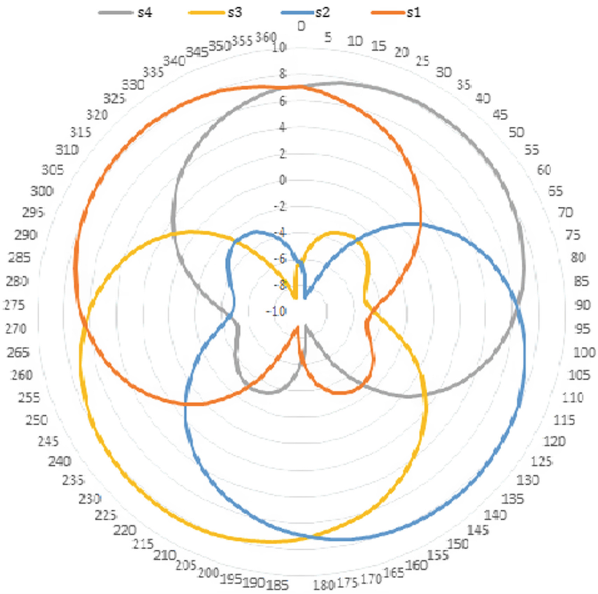

Fig. 7. All situations: 2D radiation pattern

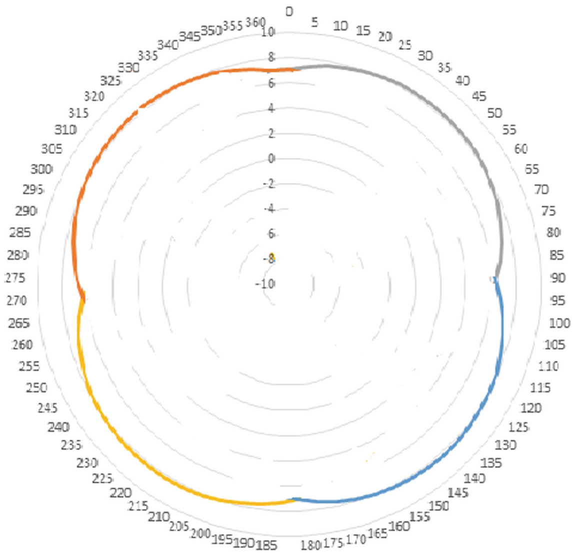

Fig. 8. 2D radiation pattern

is at any cases the monopoles 1 and 3 in x-axis are both excited at same time and at any cases the monopoles 2 and 4 in y-axis are both charged at same time. So situations are:

– Situation 1: Monopole 1 is excited by a unit power, Monopole 2 is charged by Z_{load} and monopoles 3 and 4 act like parasitic elements.
– Situation 2: Monopole 1 is excited by a unit power, Monopole 4 is charged by Z_{load} and monopoles 2 and 3 act like parasitic elements.
– Situation 3: Monopole 3 is excited by a unit power, Monopole 2 is charged by Z_{load} and monopoles 1 and 4 act like parasitic elements.
– Situation 4: Monopole 3 is excited by a unit power, Monopole 4 is charged by Z_{load} and monopoles 1 and 2 act like parasitic elements.

All of this cases are programmable by pin diodes which allow to swich all the time in the needed (θ_0, ϕ_0) direction until covered all 360 deg azimuthal plan for reconfigurability. Cases as stated below by Figs. 7 and 8 are in order to reconfigure the directivity, for 360 deg azimuthal plan coverage.

2.2 Simulation and Results

The antenna array as stated is an array of 4 monopoles 0.1λ spaced one from others, in form of lozenge and linear 2 by 2 associated. Monopoles are used for IoV at 5.9 GHz frequency (5.875 GHz–5.905 GHz), with an infinite ground plan confused to vehicule's roof. Simulations are done as stated with Ansys HFSS.

Results show that array antenna has good bandwidth of more than 30 MHz and −20 dB at 5.9 GHz resonant frequency as shown by Fig. 2. Figures 3, 4, 5 and 6 relate a supergain of about 8.2 dB reconfigurable as we can see it in a desired direction. Situations 2 and 4 are respectively reconfigurable cases of situations 1 and 3. Thus, an integral coverage of all 360 deg of azimuthal plan is so far obtained as stated by Figs. 7 and 8 with $s1$ meaning situation 1, $s2$ situation 2, $s3$ situation 3 and $s4$ corresponding to situation 4.

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