An Optimal Antenna Array Design for RSU Use of Dedicated Short Range Communications

Hsi-Tseng Chou*, Yung-Chang Hou and Wen-Jiao Liao

The Department of Communications Engineering, Yuan Ze University
135 Yuan-Tung Rd., Chung-Li 320, Taiwan
E-mail: ***hchou@saturn.yzu.edu.tw*** *Fax: 886-3-455-4264*

Abstract

In this paper an antenna array is designed for the use of road-side units (RSU) in the dedicated short range communications (DSRC). The array employs four elements of Yagi type antennas printed on FR4 substrates to create a narrow beam width and the beam-scanning capability. To accelerate the design procedure and optimize the performance, the antenna is designed using a program based on an implementation of a genetic algorithm in conjunction with a commercial software to auto-adjust the geometric parameters of the antenna element. Simulated and measurement results agree very well and show distinguished antenna performances.

1. INTRODUCTION

Foreseeing the coming potentials in the car-based communication services has driven the development of the dedicated short range communications (DSRC) system [1] for car based applications. Electronic toll collections on the highways are typical examples of applications. It thus drives the motivation of this work to design an antenna array that may be used for the road side units (RSU) of the DSRC applications. The objective of this work is to design an antenna covering the unlicensed frequency band of 5.8 GHz[2] with significant narrow beam width, to illuminate each lane of the road, and beam scanning capability for DSRC applications. Thus Yagi type antenna elements are employed to form an array antenna that may create significant narrow beam and beam scanning if proper phase shifts are imposed on each element, which may remain a significantly small size and is suitable for the use in the road side units of DSRC system.

The antenna elements proposed in this work are printed on dielectric substrates. To accelerate the antenna design in an efficient fashion as well as to optimize the antenna performance, a design program is first established by integrating a genetic algorithm (GA) [3,4] with an electromagnetic (EM) simulation tool of IE3D. Thus the antenna design may be performed in a self-adjusting manner. The geometrical parameters that may alter the antenna structures and performances are selected to provide relatively freedoms and variables in the optimization procedure to come out an optimum antenna structure fulfilling the operational requirements.

2. DESIGN PROCEDURE

(A) The GA based Program for Array Elements Design

The array elements of Yagi antenna are designed using a program that implements GA in conjunction with the IE3D EM simulation code following the fundamental procedure of an antenna design optimization as illustrated in Figure 1. The IE3D is a method of moment (MoM) [5] based simulation tool and had been widely and successfully employed in the design of planar antenna structures. The design program is written of Fortran languages, and thus the integration of IE3D in the procedure can be performed using a Fortran intrinsic function to call the DOS commands, where the filename of the IE3D executive file serves as the DOS command in this case. The interaction interface to transfer the values of parameters between the GA procedure and IE3D is performed through the utilization of IE3D's input and output data files.

The GA operator uses a fitness function to justify the performance of a design. In this case, the return loss spectrum is considered and the fitness function is defined by:

$$F_n = \frac{1}{\left(\sum_{m=1}^{M} C_{nm}\right) + 1} \tag{1}$$

where the n^{th} structure out of N structures in GA is indicated, and

$$C_{nm} = \begin{cases} S_{11}(f_m) - S_{11}^{*}(f_m) & \text{if } S_{11}(f_m) > S_{11}^{*}(f_m) \\ 0 & \text{if } S_{11}(f_m) \leq S_{11}^{*}(f_m) \end{cases}, \tag{2}$$

with M sampled frequency points selected in the designated frequency bands and f_m being the m^{th} sampled frequency. For each frequency point, if the simulated S_{11} is lower than the prescribed S_{11}^{*}, then C_{nm} is assigned as 0. Otherwise, the difference in simulated and desired values in dB is assigned to C_{nm}. The summation of C_{nm} contributes to the denominator of F_n. A proper design, which meets the S_{11} specifications in all bands, will yield a largest fitness value equal to one. Thus a larger value indicates a better design.

(B) Design of the Antenna Elements

Figure 2 shows the geometrical structure of the fundamental array element, which is a Yagi antenna printed on a FR4 substrate (thickness=0.8mm and $\varepsilon_4 = 4.4$) with a metal plate located at the back as a reflector. This type of antenna element alone will radiate directive patterns in the boresight direction with significant low sidelobes. Thus is very suitable for the use in the RSU. In realistic design, the lengths of the printed strips as well as their spacing need to be adjusted in order to fulfill the requirements.

In this work, the design goal is to achieve a band broad enough to cover the 5.8 GHz band with significant bandwidth. The design procedure employs and alters six geometric parameters sequentially as indicated in Figure 2 and Table 1. In this case, the directive strips are assumed to be identical while the feeding dipole is treated separately, where five directive strips are considered. The cell size is one fifteenth of a wavelength. Most of the time was spent on the IE3D program, which is proportional to the complexity of the simulated structure, and the time spent on the GA operator is negligible. The initial and optimized values of the geometrical parameters are listed in Table 1.

C. The Antenna Array for Beam Scanning

The array is formed using four identical elements designed in part B of this section as shown on Figure 3. To retain the antenna performance, the array element's spacing as well as the back reflector metal dimensions needs to be adjusted. Thus they are used as parameters to be optimized. The optimized values are shown in Table 2 for references.

3. EXAMINATION OF ANTENNA PERFORMANCES

The performance of the array Yagi element is first examined by comparing the performance parameters between the initial and optimum designs in terms of simulated and measured data of an antenna protype. Figure 4 (a) shows the simulation comparison of the return loss spectra of the initial and optimized designs. According to these values in Table 1, the initial design has a band located at 5.55GHz with -7.5dB bandwidth of 0.5GHz. After the optimization, the resonant band is shifted up to 5.85GHz with -7.5dB bandwidth of 7.8% to cover the 5.55 to 6 GHz range. To validate the simulation, Figure 4(b) shows the measured results of the return loss with respect to the protyped antenna. It is observed that Figure 4(a) and (b) agree very well.

The radiation patterns of the array Yagi element are shown in Figure 5 at 5.8GHz, where the simulated and measured data are shown and compared with 11.42 and 10.39 dBi gains are observed. It is observed that the patterns points to the boresight direction, and both patterns of simulation and measurement agree very well in the main beam except the measurement exhibits sidelobes which might be caused by the presence of the back metal plate. The sibe lobe levels are -10.65 and -7.85dBi and F/B ratios are 17.96 and 14.92dBi, respectively.

One next considers the performance of the antenna array in the beam scanning capability. A one-to-four power divider is employed to feed the four elements, and the phase differences of each element are imposed by using different lengths of transmission lines. One first examines the case of boresight radiation where equal phases are imposed on each element. The patterns obtained by simulation and measurement are shown in Figure 6 (a). In this case, both patterns agrees except slight distortion on the main beam is observed, which might be cause by the imperfection on the transmission lines to result in unequal phase delays. Almost 4dBi increases in the gains were achieved. Next one considers a beam scanning in the 20 degrees direction as shown in Figure 6(b). In this case, the simulated patterns exhibit very nice patterns while more distortions are observed on the measurement. Note that in the simulation, it is assumed that array elements are identical and the mutual coupling is ignored to compute the pattern while in the measurement the mutual coupling exhibits significant impact on the antenna gain by almost 2.5dBi. However, the scanning direction remains relatively stable and points to 20 degrees.

4. CONCLUSION

In this work, an array antenna using Yagi antenna elements is design for the use in the RSU of a DSRC system. The antenna design uses a design code that integrates GA and IE3D code, and achieves distinguished performances as required in the RSU system of DSRC. The simulation and measured results agree very well. It not only indicates the effectiveness of the design scenario by using code integration, but also achieves a good antenna design for the DSRC applications. Measurement results have validated the proposed works.

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Table 1: The values of the geometrical parameters shown in Figure 2 before and after the optimization. (unit: mm)

Parameter	Ini. Values	Opt. Values
W	30	22
W1	15.5	17.6
W2	19.75	18
L	63	80
L1	0.75	0.5
L2	15.4	15

Table 2: The values of the geometrical parameters shown in Figure 3. (unit: mm)

Parameter	Values
W3	40
L3	98
d	26

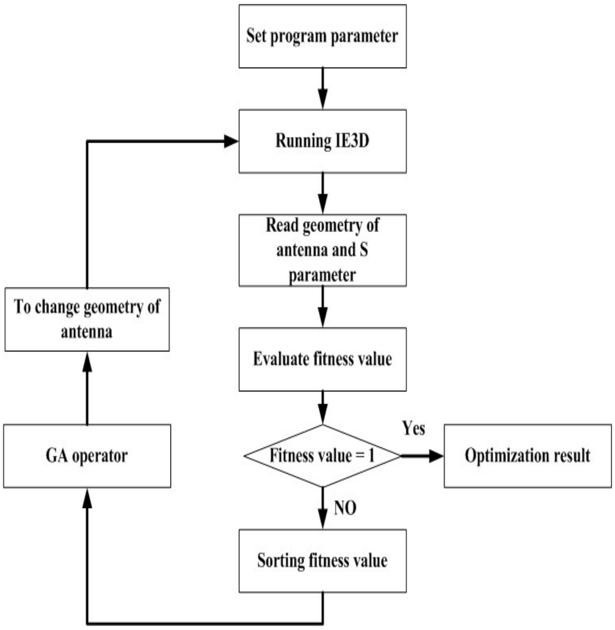


Figure 1: Antenna design optimization procedure based on an integration of GA and IE3D EM simulation code.

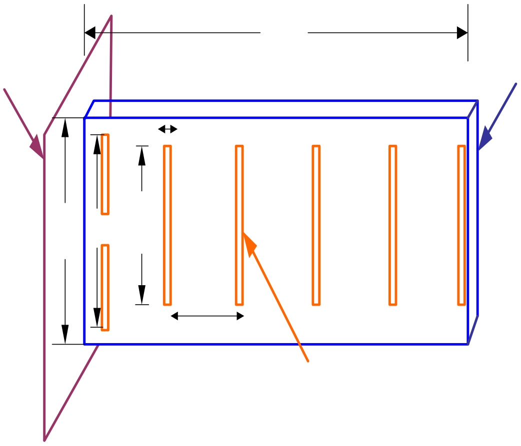


Figure 2: Geometry of the proposed Yagi antenna element. The geometrical parameters selected for the GA optimization are also shown in the figure.

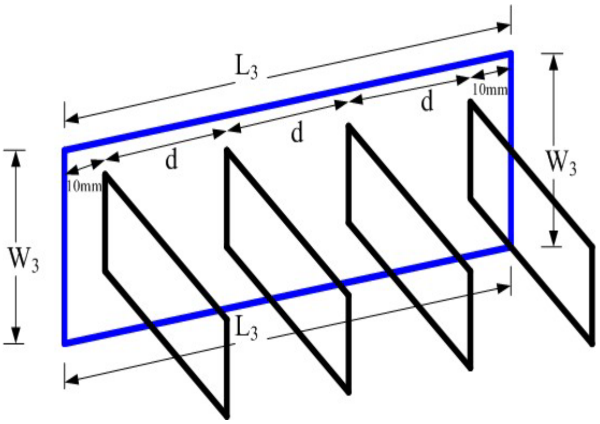
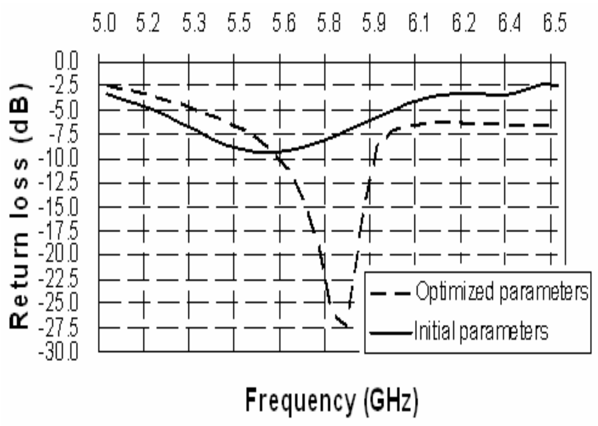
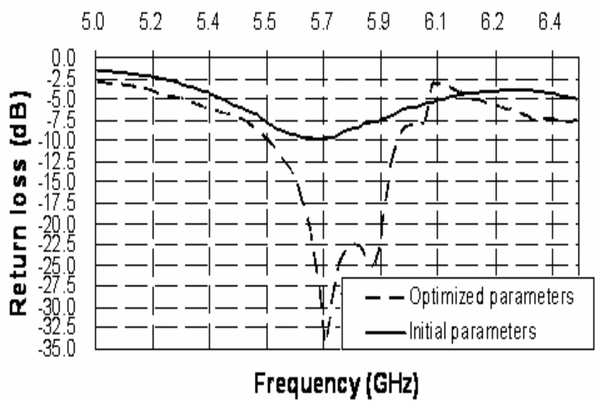


Figure 3: The structure of the Yagi antenna array, where four elements of Yagi elements are employed. The parameters of the array are also shown.



(a) Simulation



(b) Measurement

Figure 4: Comparison of the return loss spectra of initial and optimized designs.

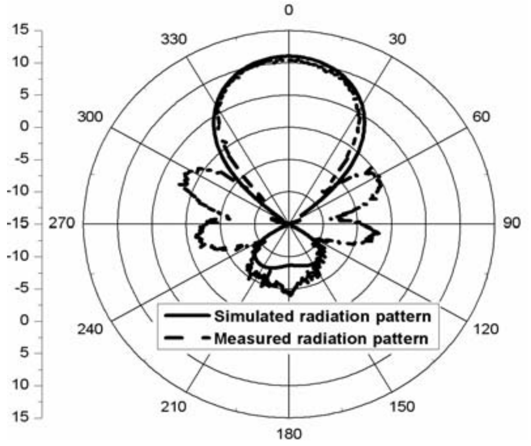
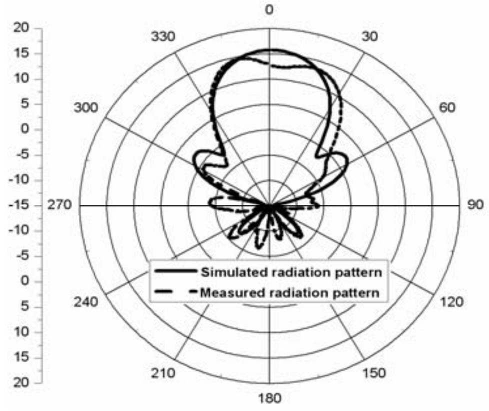
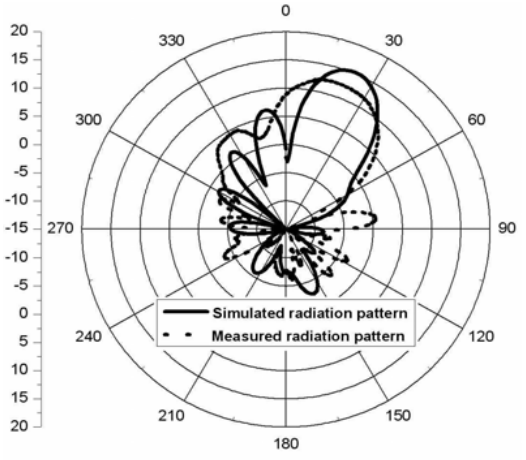


Figure 5: Radiation patterns of the optimized Yagi antenna element.



(a) Boresight scanning



(b) 20 degree scanning

Figure 6: Radiation patterns of the optimized Yagi antenna array.