Optimum Horn Antenna Design Based On an Integration of HFSS Commercial Code and Genetic Algorithms for the Feed Application of Reflector Antennas

Hsi-Tseng Chou[1], Chia-Wei Liu[2], Hsi-Hsir Chou[3] and Wen-Jiao Liao[4]

[1]The Department of Communication Engineering
Yuan Ze University, Chung-Li 320, Taiwan
hchou@saturn.yzu.edu.tw

[2] ElectroScience Laboratory,
The Ohio State University, Columbus, OH 43212, USA

[3] The Department of Engineering
Cambridge University, Cambridge, U.K.

[4] The Department of Electrical Engineering
National Taiwan University of Science and Technology, Taipei, Taiwan

***Abstract*─** The optimum design of horn antennas for the application as feeds to reflector antennas is performed utilizing a simulation tool based on an integration of HFSS commercial code as an electromagnetic computational engine and an add-on optimization scheme of genetic algorithm. This work is motivated by the need of antenna operations at multiband frequencies, where the horn antennas tend to radiate narrower beams at higher frequencies and result in inefficient uses of the reflector surface since the narrow beams will illuminate only a portion of the reflector surface. Optimum design of the horn antenna may significantly increase efficiency. The philosophy of this work is based on a fact that the currently available commercial codes are reliable and relatively accurate in the analysis with more efforts tending to enhance the computational efficiency. The quality of the antenna design will mainly rely on an effective optimization algorithm that can be and should be developed independently according to engineers' own need, since the variables and cost functions for optimization can be flexibly selected. The integration of existing analysis codes, as mentioned above, and self-developed algorithms will be most effective for an engineer in the customized antenna design. The concepts and strategies are addressed with numerical examples to validate.

***Index Terms*─** Reflector Antenna, Feed Horn, Genetic Algorithm, Optimization Algorithm, Code Integration.

I. INTRODUCTION

The boom of satellite communications for digital TV program reception [1] has increased the uses of reflector antennas that provide sufficiently high gain and directivity. The increasing trend for using reflector antennas is in the multiband and multi-satellite operations by utilizing a single reflector with either multi-feeds, pointing to various satellites and operating independently at various frequencies, or a single feed operating at multiple frequencies [2]. The requirements for feed radiations become very strict since a single reflector is desired to be used. First of all, the electrical sizes of the reflector antenna increase with the increases of frequencies even though its physical size remains same. At higher frequencies of operation, the reflector has a larger electrical size in terms of wavelengths. Similarly, a horn antenna operated at a higher frequency has a larger aperture size in terms of wavelengths, and radiates narrow beams [3]. They will illuminate only a portion of the reflector's surface if the reflector surface is designed to meet the requirements of a low frequency operation. One typical example is the simultaneous use of 20 and 30 GHz frequency bands for a reflector antenna, which is popularly employed in satellite communications. Thus, at higher frequencies the efficiency of utilizing the reflector surface can be relatively low unless the radiation patterns of the feeds at the multiple frequencies are simultaneously optimized to provide a global maximum efficiency for the utilization of the reflector surface.

It is thus motivated in this paper to develop useful simulation tools that can be efficiently employed in the design of such optimum horn antennas to avoid the need of tuning antenna parameters in an ad hoc manner, which is relatively time consuming and inefficient. Prior works have attempted to integrate EM numerical methods and optimization approaches such as the genetic algorithm [4─6]. Chen et. al [7] demonstrates that the NEC code can be integrated within an GA-based automated fish bone antenna design optimizer.

Considering the development of design tools, currently available commercial codes based on finite element method [8], HFSS [9], have been shown to be very reliable and relatively accurate in the electromagnetic (EM) analysis of antenna performance with most of the current efforts tending to enhance the computational efficiency. Thus, the quality of the antenna design and its performance will mainly rely on an effective optimization procedure that can be and should be developed independently according to engineers' own needs. An automatic optimization procedure may significantly save the engineers' efforts, which were spent in tuning the antenna structures manually. It is noted that even though some simple optimization functions are available in HFSS, however, the framework of this paper allows the variables and cost functions for optimization be flexibly selected and defined. Also, the engineers can focus on developing their own design procedure and algorithms to optimize the antenna designs to the best extent of their experiences and knowledge. The integration of this existing analysis code and self-developed algorithms is apparently most effective for an engineer in the customized antenna design. Furthermore, it may extend the application scopes of the simulation tool since a variety of new features may be developed.

This code integration is developed to automate the optimization process. A program is established to monitor the optimization process and interact with the computation engine, which is HFSS in this paper, to optimize the radiations of the feed horn antennas. It may, however, be extended to treat a variety of antenna types since the fundamental concepts and code structure remain similar. The procedure begins with an initial setting within the framework of HFSS. The computation engine returns prescribed performance parameters (i.e., radiation patterns, return loss, etc.). The program next adjusts the stepping size of the adjustable parameters according to its built-in optimization algorithm. The above process is performed iteratively until the desired performance or the specified iteration number is met. In this paper, genetic algorithm (GA) [10─12] is employed to realize the concept because it can be effectively employed to optimize discrete variables.

As to its application potentials, such an add-on optimization program could be made more capable than the optimization functions provided by commercial simulation packages. The optimization criteria are not limited to antenna structure parameters, and can be the structure itself, which is suitable for antenna design using genetic algorithms. Furthermore, design packages from different venders could be coordinated using this intermediate program, and thus create most values in the antenna design. A potential example is to further integrate the EM analysis code of the reflector antennas [13, 14], which will make the design of the entire reflector antenna system in a self-completeness fashion. This extension will be reported in the future phase of this work.

This paper is formatted in the following order. Section 2 addresses the implementation strategies of this code integration as well as the interfaces to interact with the HFSS. Section 3 demonstrates the concepts by considering the radiation patterns optimization of a single band and a dual-band horn antenna designs for the application of reflector's feed in the satellite communications. Finally a short discussion is presented in section 4 for a conclusion.

II. IMPLEMENTATION STRATEGIES

A. General Concepts and the Program Structure

The concept of this work follows a general optimization procedure of an antenna design as illustrated in Figure 1(a). It starts with an initial guess of the horn antenna structure and parameter inputs to classify the antenna radiation through the EM analysis using HFSS. The antenna radiations are justified by a comparison with the expectations, such as beamwidths, sidelobe levels and cross-polarizations, through an evaluation of a cost function or a fitness function. If the expectations have been reached, then the design procedure is completed. Otherwise, new designs with improved radiation characteristics are created based on the changes in the values of the fitness function, where the new antenna structures are produced by a GA procedure. Those new antenna structures are used in the next iteration (or next generation) for HFSS analysis to justify their performances with respect to the expectations. This procedure continues until the expectations are reached.

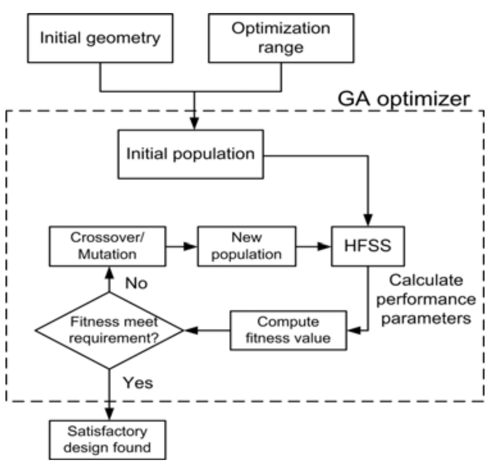


Fig. 1. The optimization procedure of a feed horn antenna design as well as the program structure of the proposed strategies to integrate HFSS commercial analysis code within the genetic algorithm.

To realize the concepts with respect to the utilization of HFSS as an EM analysis engine with an add-on procedure of GA to adjust the antenna's parameters. It is established within a framework of an automation control program that first sets up the program control parameters such as the expectations of the desired radiation patterns and the maximum number of iterations, and then establishes the procedures of code control and optimization algorithm. The initial antenna setting is analyzed by HFSS to estimate antenna performance which is used to compute the fitness values. Thus the parameters with respect to the antenna operation, such as the operational frequency bands and radiation analysis, are input through the automation program to HFSS. The main body of the automation program is composed by four blocks. The "geometry controller" specifies the parameters and variables of the antenna structure to be optimized such as the dimensions and coordinates of particular geometries in the structure, which are used in the "GA operator" block to produce new values for creating a new antenna structure with superior performance. The "GA operator" implements the GA algorithm. Also the antenna performance with respect to the design anticipation is evaluated in the "fitness function" block to justify whether the expectation has been reached based on the analysis of "HFSS simulation" block which uses the HFSS as the EM analysis tool. If the fitness value meets the prescribed conditions of requirement, we can declare that a satisfying design is found. Otherwise, the GA operator will sort designs according to the fitness values, then generate new designs as well as new values of the parameters for the next generation from superior designs.

B. Genetic Algorithm for Antenna Design Optimization ("GA operator" block)

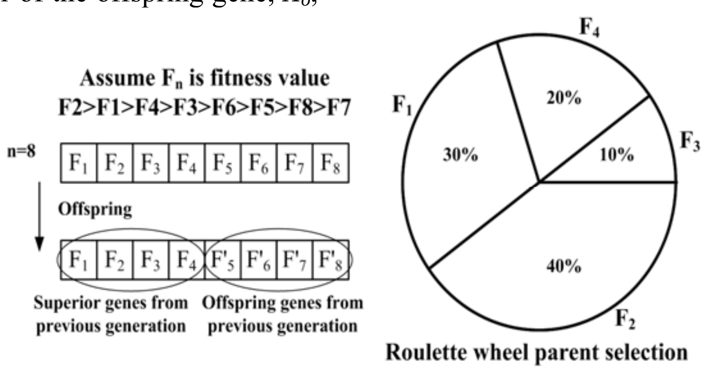
GA is employed to optimize the antenna structure to meet the prior requirements of the antenna operation. It sorts the design according to computed values of the fitness function, and creates new designs according to the superior designs from previous generations as illustrated in Figure 2(a). For the case shown, there are eight genes (n=8) representing eight antenna design. Each gene comprises a set of parameters' values for an individual antenna designs. The genes are created from superior parents in attempt to generate even better performance. The values of the fitness function are computed for each gene, and compared to justify the superiority of the antenna performance. In Figure 2(a) it is assumed that a larger fitness value indicates a superior performance of the antenna associated with this gene. The superior genes are retained while the rest are abandoned in the next generation. New genes are produced from the superior parent genes (i.e., the superior genes retained in the previous generation) based on a roulette wheel parent selection approach. The creation of the new genes uses either crossover or mutation methods as illustrated in Figure 2(b). The crossover method means that design parameters are swapped between two parent designs, while the mutation method implies that a parameter of the parent gene is replaced with a randomly generated number. The decision of using either crossover or mutation method is also random. The selection of parent designs is done via the roulette wheel method, that is, a superior design is assigned to a larger piece in the wheel, which is equivalent to a larger probability density value. Therefore, superior parents are more likely to produce more children. In this work, the crossover and mutation are performed based on the operations over the binary codes of the parents' genes. For the crossover method, assuming the values of each parameter of a gene are represented by N_g bits, and randomly selecting an integer number, N_c ($1 \leq N_c \leq N_g$), the corresponding parameter of the offspring gene, X_o, is produced by extracting the first N_c bits from the parameter of the first parent gene, $X_{p,1}$, and the last ($N_g \leq N_c$) bits from that of the second parent gene, $X_{p,2.}$ Similarly mutation is performed based on randomly selected bits of the parent gene, and the polarities of the selected bits are inverted. These crossover and mutation operations are subsequently performed over every parameter of a gene.

After the prescribed number of iterations has been performed, the gene with the largest fitness value is chosen as the optimized antenna design.

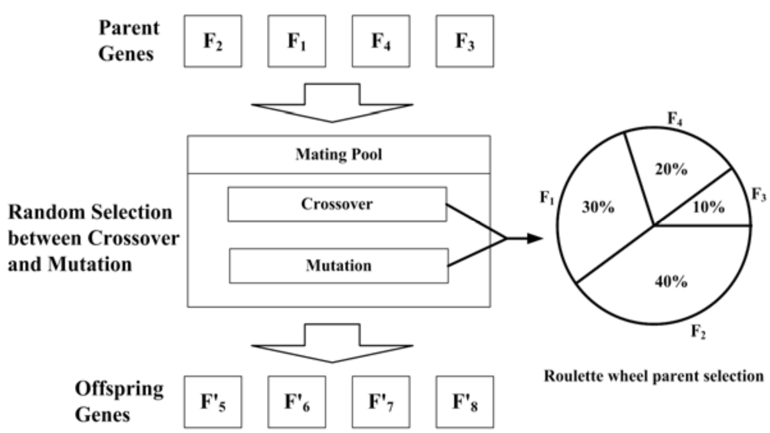
C. Interface to Interact with HFSS

(1) Initial parameter setup:

Within the framework of the automation control program, a subroutine is established to specify the configurations of the horn antenna including the geometrical parameters. An initial antenna setting is first performed within the work of this subroutine. The fundamental parameters such as the sampled frequencies,



(a)



(b)

Fig. 2. The illustration of genetic algorithm to generate new antenna structures with superior performance: (a) general concepts and (b) production of superior offspring genes.

radiation patterns and geometries of antenna structures are assigned tentatively. This subroutine transforms the values of the parameters into a script file (called VBScript file by HFSS [9]) that can be recognized by HFSS, and then passes the parameters to the HFSS to perform the EM analysis and compute the radiations patterns of the initial antenna structure.

The selection of the initial antenna structure plays a dominant role for the success of the optimization procedure. It should be capable of providing the essential possibility to achieve the design goal since the optimization procedure tends to fine tune the values of the antenna's parameters instead of altering the structure dramatically. For example, if equal beamwidth in the radiation band is desired, the changes in antenna's parameters should result in substantial difference in radiation patterns for the first few iterations and gradually converge until the optimum design is reached. In this case, the GA procedure will tune the parameter values to adjust the radiation patterns in an effective fashion until the designated beamwidth features are obtained.

(2) Interaction with the HFSS by a VBScript file

Interactions of the subroutines within the automation control program with HFSS are performed by using a VBScript file which can be executed in HFSS. In this case, the commands and functions within the antenna configuration subroutine that specify the antenna structures can be properly identified and transformed into the format recognizable by HFSS. The antenna model is then established within the HFSS GUI program. Commands and functions that read the antenna radiation data can be similarly established by identifying the commands in the HFSS VBScript file, which can be used to compute the fitness functions. The following statements show an example of HFSS's internal functions that define a "Waveport Port" [9] for the excitation of the horn antenna within a waveguide:

```
oModule.AssignWavePort _
Array( _
"NAME:WavePort", _
"NumModes:=", 1, _
"PolarizeEField:=",  false, _
"DoDeembed:=", false, _
"DoRenorm:=", false, _
Array("NAME:Modes", _
Array("NAME:Mode1", _
"ModeNum:=",  1, _
"UseIntLine:=", false) _
), _
"Objects:=", Array("circle"))
```

They can be established by using the fprintf command in C-language. For example, the function can be set up by following statement:

```
fprintf(fid, "%s%c%s%c%s", "Set oModule = oDesign.GetModule(",symbol,"BoundarySetup", symbol,") \n");
```

Other functions of HFSS can be established in a similar fashion, and are not repeated here for simplification.

(3) Intervention with HFSS Execution via key-board controlling keys

The execution of the entire antenna design procedure is performed within the control program. The program knows when to call the HFSS for EM analysis, when the HFSS has completed the analysis, how to access the antenna radiation data and where to pass the parameters between HFSS and the GA operator via the VBScript file and data files. The access of HFSS is performed by simulating key-board controlling keys using C-languages commands and ANSI codes [15] for English characters. The key-board controlling keys allow one to run the functions of HFSS through its GUI program. Two examples of running the HFSS analysis and retrieving the radiation patterns from HFSS, which are key functions required in this code integration, are demonstrated. The execution of other functions within HFSS can be performed similarly. The following statements are part of the C-language commands that are used to execute a VBScript file named "modify", which perform the antenna model establishment and execute the HFSS analysis:

```
ShowWindow(handle,SW_SHOWNORMAL);
SetForegroundWindow(handle);
SetActiveWindow(handle);

keybd_event(VK_MENU,0,0,0);        //key "alt"
```

```
6       keybd_event(84,0,0,0);              //key "T"
7       Sleep(100);
8       keybd_event(VK_MENU,0,KEYEVENT
F_KEYUP,0); //Release key "alt"
9     keybd_event(84,0,KEYEVENTF_KEYUP,0);
          //release key "T"
```

The above statements emulate the keyboard strokes and hence provide a means to communicate with HFSS. Their results are illustrated in Figure 3. Lines 1─3 lock the HFSS GUI windows so that the following operations can be performed without being interfered by other codes running in the computer. Lines 5─9 execute the input of key-board command "Alt-T" and will open an HFSS window pending from "Tools" icon to run script commands as shown in Figure 3(a). There are also other lines that simulate the input of key "s" from keyboard, which will open the window for file access from the hard disk to run a script file. Thus a window is opened for inputting the filename of the script file, where a script file named "modify" is input one character after another using above fashion. Figure 3(b) shows the dialog window evoked.

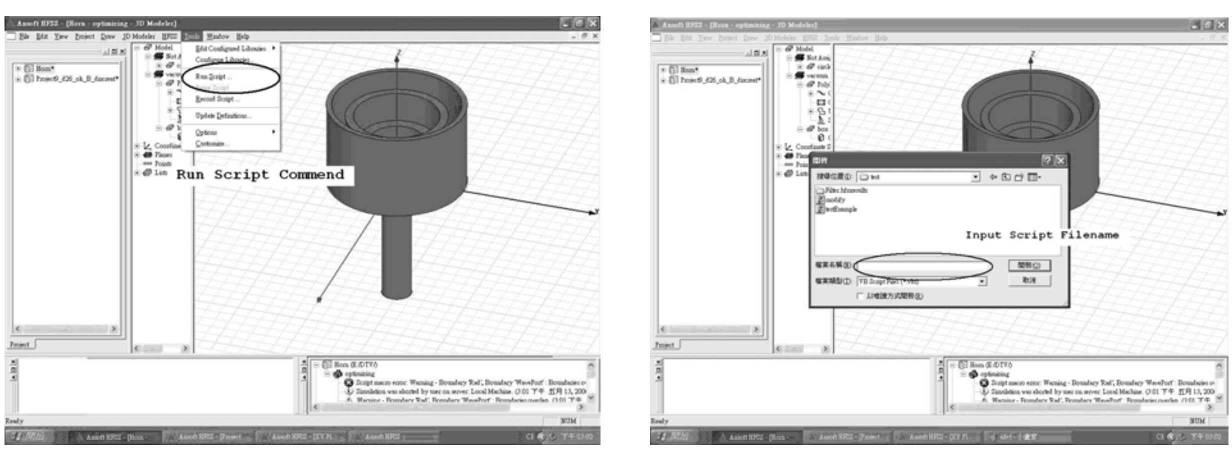
After the HFSS analysis, the data of the radiation patterns should be retrieved. Using statements similar to the one shown above, data can be retrieved and saved into a file that can be accessed by the automation program to compute the values of the fitness functions. Note that the statements should be repeated if multiple sets of data are required in the optimization procedure. For example, the radiation patterns of different observation planes can be treated as different sets of data and one should execute the statements separately.

After all radiation patterns are saved as external files, they may be employed in the automation program to compute the fitness values, and can be subsequently used in the GA procedure to produce a better design in the iterative procedure.

III. DEMONSTRATION EXAMPLES

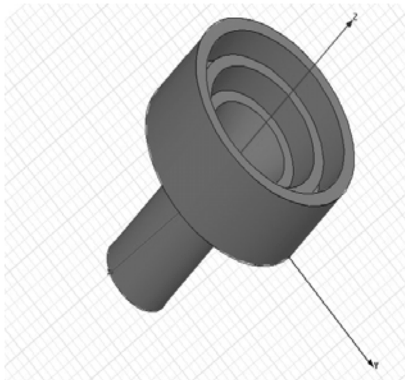
A. Single Band Horn Antenna Design with Similar Beamwidths at Two Principal Planes

The first example considers the design of a single band horn antenna for radiation with equal beamwidths at two principal planes so that it can be employed as a feed to a rotationally symmetric reflector antenna. The operation frequency is assumed to be 20 GHz. A -10 dB normalized beamwidth of 60 degrees (i.e., ±30 degrees) is pursued in this design. The antenna structure considered is illustrated in Figure 4, where the corrugations are perpendicular to the antenna aperture in consideration for mass production. In this case, 3 corrugations are implemented, and 13 parameters associated with depth, width and thickness of the corrugations are employed as the variables to be adjusted along the optimization

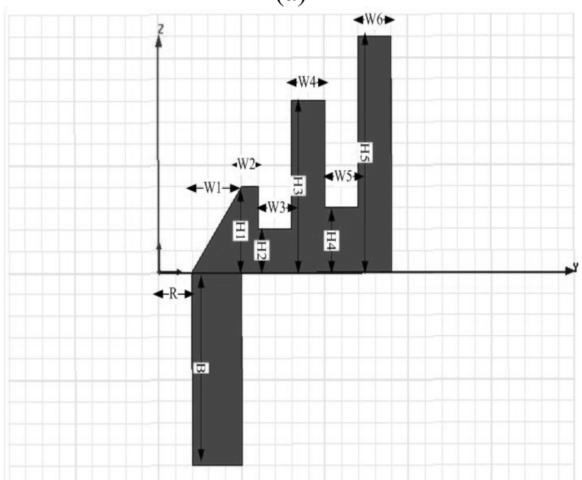


(a) (b)

Fig. 3. The procedure within HFSS GUI to execute a VBScript file: (a) "Alt-T" to open the window of the "Tools" icon, and (b) run a script file.



(a)



(b)

Fig. 4. The corrugated horn antenna structure for the feed to a reflector antenna. The corrugation is perpendicular to the antenna aperture for the convenience of a mass production: (a) horn structure and (b) cross section and parameters.

procedure so that the overall radiation patterns can be rotationally symmetric along the boresite. Note that 8 bits are employed to each parameter of the antenna structure in this case.

The radiation patterns at the two principal planes are used to calculate the fitness function, where the fitness function for the n^{th} gene is defined by

$$F_n = \frac{1}{\left(1+\sum_{m=1}^{M}\Delta G_{nm}\right)\left(1+\sum_{p=1}^{2}\Delta B_{np}\right)}, \tag{1}$$

where

$$\Delta G_{nm} = \begin{cases} \left|G_{nm,E} - G_{nm,H}\right| & \left|G_{nm,E} - G_{nm,H}\right| > G_{tol} \\ 0 & \left|G_{nm,E} - G_{nm,H}\right| \le G_{tol} \end{cases}, \tag{2}$$

$$\Delta B_{np} = \begin{cases} \left|B_{np} - B_{req}\right| \big/ B_{req} & \Delta B_{np} \big/ B_{req} > B_{tol} \\ 0 & \Delta B_{np} \big/ B_{required} \le B_{tol} \end{cases}. \tag{3}$$

In (2), $G_{nm,E}$ and $G_{nm,H}$ are the radiation gain patterns sampled at E- and H-planes, respectively (assuming M samples at each plane), and G_{tol} is the allowable tolerance for the pattern difference at the two principal planes. In general specifying main beam pattern and first sidelobe level is enough for good performance since the corrugated horn antenna has characteristics of low sidelobes. The difference between the patterns at the two principal planes is computed in (2). If the difference is larger than the allowable tolerance, then it is included in the computation of fitness value. On the other hand, if the difference is smaller than the tolerance, then the patterns are considered as being matched and the difference is ignored. Note that each set of genes represents an individual antenna structure, and thus the pattern difference should be computed for each gene. In this case, 10 genes (n = 1 ~ 10 in (1)) are employed in the GA optimization.

Similarly, B_{np}(p = 1, 2) specify the -3dB beamwidth at the two principal planes so that the radiation patterns can satisfy the required beamwidth, B_{req}. In fact, (3) computes the differences of the beamwidths. If the difference is larger than the allowable tolerance, B_{tol}, then it is included in the computation of fitness function. However, if the difference is smaller than the tolerance, it is ignored since the beamwidth requirement is satisfied.

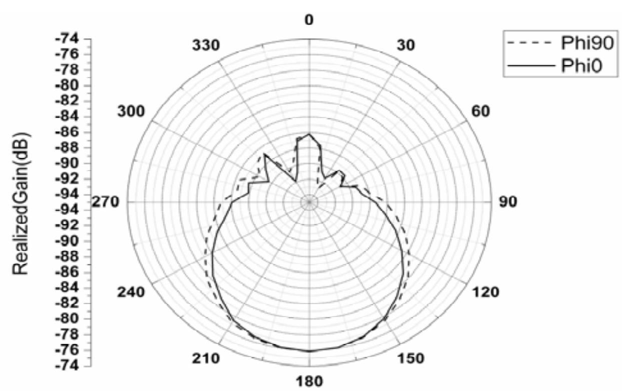
The summations of ΔG_{nm} and ΔB_{np} contribute to the denominator of F_n. A proper design, which meets the pattern specifications, will yield a fitness value of one (F_n = 1) that is the largest value possible in the optimization procedure. A larger F_n value implies a superior performance as required in the GA procedure. Figure 5(a) shows the radiation patterns of an initial arbitrary geometry setting with parameters specified in Table 1, where it is observed that the pattern at $\phi = 0°$ plane has a larger beamwidth than that at $\phi = 90°$ plane. In particular, the -10 dB beamwidths are 70° and 55° at $\phi = 0°$ and $\phi = 90°$ planes, respectively. It is noted that this initial setting of waveguide radius is 2.873mm, which makes the operational frequency below the cutoff frequency of a fundamental mode propagation. Thus the antenna will not radiate and makes the simulated gain severely small (roughly -76dBi). The proposed tool will automatically correct this problem and optimize the structure until it fulfills the desired requirements. Figure 5(b) shows the radiation patterns of the optimized antenna design, where one has observed almost identical main beam patterns at the two principal planes. In particular, the -10 dB beamwidth is 58 degrees as required in the design criterions. The values of the optimized parameters are also shown in Table 1 for comparison. In this design optimization, the analysis of each antenna structure costs 8 minutes of CPU time running on an AMD K8 3000 (with 1 GB RAM) computer. The overall CPU time is 26.7 hours for the entire optimization procedure, where approximately 250 antenna structures have been analyzed with HFSS. Note that most of the CPU time was spent in evaluating radiation patterns from various designs in the population via HFSS while the CPU time spent in performing crossover/mutation operations is negligible.

B. Horn Antenna Design with Equal Beamwidths in Radiation Patterns at Two Operation Frequencies

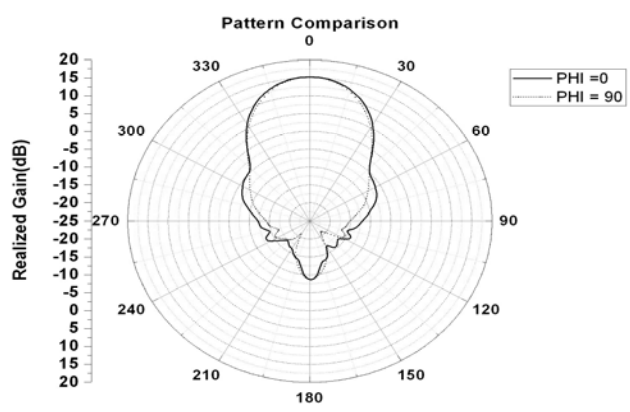
The second example considers a dual band horn antenna design that is operated at 20 and 30 GHz. The antenna is employed as the feed of a reflector antenna. Thus it is desired for the horn antenna to radiate with equal beamwidths so that the reflector surface can be well illuminated at the two different bands. In this case, the design goal is to have a -10dB beamwidth of 70 degrees with maximum gains. Similar to the previous example, a corrugated horn structure illustrated in Figure 4 is employed. Values of the initial setting parameters are given in Table 2. Total of 13 parameters are employed to specify the antenna structure. The terrible radiation patterns of the initial setting are shown in Figure 6(a). The gains at 20 and 30 GHz are less than -72 dBi. Furthermore, similar to the previous example, most of the energy return back to the waveguide and doesn't radiate because

Table 1: The initial and optimized values of the antenna dimensions for the first example.

Parameter Name	Initial Values (mm)	Optimized Values (mm)
R	2.873	4.4444
B	24.206	26.667
W1	2.4286	4.86
W2	1	1
W3	1	1
W4	1	1
W5	1	1
W6	1	1
H1	7.2222	14.365
H2	3.8571	3.143
H3	14.841	21.825
H4	7.2222	15.317
H5	15.794	26.889



(a)



(b)

Fig. 5. Radiation patterns of the horn antenna at the two principal planes before (a) and after the optimization (b). The desired radiation direction in (a) should point to 0 degree as achieved in (b).

the fundamental mode is not supported in this initial guess of waveguide radius. The GA algorithm adjusts the dimensions of the corrugations to optimize the radiation patterns at these two frequency bands. The radiation patterns at the two principal planes are employed to justify the required beamwidth performance. The four sets of patterns were employed to compute the fitness function. The fitness function for n^{th} set of genes is defined similarly by

$$F_n = \frac{1}{\left(1+\sum_{m=1}^{M}\Delta G_{nm}\right)\left(1+\sum_{p=1}^{4}\Delta B_{np}\right)}, \tag{4}$$

where

$$\Delta G_{nm} = \begin{cases} \sum_{q=2}^{4}\left|G_{nm,q} - G_{nm,1}\right|; & \Delta G_{nm} > G_{tol} \\ 0 & \Delta G_{nm} \le G_{tol} \end{cases}, \tag{5}$$

$$\Delta B_{np} = \begin{cases} \left|B_{np} - B_{req}\right| / B_{req} & \Delta B_{np} > B_{tol} \\ 0 & \Delta B_{np} \le B_{tol} \end{cases}. \tag{6}$$

In (5), $G_{nm,q}$ (q = 1~4) indicates one of the four radiation patterns. In particular, $G_{nm,1}$ is selected to the one with beamwidth closest to the specification. The computation of (5) intends to minimize the differences in the four patterns. ΔG_{nm} =0 if the difference between patterns are all smaller than the tolerance threshold. Equation (6) drives the beamwidths of the four patterns close to the required beam width. Similar to the characteristics described in the previous example, a proper design will yield a fitness value of one (F_n = 1). Similar to the previous example, 10 genes are employed in each generation to determine superior parents and each parameter of the antenna structure is represented by 6 bits. These optimization parameters are selected to provide a relatively quick convergence in the GA optimization procedure.

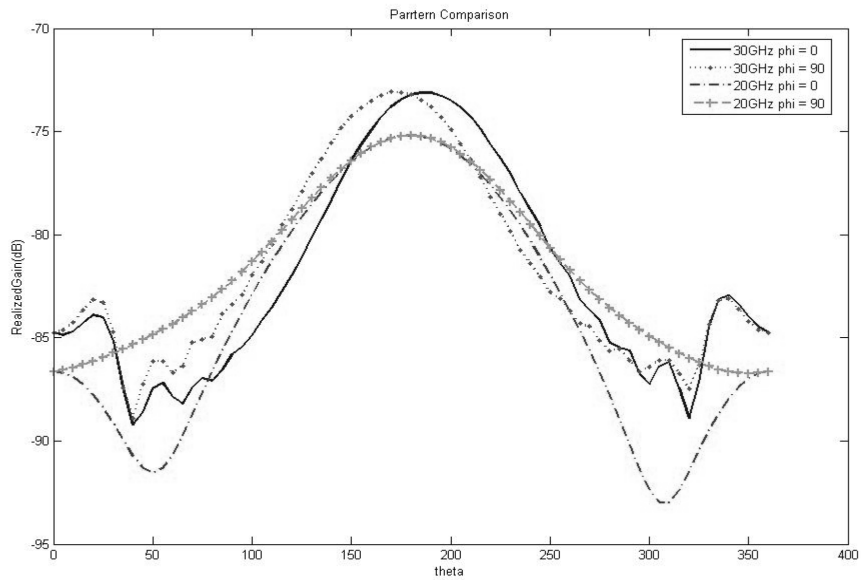
The proposed scheme is performed to optimize the antenna structure for its patterns at both 20 and 30 GHz. Figure 6(b) shows the radiation patterns of the optimized antenna design, which has identical main beam patterns in the two principal planes at both 20 and 30 GHz. In particular, the beam width is 72 degrees as required in the design criterions. Approximately compared with Figure 6(a), the gains at both frequencies are almost identical and are approximately 14 dBi. The values of initial setting and optimized design parameters are shown in Table 2 for comparison, while the performance parameters such as gain, beamwidth, and front-to-back ratio at 20 and 30 GHz are tabulated in Table 3. In this design optimization, each antenna structure costs 20 minutes of CPU time, which is 2 times larger than that in the previous example because now the analysis needs to be performed at 2 frequencies. The whole simulation cost 25.5 hours of CPU time, which comprised 75 HFSS analyses (i.e., 75 antenna structures have been analyzed in the GA procedure).

Table 2: The initial and optimized values of the antenna dimensions for the second example.

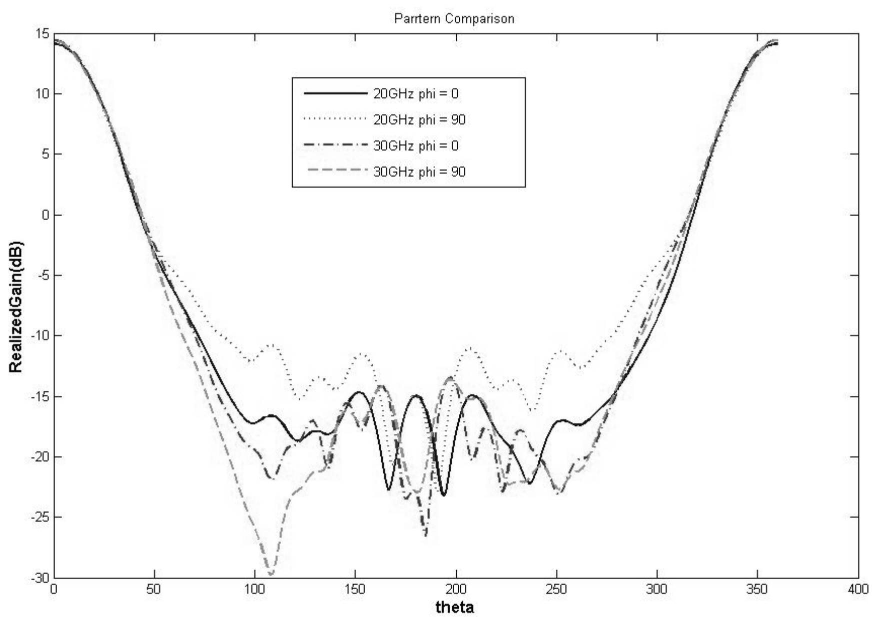
Parameter Name	Initial Values (mm)	Optimized Values (mm)
R	2.254	4.9841
B	22.46	24.683
W1	2.4285	2.0476
W2	1.2857	1.8571
W3	2.5873	1.3016
W4	2.0714	1.8809
W5	1.2222	1.5714
W6	1.8881	2.0714
H1	7.3333	6.7619
H2	3.6508	2.619
H3	11.937	10.6984
H4	8.2689	7.1429
H5	14.048	14.2381

Table 3: Comparison of radiation performance of initial setting and optimized designs.

Parameter Name	Initial Setting	Optimized Design
Gain @ 20 GHz	-73 dBi	14 dBi
10 dB beamwidth @ 20 GHz	180 deg.	72 deg.
Front-to-back ratio @ 20 dB	12 dB	30 dB
Gain @ 30 GHz	-75 dBi	14 dBi
10 dB beamwidth @ 30 GHz	150 deg.	72 deg.
Front-to-back ratio @ 30 dB	12 dB	37 dB



(a)



(b)

Fig. 6. The radiation patterns of the horn antenna at the two principal planes, which are operated at 20 and 30 GHz. The desired radiation direction in the initial setting (a) should point to 0 degrees as achieved after optimization in (b).

IV. CONCLUSION

In this work, a GA-based design optimizer and HFSS simulation tools are integrated within an automated control program to optimize the design of horn antennas for the application as feeds to reflector antennas. The validity of this work is verified via the optimization of the radiation patterns of the dual band antennas so that the effective antenna aperture of the reflector can be maximized. The presented examples show that the optimization can be performed automatically and therefore save tremendous efforts compared to manual tuning.

REFERENCES

[1] O. Yamada, H. Matsumura and M. Sasaki, "Development of Satellite and Terrestrial Digital Broadcasting System in Japan," *IEEE MTT-S International Microwave Symposium Digest*, vol. 1, pp. 71-75, June 7-12, 1998.

[2] E. Lier and R. Landes, "High Gain Linearly Polarized Dual-Band Horn for Multi-feed Reflector Antenna", *Electronic Letters*, vol. 39, no. 17, pp. 1230-1232, Aug. 2003.

[3] C. A. Balanis, *Antenna Theory- Analysis and Design*, Chap. 13, 2nd Ed., John Wiley & Sons, New York, 1997.

[4] J. Kim, T. Yoon, J. Kim and J. Choi, "Design of an ultra wide-band printed monopole antenna using FDTD and genetic algorithm," *Microwave and Wireless Components Letters*, vol. 15, no. 6, pp. 395-397, Jun. 2005.

[5] H.-J. Wang, K.-F. Man, S.-W. Zhang, J. Li and H.-G. Liu, "Large Bandwidth Fourfold-T-shaped Microstrip-fed Slot Antenna Using FDTD and Genetic Algorithm," *Proceeding of ICIT 2005*, pp. 287–290, Dec. 2005.

[6] S. Alfonzetti, G. Borzi, E. Dilettoso and N. Salerno, "Optimization of a Patch Antenna by Genetic Algorithms and a Hybrid FEM/RBCI Method," *Proceeding of 12th Biennial IEEE Conference on Electromagnetic Field Computation*, p. 375, 2006.

[7] X. Chen, K. Huang and X.-B. Xu, "Automated design of a three-dimensional fishbone antenna using parallel genetic algorithm and NEC," *Antennas and Wireless Propagation Letters*, vol. 4, pp. 425-428, 2005.

[8] J. L. Volakis, A. Chatterjee and L. C. Kempel, *Finite Element Method for Electromagnetics- Antennas, Microwave Circuit and Scattering Applications*, IEEE Press, New York, 1998.

[9] Ansoft Corporation, *High Frequency Structure Simulator (HSFF) User Manual*, Pittsburgh, PA, Ansoft Corporation, 2001.

[10] F. Hsu, P.-R. Chang and K.-K. Chan, "Optimization of two-dimensional radome boresight error performance using simulated annealing technique," *IEEE Trans. on Antennas Propagat.*, vol. 41, pp. 1195-1203, Sept. 1993.

[11] J. H. Holland, "Genetic algorithm," *Scientific American*, pp. 44-51, Jul. 1992.

[12] J. M. Johnson, Y. Rahmat-Samii, "Genetic algorithms in engineering electromagnetics," *IEEE Antennas and Propagat. Magazine*, vol. 39, pp. 7-21, Aug. 1997.

[13] T.-H. Lee and R.C. Rudduck, *OSU Reflector Antenna Code- Version 3.0 (NECREF Version 3.0)*, Technical Report 318021-1, ElectroScience Lab., Ohio State University, Feb. 1994.

[14] P. H. Nielsen and S. B. Sorensen, *GRASP9 Software User Manual, version 8.0*, Copenhagen, Denmark, TICRA, 1997.

[15] P.S. Wang, *An Introduction to ANSI C on Unix*, Belmont, CA, Wadsworth, 1992.

Hsi-Tseng Chou was born in Taiwan, in 1966. He received his B.S. degree in electrical engineering from National Taiwan University in 1988, and his M.S. and Ph. D. degrees also in electrical engineering from Ohio State University (OSU) in 1993 and 1996, respectively. He joined Yuan-Ze University (YZU), Taiwan, in August 1998, and is currently a professor in the Department of Communications Engineering.

His research interests include wireless communication network, antenna design, antenna measurement, electromagnetic scattering, asymptotic high frequency techniques such as Uniform Geometrical Theory of Diffraction (UTD), novel Gaussian Beam techniques, and UTD type solution for periodic structures. Dr. Chou has received two awards from Taiwanese Ministry of Education and Ministry of Economic Affairs in 2003 and 2008, respectively to recognize his distinguished contributions in promoting academic researches for industrial applications, which were the highest honors these two ministries have given to university professors to recognize their industrial contributions. He has published more than 250 journal and conference papers.

Dr. Chou is a senior member of IEEE AP-S and an elected member of URSI International Radio Science US commission B.

Chia-Wei Liu was born in Taiwan, in 1983. He received his B.S. degree in communication engineering from Yuan Ze University in 2006. He is currently an M.S. student in the Electroscience Laboratory, Ohio State University. His research interests include EM numerical simulations and antenna designs for wireless communications.

Hsi-Hsir Chou was born in ChangHua Taiwan, in 1975. He received his PhD degree in Engineering from Cambridge University, U.K. in 2008.

He was involved in collaborating with ALPS UK Co. Ltd and Dow Corning Co. Ltd in the development of patented free-space optical interconnection technologies, ferroelectric liquid crystal devices and carbon nanotube dielectric devices during his PhD program at Cambridge University from 2004 to 2008. He joined the Department of Engineering Science, Oxford University, U.K. in July 2008 as a Post-Doctoral Researcher in the development of high-speed visible light communication technologies sponsored by Samsung Electronics Co. Ltd., Korea, before he returned Taiwan to join the Communication Research Center, Yuan Ze University, Taiwan as a Researcher in May, 2009. His current research interests include free-space optical interconnection technologies, ferroelectric liquid crystal devices, carbon nanotube dielectric devices and antenna design.

Dr. Chou is a lifetime member of Trinity College, Cambridge and a Fellow of Cambridge Overseas Society since 2005.

Wen-Jiao Liao was born in Taipei, Taiwan. He received the B.S. degree in electrical engineering from the National Taiwan University, Taipei, Taiwan in 1995. He received the M.S. and Ph.D. degrees in electrical engineering from The Ohio State University, Columbus, in 1999 and 2003, respectively. After receiving his Ph.D. degree in 2003, He was employed by Syntonics, LLC as a project scientist. In 2004, he continued his research work in the Electroscience laboratory of the Ohio State University as a post-doctoral researcher. In 2004-2007, he was an Assistant Professor at Yuan-Ze University in the Department of Communications Engineering. He is currently an Assistant Professor at National Taiwan University of Science and Technology in the Department of Electrical Engineering. His main interests are antenna design and measurement, wave propagation, EMC/EMI issues, electro-optical sensor signatures, and image processing.