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Electromagnetic Bottom-Up Optimization for Automated Antenna Designs

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***Abstract*—This paper presents an automated design of antennas by using *bottom-up* optimization-oriented strategy in conjunction with a full-wave electromagnetic (EM) analysis. The proposed approach firstly set up a co-simulation environment between a commercial Electronic Design Automation (EDA) software and a numerical analyzer. Then bottom-up optimization method is applied by increasing the number of *microstrip transmission lines (TLs)* and examining various structures of TLs for modeling the antenna geometry. The optimization process is automated using ADS and MATLAB. ADS is preferred among other EDA tools as EM analysis criteria can be optimized well in this tool. In particular, the optimization method is applied for designing two single antennas in the operation bands of 16.3 GHz - 17.43 GHz (Ku band) and 10.1 GHz- 10.9 GHz (X band), respectively. The optimized antennas exhibit gain performance between 5.57 dB- 8.6 dB and 2.12 dB- 4.1 dB, respectively. The simulated results have also been positively tested in Ansys HFSS tool.**

***Index Terms*—antenna, automated design, electromagnetic bottom-up optimization (EBUO).**

I. Introduction

In modern communication systems, high-speed data transmission and high capacity are among the required crucial requirements. Recently, due to the increased importance of communication systems, demand for requirements on antennas has enjoyed a rapid growth [1]. Antennas are essential components in telecommunications networks and are characterized by some specifications such as frequency bands, sensitivity, impedance bandwidth (BW), and gain. Wide BW and gain are the most substantial aspects to design antennas [2], [3] and are deeply needed for antennas to be efficiently used in practical ways. For these reasons, there are many efforts that are considered to increase and enhance BW and also to obtain linear gain performance in antennas [4], [5]. Printed antennas, because of variety of reasons such as cost effective and simple fabrication process are used for communication systems [6], mostly. Patch antennas of ordinary shapes are commonly used to increase the antenna performance [7], [8].

For improving the characteristics of antennas, optimization methods in association with electromagnetic (EM) analysis can be used. This requires to optimize given objective functions and achieve suitable design variables and parameters [9] such as width (W) and length (L) of antennas (in case of rectangular radiators). There are various optimization algorithms such as particle swarm, genetic algorithm, differential evolution [9] and bottom-up optimization [10], [11] that have already been efficiently applied for designing microwave and radio frequency circuits. The optimization methods are generally applied with the aid of Electronic Design Automation (EDA) tools such as ADS, AWR, HFSS, etc. However, when the huge amount of data are to be handled, these tools can not be successful for efficiently perform the optimization and numerical analyzers such as MATLAB are also needed for providing suitable environment to do so [12].

This study presents an automated optimization methodology using *electromagnetic bottom-up optimization (EBUO)* method for designing wide BW antennas. Bottom-up algorithm is preferred in this study as this method provides the desired accuracy [10] and overcomes complexity and other issues of design process. Additionally, to have strong optimization environment for designing antennas, ADS with MATLAB are co-operated together which results in an automated optimization process. ADS tool is used during the optimization process and developed with collaboration of this simulator to consider EM compatibility as explained in [13]. For providing the validity of our proposed optimization method, antennas are tested in HFSS tool as well. This work is organized as follows: Section II presents details of the automated optimization method. In the third section practical antenna designs and optimization are briefly discussed. Finally, the last sections provides conclusion for this work.

II. Automated Bottom-Up Optimization Method for Antenna designs

This section illustrates the steps of automated EBUO process for designing single antennas as shown in Fig. 1. The first step of the optimization is corresponded for providing co-operation between ADS and MATLAB [12] where an automated design environment is created. ADS tool is working in the background and send the result of simulations in the output data file named as *'spectra.raw'* to MATLAB. Then, a related *'netlist'* file includes a set-up of large signal S-parameter simulation is extracted from ADS as a initial start-up netlist (Step-2) where antenna designs will be modified in this file in the next following steps. Finally, bottom-up optimization is applied for designing antennas in the determined frequency

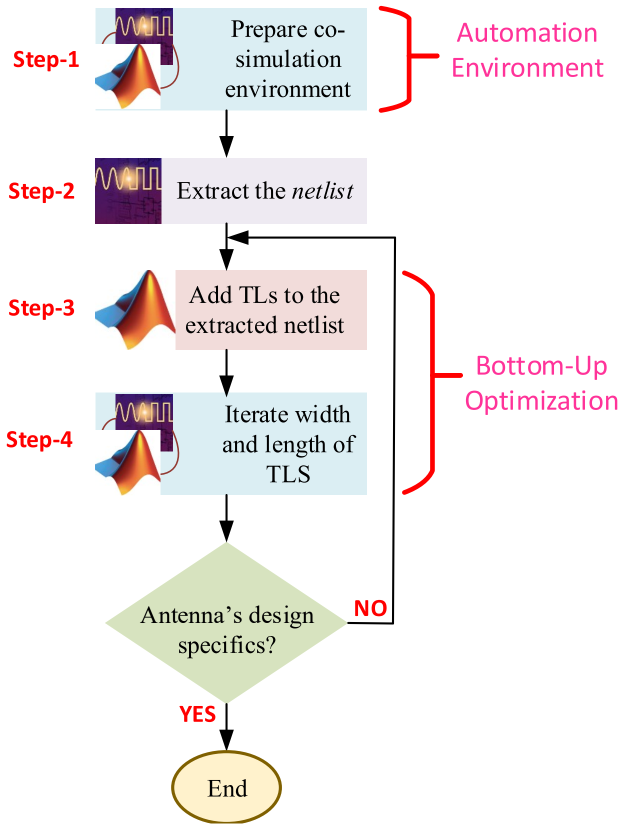


Fig. 1: Proposed automated EBUO algorithm for designing antennas.

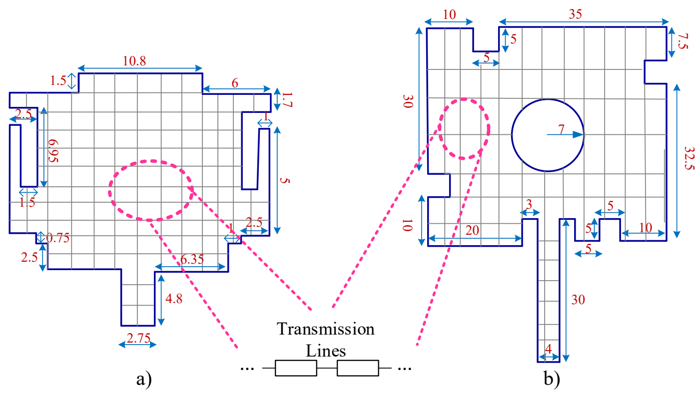


Fig. 2: Designed two antennas with the EBUO algorithm; Antenna "a" (left) and Antenna "b" (right). All antenna dimensions are in *mm* unit.

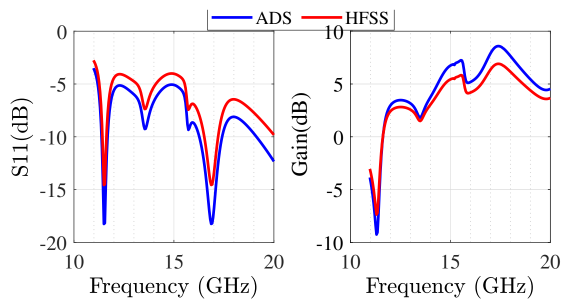


Fig. 3: Simulated S_{11} and gain outcomes for optimized antenna in Fig.2a in ADS and HFSS environments.

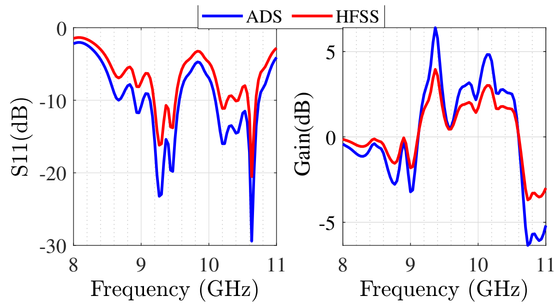


Fig. 4: Simulated S_{11} and gain results for optimized antenna in Fig.2b in ADS and HFSS environments.

band automatically (Step-3 and Step-4). For passing full-wave EM analysis and making the designs ready to fabricate, we use transmission lines (TLs) for designing and we exert design rules and criterias inside the optimization method [14]. In bottom-up process the optimization is exploited on the extracted netlist from Step-2 and incremental TLs are added to the netlist and dimensions of each TL (i.e., W and L) are iterated (increasing/decreasing) automatically [12] in order to achieve appropriate and acceptable BW. If the obtained results are not corresponding to the requirements, bottom-up optimization repeats the process from the third step of the algorithm up to obtaining determined design goals.

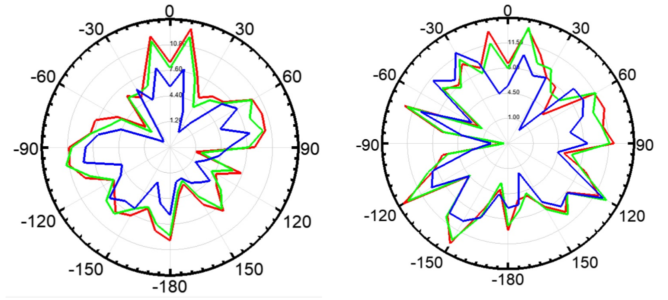
III. Practical Antenna Designs and Optimizations

We apply our proposed method for designing two antennas shown in Fig. **??**. Fig. 2 illustrates the geometry of two optimized antennas named as antenna "a" and antenna "b". Antenna "a" has been designed on substrate with $\epsilon_r = 4.3$, $\tan\delta = 0.025$ and the thickness is 1.6 mm, and the design of antenna "b" has been performed on Rogers substrate with $\epsilon_r = 3$, $\tan\delta = 0.0011$ which the thickness is 1.52 mm.

S_{11} and gain of both antennas have been simulated in large frequency range: in the range of 11 GHz- 20 GHz and 8 GHz-11 GHz for antenna "a" and "b" and presented respectively in Fig. 3 and Fig. 4. Both antennas are also examined in Ansys HFSS tool as well for testing and validating our optimization method which results in improved outcomes. The operation bandwidth for antenna "a" is 16.3 GHz - 17.43 GHz and for antenna "b" is 10.1 GHz - 10.9 GHz. Antenna "a" has a gain performance between 5.57 dB - 8.6 dB and the other antenna has gain in the interval 2.12 dB - 4.1 dB. Radiation patterns for both designed antennas have been shown in Fig.5 and Fig. 6 which are corresponded to H-plane and E-plane, respectively for various frequencies. Also, 3D polar radiations for both antennas have been illustrated in Fig. 7.

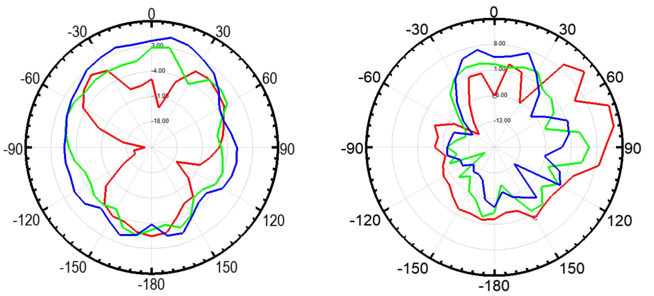
IV. Conclusion

The platform of the proposed automated optimization is constructed by combining Keysight ADS S-parameter simulation and MATLAB programming environments. The optimization strategy is a one-time approach where both software tools become successful in being compatible with the formats



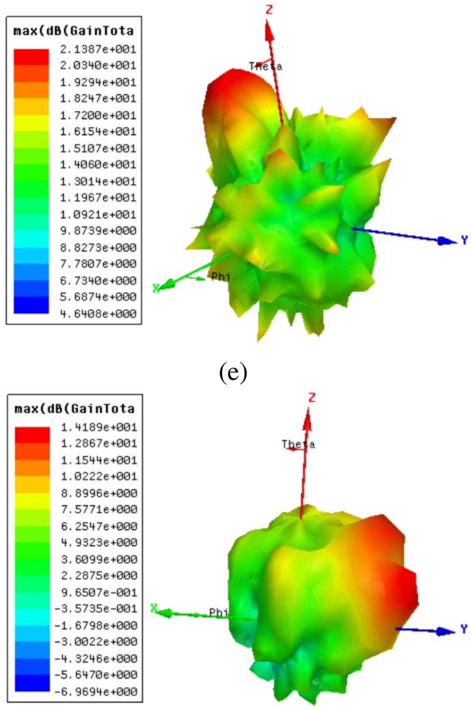
(a) (b)

Fig. 5: Radiation patterns of the antenna in Fig.2a for 0° (a) and 90°(b) planes at f=16.3 GHz (blue), f=17 GHz (green), and f=17.4 GHZ (red).



(c) (d)

Fig. 6: Radiation patterns of the antenna in Fig.2b for 0° (c) and 90°(d) planes at f=10.1 GHz (blue), f=10.4 GHz (green), and f=10.9 GHz (red).



(e)

(f)

Fig. 7: 3D radiation patterns of optimized antennas; a) for antenna in Fig.2a, and b) for antenna in Fig.2b.

of each other. This compatibility facilitates the development of an electromagnetic bottom-up optimization method exploited in an automated environment to achieve suitable design parameters for antennas. This method provides an effective way to improve BW and gain in a short-time in comparison with traditional methods and prepare ready-to-fabricate layouts. Also, with the use of bottom-up technique in our design, a good and advanced connection between the results in ADS and Ansys HFSS have been provided.

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