Designing a Dual-Polarized Octave Bandwidth Bowtie Antenna for a Linear Array

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***Abstract*—In this paper, we propose a linear array configuration for Random Line-of-Sight Over-The-Air testing set-up in anechoic chamber. For this aim, we use the self-grounded dual-polarized bowtie antenna as the element in the array. We present a new design of the bowtie to improve the array performance in terms of reflection coefficient and directivity. The new design has a simpler profile to manufacture. A good reflection coefficient performance has been achieved over the entire band of interest, i.e., 1.6-3GHz. The directivity of the array is almost constant for both polarizations over the entire frequency band.**

***Index Terms*—OTA, Random-LOS, MIMO, Bowtie.**

I. INTRODUCTION

Autonomous cars will most likely play a major role in transportation systems in the near future. Potential advantages over non-autonomous cars are many, e.g., route planning, human safety, fuel efficiency, etc. To achieve these potentials, autonomous cars should have a fast and reliable connection to the nearby networks and to other cars too. Therefore, OTA (Over-The-Air) performance testing of wireless communication to cars will become indispensable [1],[2].

The OTA testing of wireless devices can be performed in both anechoic and reverberation chambers. The former is able to emulate the LOS (Line-of-Sight) propagation channel and the latter is used to emulate RIMP (Rich Isotropic Multipath) environment. Cars in highways mostly experience LOS connection to the base stations and also to the neighboring cars. The term Random-LOS propagation channel has been introduced in [3], [4] to take into account the randomness introduced by the location of base stations and the randomness in the positioning of the communication devices. The term random refers here to the randomness of both polarization and AoA (Angle-of-Arrival) of the LOS component. However, in automotive car applications, the polarization of the LOS component can be assumed to be fixed, because of the fixed position of the car. Also in this case, the AoA can be restricted to the horizontal or near the horizontal plane.

A simple Random-LOS set-up is described in [1]. In that set-up, a car is located on a turntable in an anechoic or semi-anechoic chamber. The far-field of the antenna on the car can be measured by means of a linear array placed at a short distance from the turntable, i.e., in the radiative nearfield region of the array. The performance of the car antenna can be measured in terms of PoD (or throughput) by connecting the output ports of the array to the wireless communication test instrument. Initial experimental characterization of an active LTE MIMO (shark-fin) car-mounted antenna in Random-LOS OTA is given in [5]. Also, a first experimental comparison of the OTA characterization of this antenna in both RIMP and Random-LOS is shown in [6]. In both these investigations we used a single bowtie element antenna to emulate a base station antenna (the chamber antenna) communicating with the DUT (Device Under Test) on the car. However, a much larger antenna may be needed to obtain a large enough test zone emulating an incident plane wave at the DUT.

In order to be able to characterize MIMO OTA performance in Random-LOS, it is necessary to use an array with dual polarized elements [7], [8]. In addition, the bandwidth of the element should cover various LTE bands. These specifications for the element come in contrast with the compactness of the array. Furthermore, using a large element can result in having grating lobes at higher frequencies within the frequency band of interest. So, a compromise between different competing constraints need to be accomplished. A preliminary study for the array configuration has been done in [2]. Other alternative configurations are analyzed in [9] and [10].

In this paper, first the previously design self-grounded dual-polarized bowtie antenna is used to simulate a 9×1 horizontal linear array.

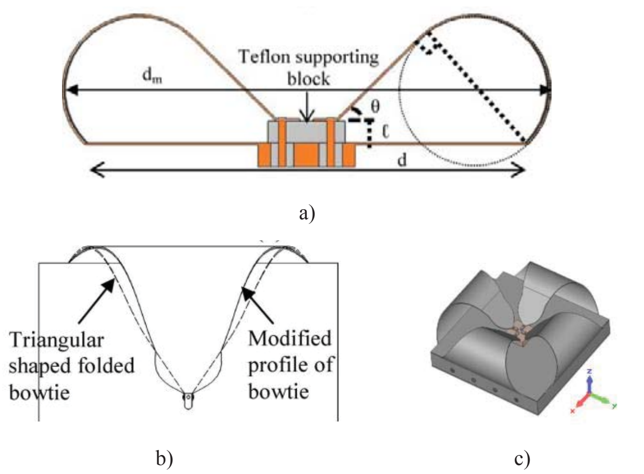


Fig. 1: Basic geometry of self-grounded dual-polarized bowtie antenna a) cross section view b) top view of a folded petal c)3D view [5]

Then we change the geometry of the antenna to simplify the manufacturing procedure and improve the array performance. The performance of the linear array antenna with elements based on the new design of the bowtie element is presented in terms of reflection coefficient and directivity.

II. USING A PREVIOUS DESIGN OF THE BOWTIE ANTENNA ELEMENT IN A LINEAR ARRAY CONFIGURATION

A. Previous design Bowtie antenna

As a starting point we show here results of the performance of a linear array based on the self-grounded bowtie antenna presented in [11]. In the array environment, the antenna is used in a 2-port mode by differential excitation of opposite petals. The bowtie itself has a reflection coefficient below -10dB over the frequency band 1.6-3.2GHz and the directivity of the bowtie changes between 5.0 and 6.5 dBi over the bandwidth. The structure of the bowtie is rather compact. The highest dimension of the antenna is around 1.18λ at the highest frequency within the -10dB bandwidth of the antenna.

B. Array results

Simulations of the antenna in an infinite horizontal linear array are performed using the CST microwave studio software. The boundary condition along the *x*-axis has been considered as infinite periodic. The array size and the element spacing of 125mm are assumed based on the study in [2]. The reflection coefficient of the active element (i.e. when element is in the array) and the directivity of the corresponding 9×1 linear array for both orthogonal polarization excitations are shown in Fig. 2. As can be seen, a null in the directivity of the linear array appears at 2.3GHz. This effect is accentuated when the petals with polarization in the direction of the array are excited as shown in Fig.2b). The radiation patterns of the array at different frequencies are shown in Fig. 3. We can conclude that the marked difference arises from the fact that grating lobes appear along the array. The radiation characteristics are affected due to the direction of radiation of the grating lobes towards the elements along the dimension of the array. This is known as scan blindness [12]. As can be seen in Fig.2, it doesn't affect the matching of the antenna significantly; However, the directivity drops drastically.

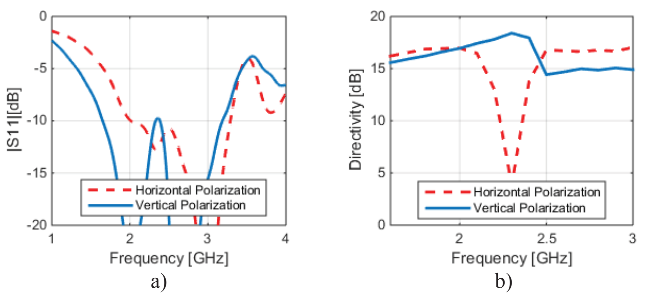


Fig. 2: Simulation results of infinite linear array made by the self-grounded bowtie: a) reflection coefficient of the active element and b) directivity of a 9×1 horizontal linear array for exciting both polarizations

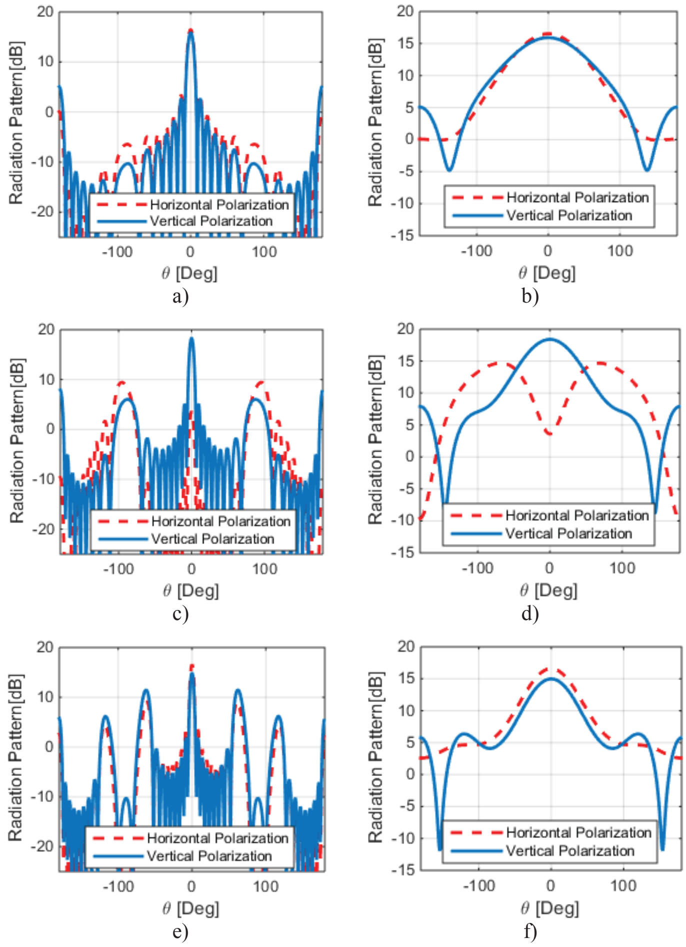


Fig. 3: Radiation pattern of a 9x1 linear array at frequencies of 1.7,2.3 and 2.9GHz (different rows) and in horizontal (left column) and vertical (right column) plane for different polarizations

As shown in [12], the requirement of non-radiating grating-lobes is

$$d_a \leq \frac{\lambda}{1+\left|\cos\alpha_0\right|+\left(\lambda/L\right)}, \quad (1)$$

where α_0 is the direction of the main beam of the array, d_a is the inter-element spacing and L is the length of the array. Considering a long end-fire linear array, grating lobes start to show when the element spacing is equal to λ/2. If the spacing is equal to λ, the grating lobes are oriented along the array direction. Choosing d_a =125mm, α_0=0° and a long enough linear array as in our design the grating lobes will come along the array at the frequencies around 2.4GHz. Since the radiation pattern of the element is directive, the grating lobes are only visible at higher frequencies.

III. IMPROVED BOWTIE IN ARRAY CONFIGURATION

In addition to controlling inter-element distance, grating lobe problems can also be avoided by suppressing them with the element pattern [12]. To suppress the grating lobes and, at the same time, to simplify the manufacturing process, a new bowtie antenna element is presented.

A. New Bowtie design

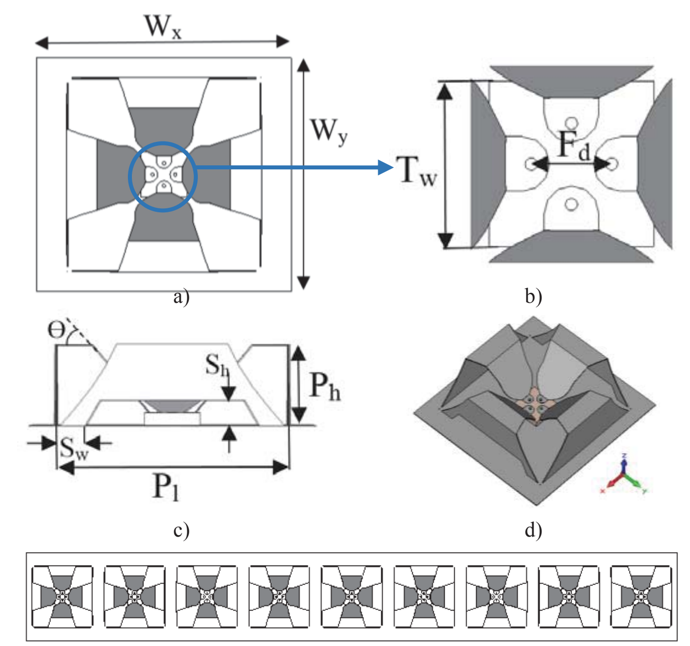
The geometry of the new bowtie antenna is shown in Figs.4a)-c). The values of the geometrical parameters are presented in Table I. The circular profiles of the petals (see Fig.1) are replaced by plates bent in discrete angles (see Fig.4). This makes the antenna much easier to manufacture. In addition, by connecting the ground planes of the elements in the array and adjusting the height of the bowtie, the vertical plates at the end of two neighboring bowties act as corrugations. The corrugations contribute to eliminating the null in the directivity of the array. Also, a slot on the petals along the array is introduced to improve the reflection coefficient especially at lower frequencies.

B. Array results

The array simulations were performed considering the infinite boundary condition along the *x*-axis. Fig.5 shows the computed active radiation pattern of each bowtie element when different polarizations are excited. As illustrated, the radiation pattern shows good stability over the frequency band of interest.

Table I: Geometrical parameters of the new designed bowtie

W_x	W_y	T_w	F_d	Θ
125mm	115mm	22.5mm	11mm	50
S_w	S_h	1	P_h	P_l
10mm	10mm	5mm	33mm	90mm



e)

Fig.4 : The geometry of new designed self-grounded dual polarized bowtie a) Top view b) feed part c) side view and d) 3D view e) in the linear array

The reflection coefficient and the directivity of the 9×1 linear array using the new element design for both orthogonal polarization excitations are shown in Fig. 6. As can be seen, the reflection coefficient is below -10dB over the 1.6-3GHz frequency band, when the vertical polarization is excited. For the horizontal polarization, the reflection coefficient is below -10dB over the frequency band of 1.8-3GHz and below -8dB at the starting frequencies (1.6-1.8GHz). The directivity of the simulated linear array is between 15-17dBi for the vertical polarization (transversal direction of the array) and it is 16-18dBi for the horizontal polarization (longitudinal direction of the array). The directivity of the linear array remains fairly constant over the entire bandwidth for both polarizations..

The radiation patterns of the linear array in the longitudinal (horizontal polarization) and the transverse (vertical polarization) planes, for three different frequencies are shown in Fig. 7. As can be seen, grating lobes for the horizontal polarization are suppressed. Furthermore, there is no null in the transverse pattern in the main beam at 2.3GHz as we had seen in the previous design.

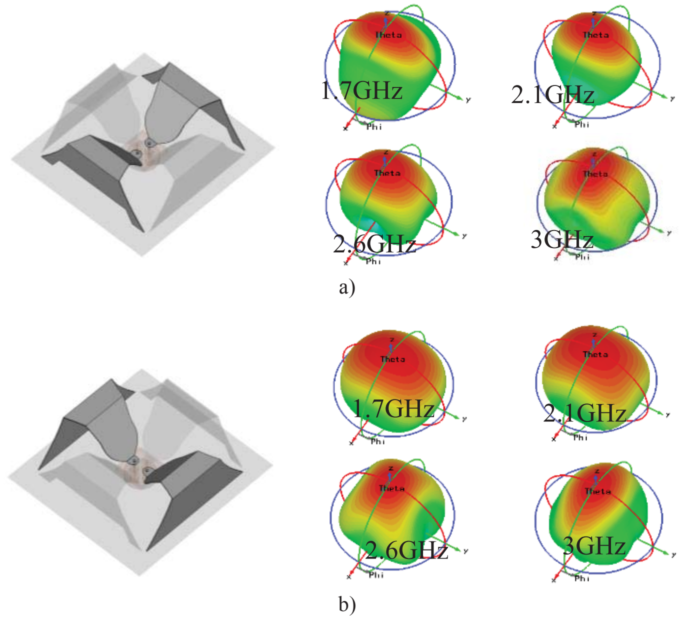


Fig.5 : The active radiation pattern of the bowtie at different frequencies when a) horizontal polarization and b) vertical polarization are excited

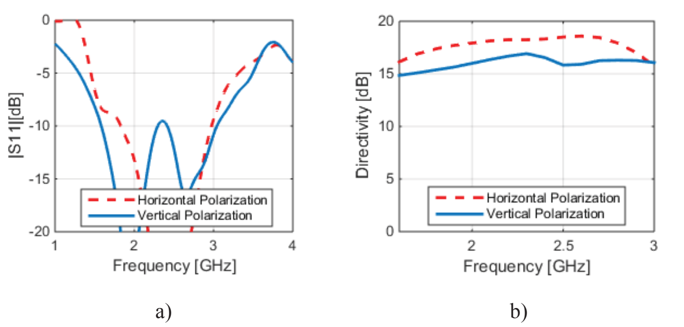


Fig. 6: Simulation results of infinite linear array made by the new designed bowtie: a) reflection coefficient of the active element and b) directivity of a 9×1 horizontal linear array for exciting both polarizations

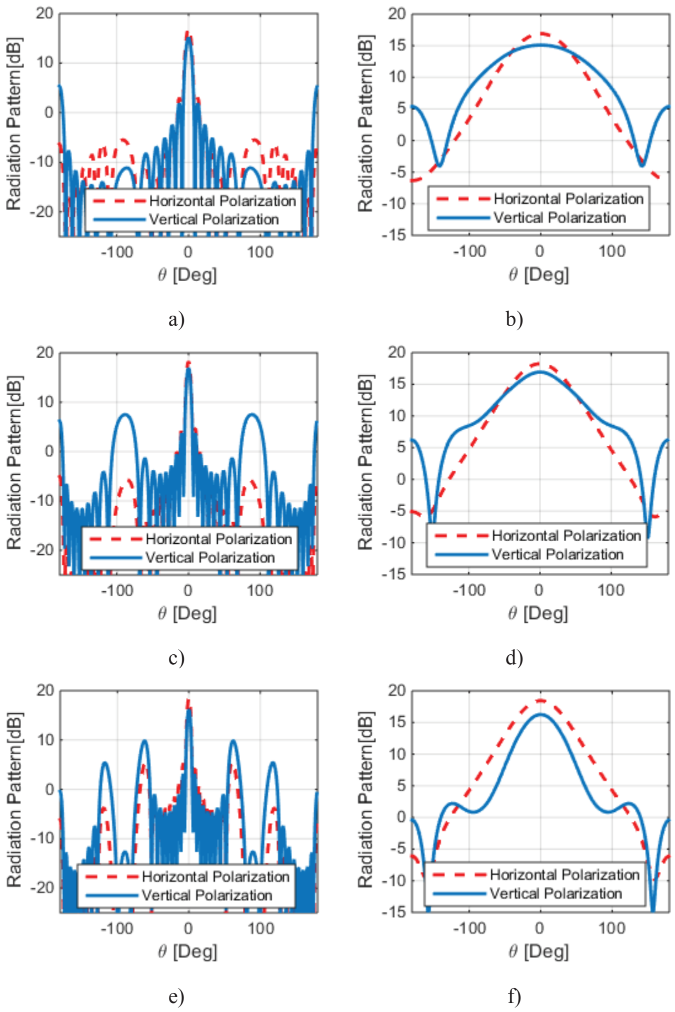


Fig. 7: Radiation pattern of a 9x1 linear array at frequencies of 1.7,2.3 and 2.9GHz (different rows) and in horizontal (left column) and vertical (right column) plane for different polarizations using new designed bowtie as the element of the linear array

There are grating lobes also in the new design, but in the present application the grating lobes are not of concern. The main requirement is constant directivity versus frequency over the large bandwidth.

I. CONCLUSION

A new self-grounded dual-polarized bowtie antenna design is presented for use as the element in a linear array antenna. The reflection coefficient of the array antenna is below -10dB within 1.6-3GHz. However, this is true except for the horizontal polarization (in the longitudinal direction of the array) for which the reflection coefficient is below -8dB at 1.6-1.8GHz. The directivity of the array shows good stability over the entire band for both polarizations. This is a considerable improvement as compared to the bad performance of the linear array (at 2.3 GHz) with the previous design of bowtie antenna element. Furthermore, the new designed bowtie has a much simpler structure which reduces the manufacturing complexity.

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