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DESIGN OF AN ULTRA-WIDEBAND ANTENNA USING BOOLEAN DIFFERENTIAL EVOLUTION ALGORITHM

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Abstract—A compact ultra-wideband (UWB) slot antenna based on a mesh-grid structure is designed. A Boolean differential evolution (BDE) algorithm is used to optimize the mesh-grid structure as well as other parameters of the proposed antenna for good impedance matching in the UWB band. The optimized UWB antenna has a compact size of 24.2 mm × 32.2 mm and is fabricated and measured. According to the measured results, the proposed antenna yields a wide bandwidth, defined by $S_{11} < -10\,\mathrm{dB}$ ranging from 2.8 to 11.2 GHz. And it shows that the BDE algorithm is an effective method for antenna design.

1. INTRODUCTION

The ultra wideband (UWB) antenna has become an intensive topic in the field of the antenna research because of some of its unique features such as transmitting and/or receiving very short time durations of electromagnetic energy and avoiding frequency dispersion and space dispersion. Recently, many antenna designs are developed to realize UWB operation, among which printed wide slot antennas have been regarded as popular candidates [1–5]. All these antenna designs have attempted to change the coupling between the feed line and the slot by designing special shapes for the slot or for both the slot and feed line. Although various slot shapes have been proposed in the literature, the design freedom is still limited by employing only conventional structures.

Genetic Algorithm optimized mesh-grid structure has been widely used in electromagnetic designs, such as microstrip patch

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antenna [6], planar monopole antenna [7], and FSS [8]. Compared with conventional structures, this structure provides more degrees of freedom for the antenna design. And the geometry of antenna is generated by the optimizer atomically, which eliminates the need of foreseeing the antenna's structure.

In this paper, an UWB slot antenna with a mesh-grid structure is introduced. The grids as well as the dimensions of the feed line are coded into a single binary chromosome and are optimized simultaneously. Instead of Genetic Algorithm, the recently proposed BDE algorithm is utilized as the binary optimizer [9]. By optimizing the mesh-grid structure, an appropriate slot shape is obtained, which has significantly enlarged the antenna's impedance bandwidth. And the effectiveness of the BDE algorithm for antenna design is demonstrated. The optimized antenna is fabricated and measured. The measured results show good agreement with the simulated ones. Details of the antenna design and both the simulated and the measured results are presented and discussed.

2. BOOLEAN DIFFERENTIAL EVOLUTION

BDE follows the general procedures of the classic DE, except that the mutation operation is implemented by Boolean algebra. Assume that $\vec{X}_{i,G} = (X_{1,i,G},\, X_{2,i,G},\, \ldots,\, X_{D,i,G})\ (i = 1, 2, \ldots, NP)$ is a solution vector at generation G, which is represented by D-bit binary strings, where NP is the population size and D is the problem dimension. For the BDE algorithm, the mutation operator is defined as follows.

$$\vec{V}_{i,G} = \vec{X}_{best,G} + F \bullet \left(\vec{X}_{r_1,G} \oplus \vec{X}_{r_2,G}\right) \tag{1}$$

where 'AND', 'OR' and 'XOR' operators are denoted by symbols ($\bullet$), ($+$) and ($\oplus$), respectively. F^b is a random N-bit binary string, which is not a control parameter in contrast to the classic DE algorithm and $\vec{X}_{best,G}$ is the best individual with the best fitness value in the population at generation G.

After the mutation phase, the "binominal" crossover operation is applied to each pair of the generated mutant vector $V_{i,G}$ and its corresponding target vector $X_{i,G}$ to generate a trial vector $U_{i,G} = (U_{1,i,G},\, U_{2,i,G},\, \ldots,\, U_{D,i,G})$

$$U_{j,i,G} = \begin{cases} V_{j,i,G} & \text{if rand}\,(0,1) \leq \text{CR or}\, j = j_{\text{rand}} \\ X_{j,i,G} & \text{otherwise} \end{cases} \tag{2}$$

where CR is the crossover constant in the range [0, 1) , which is the only control parameter of BDE. j_{rand} is a randomly chosen integer in the range [1, D].

The selection operation selects the better one from the parent vector $X_{i,G}$ and the trial vector $U_{i,G}$ according to their fitness values. For example, if we have a minimization problem, the selected vector is given by

$$X_{i,G+1} = \begin{cases} U_{i,G}, & \text{if } f\left(U_{i,G}\right) < f\left(X_{i,G}\right) \\ X_{i,G} & \text{otherwise} \end{cases} \tag{3}$$

and is used as a parent vector in the next generation.

The above 3 steps are repeated generation after generation until some specific stopping criteria are satisfied.

3. ANTENNA DESIGN

The antenna is printed on a 24.2 mm × 32.2 mm substrate with the thickness of 1 mm and the dielectric constant of 2.65. The upper part of the ground plane consists of a 12 by 9 grid of metallic sub-patches. The overall dimensions of the grid structure is 24.2 mm × 18.2 mm. Each metallic sub-patch of the grid structure can be switched "on" or "off" by the BDE algorithm. Figure 1 shows all sub-patches switched "on." Each sub-patch is a 2.2 mm × 2.2 mm square. They are overlapping by 0.2 mm to ensure electrical contact in such constellations where two subpatches are touching only at the corner. This is used to avoid impractical one-point sub-patch contacts [10]. The geometry of the overlapping sub-patches is shown in Figure 2. In the optimization process, various slot shapes may be created, and that fragments separate from the main ground plane may be created as a loading structure. Besides the grid of sub-patches, the length of the feed line which depends on the values of L_f should also be optimized. This

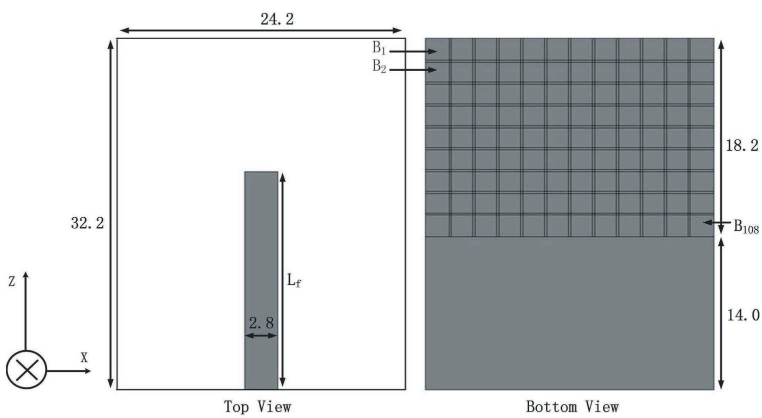

Figure 1. Geometry of the proposed UWB antenna.

parameter is encoded with a binary code of length 8. Consequently, the structure of the antenna is represented by a 116 bit long binary code. The grid structure is represented by the anterior 108 bits and the remaining 8 bits represent the value of L_f.

The fitness function for the antenna design is given by

$$f = \max\left\{S_{11}\left(3.1 - 10.6\,\mathrm{GHz}\right)\right\} \tag{4}$$

to improve the impedance matching within the UWB band. The S_{11} is calculated by using IE3D software which is based on method of moment [11]. For the BDE algorithm, CR is set to 0.2 and an initial population is produced randomly. The size of population is 30. The maximum number of function evaluations is set to 4500.

4. RESULTS AND DISCUSSION

From the convergence curve shown in Figure 3, it is observed that the obtained optimal design has a simulated return loss less than -12 dB. However, it should be noted that a better solution may exist if we have more fitness function evaluations. The optimum value of L_f is 26.3 mm

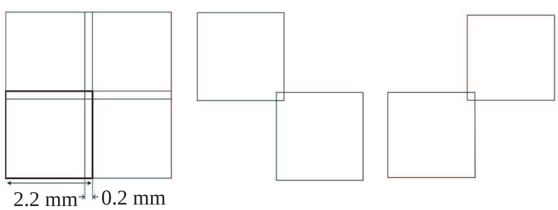

Figure 2. Geometry of overlapping sub-patches.

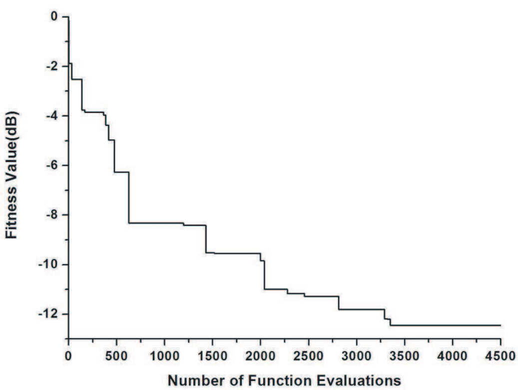

Figure 3. Convergence curve for the optimization of an UWB antenna using BDE.

and the geometry of the optimized antenna is shown in Figure 4. And as we expected, we have obtained an irregular slot shape as well as a separated loading structure which are responsible for the antenna's wideband performance.

The optimized antenna has been simulated using Zealand's IE3D package and measured on a network analyzer. Figure 5 shows the simulated and measured S_{11} of the optimized antenna, where a good agreement between the simulated and measured results is observed. From Figure 5, we can see that the antenna has a bandwidth ranging from 2.8 to 11.2 GHz for $S_{11} < -10$ dB, which is very attractive for UWB application. The normalized radiation patterns of the proposed antenna at 3.0, 6.0, and 9.0 GHz are shown in Figure 6.

Figure 4. Geometry of the optimized antenna.

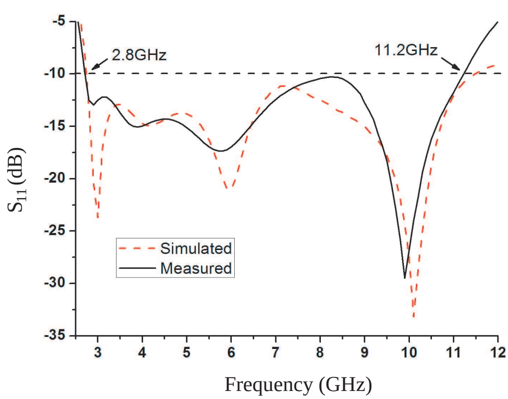

Figure 5. Simulated and measured S_{11} of the optimized antenna.

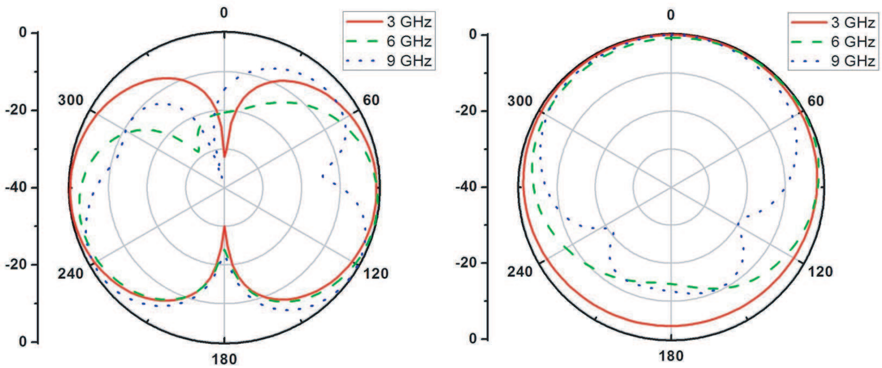

Figure 6. Radiation patterns of the optimized antenna: (a) y-z plane, (b) x-y plane.

5. CONCLUSION

The optimization of a compact UWB slot antenna has been implemented by Boolean differential evolution algorithm. By introducing a mesh-grid structure on the ground plane, the design freedom is improved significantly. The optimized antenna is fabricated and measured. Measured results show that the optimized antenna has a bandwidth, defined by $S_{11} < -10\,\mathrm{dB}$, ranging from 2.8 to 11.2 GHz. It indicates the effectiveness of the design method and the applicability of the BDE algorithm to other optimization problems in electromagnetics.

REFERENCES

1. Zhu, X.-F. and D. Su, "A study of a compact microstrip-FED UWB antenna with an open T-slot," *Progress In Electromagnetics Research Letters*, Vol. 13, 181–189, 2010.
2. Sadat, S., M. Houshmand, and M. Roshandel, "Design of a microstrip square-ring slot antenna filled by an H-shape slot for UWB applications," *Progress In Electromagnetics Research*, Vol. 70, 191–198, 2007.
3. Fallahi, R., A. A. Kalteh, and M. G. Roozbahani, "A novel UWB elliptical slot antenna with band-notched characteristics," *Progress In Electromagnetics Research*, Vol. 82, 127–136, 2008.

4. Shiu, J.-Y., J.-Y. Sze, and P.-J. Tu, "Compact ultrawideband square slot antenna with an asymmetric protruding stub," *Microwave and Optical Technology Letters*, Vol. 50, No. 7, 1776–1779, 2008.
5. Fan, S.-T., Y.-Z. Yin, L. Kang, S.-J. Wei, Y.-Z. Wang, and K. Song, "Bandwidth enhancement of a coplanar waveguide-fed asymmetrical slot antenna with a rectangular patch," *Microwave and Optical Technology Letters*, Vol. 52, No. 10, 2259–2261, 2010.
6. Choo, H. and H. Ling, "Design of broadband and dual-band microstrip antennas on a high-dielectric substrate using a genetic algorithm," *IEE Proceedings Microwaves Antennas and Propagation*, Vol. 150, No. 3, 137–142, 2003.
7. Kerkhoff, A. J., R. L. Rogers, and H. Ling, "Design and analysis of planar monopole antennas using a genetic algorithm approach," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 10, 2709–2718, 2004.
8. Ohira, M., H. Deguchi, M. Tsuji, and H. Shigesawa, "Multiband single-layer frequency selective surface designed by combination of genetic algorithm and geometry-refinement technique," *IEEE Transactions on Antennas and Propagation*, Vol. 52, No. 11, 2925–2931, 2004.
9. Zhang, L., Y. C. Jiao, Z. B. Weng, and F. S. Zhang, "Design of planar thinned arrays using a boolean differential evolution algorithm," *IET Microw. Antennas Propag.*, Vol. 4, No. 12, 2172–2178, 2010.
10. Johnson, J. M. and V. Rahmat-Samii, "Genetic algorithms in engineering electromagnetics," *IEEE Antennas and Propagation Magazine*, Vol. 39, No. 4, 7–21, 1997.
11. Liu, X. F., Y. B. Chen, Y. C. Jiao, and F. S. Zhang, "Modified particle swarm optimization for patch antenna design based on IE3D," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 13, 1819–1828, 2007.