Optimized planar terahertz Yagi-Uda antenna using hybrid GSA-PSO optimization algorithm

To cite this article: A Megahed *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **610** 012092

IOP Conf. Series: Materials Science and Engineering **610** (2019) 012092 doi:10.1088/1757-899X/610/1/012092

Optimized planar terahertz Yagi-Uda antenna using hybrid GSA-PSO optimization algorithm

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Abstract: In this paper, a planar Yagi-Uda antenna design for Terahertz applications is presented and optimized. The lengths of Yagi-Uda antenna elements beside the spaces between directors' elements are optimized seeking for obtaining high gain and minimum return loss simultaneously at 300 GHz. Thus, the directivity enhancement enables to overcome the high atmospheric attenuation influence that faces the high frequency range and limit its communication capabilities, and the return loss minimization enables to minimize the return loss to improve the impedance matching besides, reducing the mismatching losses. The Gravitational Search Optimization Algorithm with Particle Swarm Optimization algorithm (GSA-PSO) as a hybrid technique is applied on the antenna elements using an offline link between MATLAB program and Ansoft HFSS simulation program. To show the convergence capability of the GSA-PSO, the results are compared with those obtained by other algorithms such as gradient local algorithm and genetic global algorithm (GA). The optimized antenna showed high gain of 15.84 dB with a return loss of -45.27 dB compared to 15.4 dB and -15.6 dB for the conventional counterpart design, and with gain of 15.8 dB, and return loss of -21 dB for the genetic algorithm, and finally with 15.75 dB, and -28 dB for the gradient algorithm. Furthermore, the GSA-PSO algorithm improves the search capability by 30%, compared with the GA algorithm.

Keywords: gravitational search algorithm, gradient local algorithm, genetic algorithm, optimization, Yagi-Uda

1. Introduction

Recently, the sub gigahertz range has become so crowded; in addition, this range cannot be used in high data rate communications. For future high data rate applications, the terahertz (THz) range is defined as the region from 0.1 THz to 10 THz which become a promising frequency band to be efficiently used in indoor environments wireless communications [1], in addition to, use THz waves for various applications such as bio- and medical science, pharmacology, and information security especially, in the spread spectrum technology. However, huge atmospheric attenuations face the high frequency range; therefore, high directive antennas have to be used to overcome the attenuation losses. The antenna gain and matching impedance can be enhanced mainly by changing the antenna

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parameters. Therefore, the importance of the optimization techniques has appeared as a trend to achieve these improvements. Recently, different optimization techniques have been developed and applied on many engineering problems and designs [2]. Actually, Yagi-Uda antennas are very appropriate for using in THz applications over the other THz antennas because of the high directive gain of the Yagi-Uda antennas to overcome the high atmospheric attenuation in this band.

In this work, the hybrid population-based algorithm is considered with the combination of Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA). The main idea is to integrate the ability of exploration in GSA with the ability of exploitation in PSO to synthesize both algorithms' strength. The GSA-PSO algorithm will be implemented in Matlab to optimize the planar Yagi-Uda antenna design carried out using the HFSS simulator for high gain and minimum return losses, simultaneously, at 300 GHz.

2. Optimization techniques and simulation tools

In GSA-PSO, all agents in the first iteration are randomly initialized. Then, gravitational force, gravitational constant, and resultant forces among agents are calculated [3]. After that, the accelerations of particles are defined. Then, the velocities of all agents can be calculated based on the selected best solution. Finally, the positions of agents are updated. The process of updating velocities and positions will be stopped by meeting an end criterion.

The optimization process can easily be performed via a link between the MATLAB software program and Ansoft HFSS simulator program. The GSA-PSO optimization is done by offline link between the Matlab program and Ansoft HFSS simulation program with a number of iterations equal to 30, population size equal to 10 with overall number of EM simulations of 300. The GSA-PSO time consumed during the evaluation steps is about 48.5 hours, which is short consumed time when it is compared with the built in GA optimization done by HFSS only which consume time closed to 144 hours with the same number of EM simulations. The computer specifications are 8 GB RAM, with Core i5 2.2 GHz Processor.

Generally, the processing time in our case is not critical point, whereas, it is an offline optimization problem. The MATLAB program creates visual basic scripting file (.vbs) to be executed by HFSS simulator. Matlab commands are applied on the antenna by HFSS. Then the results are exported to the MATLAB to be updated to adapt the antenna dimensions and optimize it depending on the optimization algorithm until stopping conditions are reached.

3. Antenna design

The Yagi-Uda antenna design as depicted in figure 1 consists of coplanar wave guide (CPW) ground planes as reflectors to coplanar strip line (CPS) transition feeding the antenna, besides 20 directors. The circuit applied on a 110 µm thickness commercially available cyclic olefin copolymer (COC 6013) substrate with low relative permittivity ($\epsilon_r \approx 2.35$), and dielectric loss factor ($\tan \delta < 9.4*10^{-4}$) [4].

The distance between the CPW or CPS conductors is 5 µm. The CPW and CPS dimensions for all directors are $W_1 = 15\mu m$, $W_2 = 480\mu m$, $W_3 = 275\mu m$, $W_4 = 20\mu m$, $W_5 = 10\mu m$. The effective resonant wavelength of the driving elements is $\lambda_{eff} = 695\mu m$, and its length is $l_0 = \lambda_{eff}/2 + 5\mu m$, at a distance $d_0 = 0.3\lambda_{eff}$ from the reflector. The i^{th} directors have lengths of $l_i = 0.95^i \lambda_{eff}/2$, and the neighboring elements distance is $d_i = 0.25\lambda_{eff}$. The quarter phase-shift line has a length $P = 97.5\ \mu m$. The total length of the antenna is $L = 4mm$, and the COC substrate has a width $W = 1.5(W_1 + 2W_2)$

4. Results and discussions

To validate our simulation results, figure 2 shows good agreement between the return loss for the design simulated by HFSS which is less than -14.1 dB compared to -15.6 dB that obtained by Fabio *et al.* [4]. While the measured return loss is -10.5 dB in [4], with an antenna gain of 12 dB at 300 GHz.

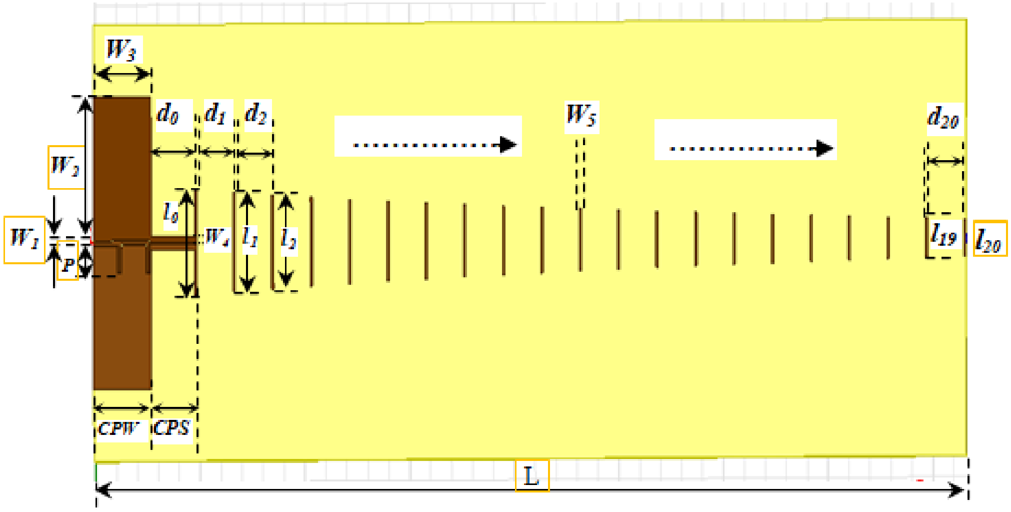

Figure 1. Yagi-Uda antenna design of 20 directors, CPW ground planes as reflectors, and CPS feeder [4].

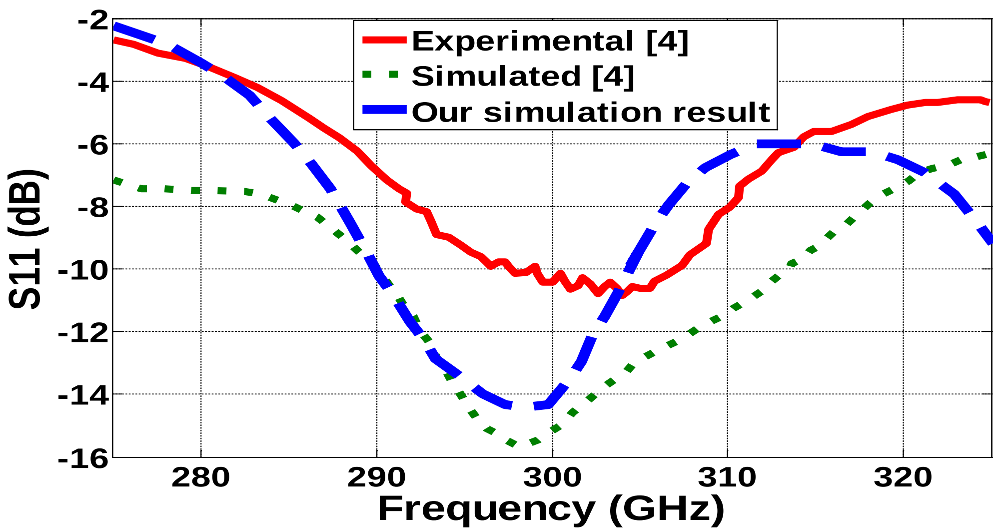

Figure 2. The validated HFSS return loss of the Yagi-Uda antenna compared to the fabricated and simulated results presented in [4].

In this design, the directors' positions and lengths (l_1, l_2, l_3, ... , l_{20}, d_1, d_2, d_3, ... , d_{20}) are taken as the optimization variables with a view to increase the antenna gain (G) and improve the return loss (S_{11}) at f = 300 GHz. These parameters will be optimized within the assigned decision space (±25% from the initial dimensions in [4]). Therefore, the objective function is considered as:

$$\text{Objective Function} = \max\left[aG(f) + b\left|S_{11}(f)\right|\right] \tag{1}$$

where, the coefficients a and b are considered to balance between the effect of the antenna gain G and its return loss S_{11}. The considered evaluation number for the optimized antenna is set to be 300. In the objective function, the weights a and b are set to be 2 and 1, respectively, to minimize the return loss and maximize the antenna gain. It is clear from figure 3(a) that, the S_{11} in GSA-PSO reached to -45.27 dB which is more improved nearly by 24 dB and 17.4 dB than the GA and the gradient algorithm, respectively, and by 34.7 dB than the conventional design. Also, the GSA-PSO gain is

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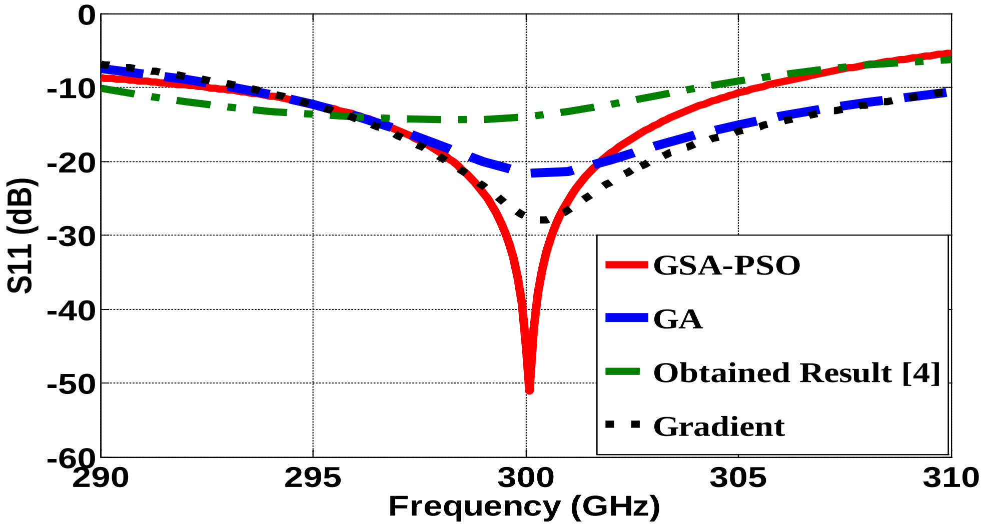
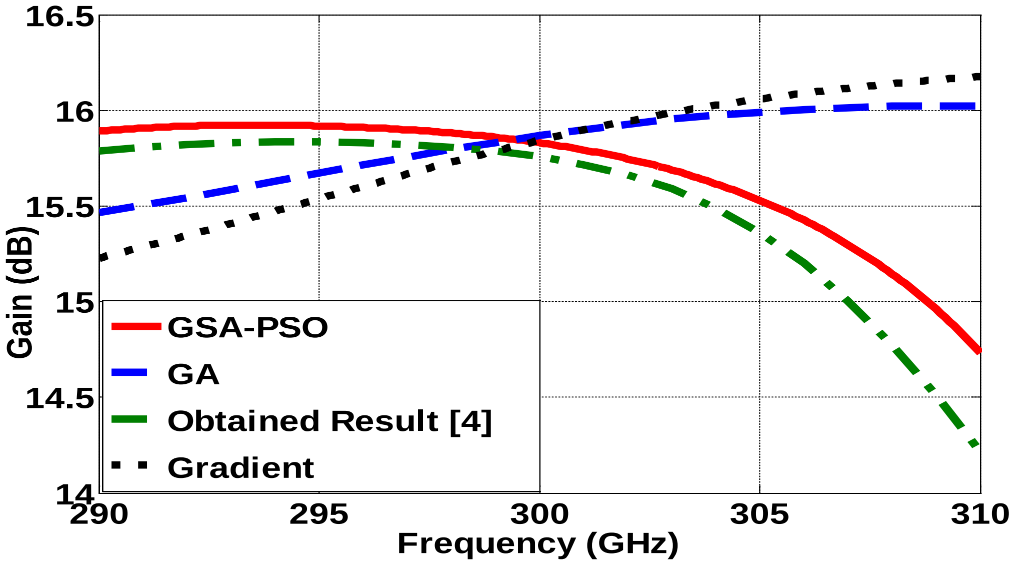
presented in figure 3(b) nearly equals to GA and Gradient gains and reaches to 15.8 dB which is higher than the simulated conventional design gain by 0.4 dB. In just case, the ratio between weights *a* and *b* can be adapted in order to increase the antenna gain at the expense of return loss.

Finally, figure 4 shows the comparison between the normalized objective values of the GSA-PSO, GA and gradient algorithms for the scenario of optimizing the antenna gain and return loss. Therefore, the GSA-PSO is continually has the ability to improve its performance throughout the iterations, unlike the GA, and gradient, as the GSA-PSO improved its global search capability till iteration 27 when it is compared with the GA and gradient which stopped the enhancement after iteration 13 and 7, respectively. On an average, the convergence improvements for the GA and gradient stopped after 43.3%, 23.5% of the iterations. While the GSA-PSO continued till 90%. This comparative study shows a powerful convergence capability for the GSA-PSO technique compared with the GA, and Gradient.



(a) Return loss



(b) Antenna gain

Figure 3. The frequency response of the optimized Yagi-Uda antenna using GSA-PSO, GA and Gradient compared to previous published results [4].

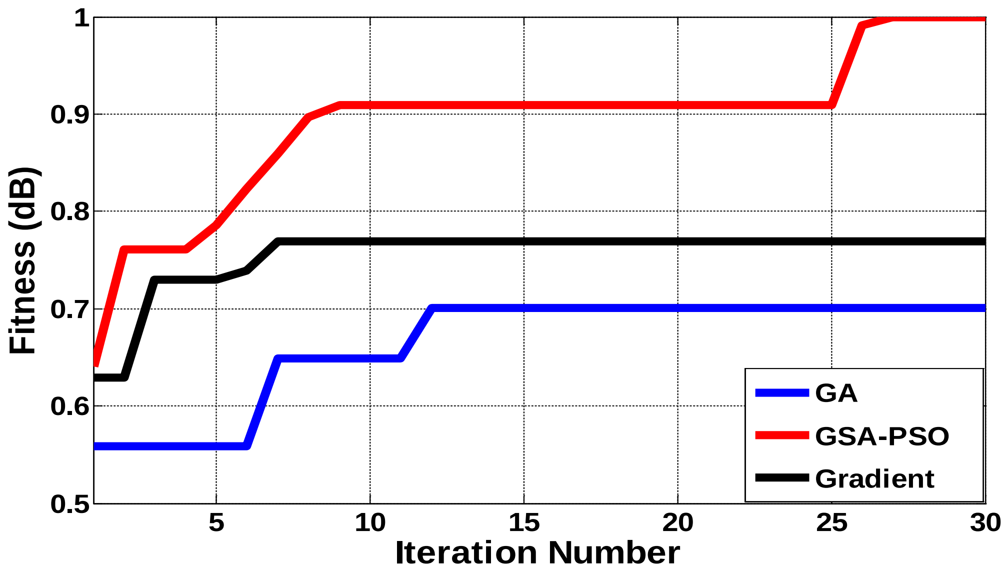


Figure 4. Comparison between the normalized objective functions of GSA-PSO, GA and Gradient versus the iteration.

5. Conclusions

In this paper, the dimensions of the planar Yagi-Uda antenna were optimized using the hybrid Gravitational Search Optimization Algorithm with Particle Swarm Optimization (GSA-PSO) to maximize the gain and/or minimize the return loss. The optimized antenna achieved a high gain of 15.84dB with a reflection coefficient lower than -45.27 dB, which satisfies the requisites for short-range wireless applications. The GSA-PSO algorithm implemented in Matlab to optimize the planar Yagi-Uda antenna design carried out using the HFSS simulator for high gain and minimum return losses. The obtained results are compared by the fabricated and simulated results presented in [4]. The GSA-PSO algorithm improves the search capability by 30%, compared with the GA algorithm.

References

[1] Pierewicz R, Jacob M, Koach M, Schoebel J and Kuner T 2008 J. Sel. Top. Quan. Elec. *IEEE* Performance analysis of future multi gigabit wireless communication systems and THz frequency with highly directive antennas in indoor environments 421–30

[2] Montaser A M, Mahmoud K R and Elmikati H A 2012 *App.Comp.Electromag.Soc.Jour* Integration of an optimized E-shaped patch antenna into laptop structure for bluetooth and notched-UWB standards using optimization techniques 786-94

[3] Mirjalili S and Hashim S Z M A 2010 Int. Conf. in Computer and Information Application *ICCIA* New hybrid PSOGSA algorithm for function optimization 374-77

[4] Pavanello F, Ducournau G, Peytavit E, Lepilliet S and Lampin J F 2014 Anten &Wirel Prop Lett. *IEEE* High-gain Yagi–Uda antenna on cyclic olefin copolymer substrate for 300-GHz applications 939-42