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ISM Band Antenna Design Based on Fuzzy MCDM Selection Technique

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Abstract-**A design methodology of an ISM band folded patch antenna is presented in this paper. The antenna is designed for covering three ISM band at 2.400 – 2.480 GHz, 5.150 – 5.350 GHz, and 5.725 – 5.825 GHz, which is ideally suitable for short-range wireless applications. Jumping Genes Evolutionary Algorithm is used for optimizing the antenna performance, and the non-dominated solution set of antenna dimensional parameters is obtained. Then, a fuzzy-based multiattribute decision method is designed for selecting the most suitable antenna solution in the non-dominated solution set. Finally, the selection solution is compared with the other solutions for demonstrating the effectiveness of the scheme.**

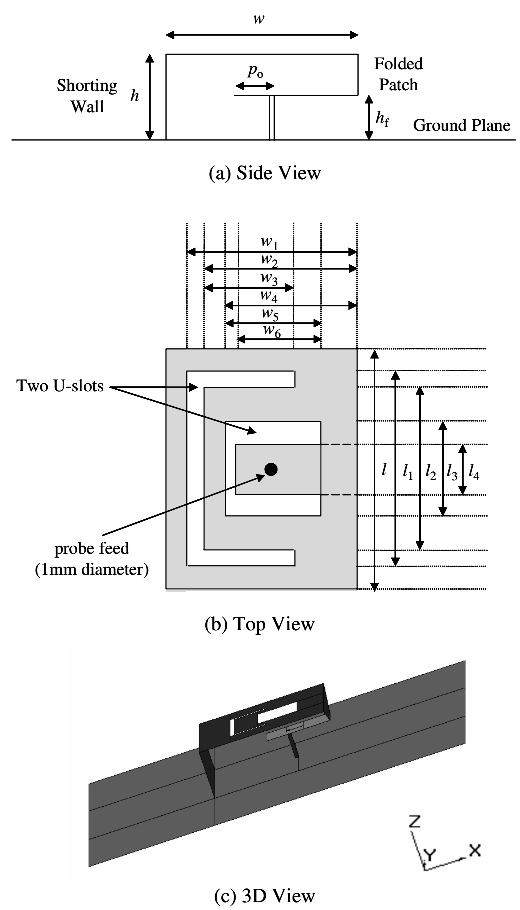


Figure 1. Antenna Configuration

I. INTRODUCTION

Patch antennae [1]–[4] are very popular in modern wireless communications because of their well-known attractive features including low profile, light weight, small size, and conformability to the architecture of the mounting locations. It also has a manufacture easy structure that meets the requirement of low cost consumer product design for ISM band [4].

However, this kind of antenna consists of a large number of tunable parameters that are demanded for the fulfillment of a series of design criteria, such as the impedance matching, radiation pattern and the miniaturization of antenna size. The typical antenna configuration being considered in this paper is shown in Fig. 1. It has some 15 dimensional parameters (w, w_1, w_2, w_3, w_4, w_5, w_6, l, l_1, l_2, l_3, l_4, h, h_f and p_o) to be optimized. The traditional trial-and-error design method would be materially wasteful and time consuming. An effective and powerful optimization method is therefore required for obtaining a desirable design within such a huge search space.

In this paper, a Jumping Genes Evolutionary Algorithm (JGEA) [5]–[7] is adopted for antenna dimensional parametric optimization. The design objectives are (i) satisfying the antenna impedance matching conditions in each of the three ISM bands and (ii) to realizing an optimally miniaturized antenna size. Hence multi-objective optimization [8] will be incorporated into the design procedures which will undoubtedly generate an abundance set of non-dominated possible antenna solutions.

While each of these non-dominated solutions may satisfy the Pareto-optimal sense, it's still extremely difficult for the designer to choose a single antenna solution that is considered to be the "best" one for hardware implementation. Thus, a fuzzy-based multicriteria (or multiattribute) decision method (MCDM) [9]–[10] would aptly be applied for the selection of the most suitable antenna design within this non-dominated solutions set.

The paper is organized as follows: The JGEA for multiobjective optimization will be described in Section II. In Section III, the optimization problem formulation and the results will be discussed. Then, the fuzzy-based selection method will be demonstrated and analyzed in Section IV. Finally, the conclusion will be given in Section V.

II. JUMPING GENES EVOLUTIONARY ALGORITHM

The formulation of JGEA [5]–[7] is a relatively new scheme for multiobjective optimization. It adopts a new genetic operator based on the concept of horizontal gene transmission mechanism, or the jumping genes transposition, that enables the genes to be transferred between the individuals within the same generation or within its own chromosome structure. JGEA comprises of two distinct types of operations, namely the cut-and-paste and copy-and-paste transposition. Fig. 2(a) shows the cut-and-paste transposition, where its action is to cut a portion of genes and then paste into a new position of its own or to another chromosome. Whereas the copy-and-paste transposition which is shown in Fig. 2(b) is to replicate a portion of genes itself and be inserted into a new position of the chromosome while keeping the original position unchanged. This methodology of gene transposition can enrich the possibility of generating new building blocks which will enhance the performance of the classical genetic operations such as crossover and mutation resulting to the increase of chances for obtaining better and wider spread of solutions over the Pareto-optimal solutions front. The capacity of JGEA for achieving a better performance both in convergence and diversity over the other MOEAs in various applications has been reported in [5]–[7].

The flowchart of the algorithm is shown in Fig. 3. The main body of the algorithm can go hand-in-hand with the non-dominated sorting algorithm II (NSGA-II) [11], in which the elitism of MOEA applies.

III. OPTIMIZATION PROCESS

The main optimization objectives of the antenna design are the minimization of the voltage standing wave ratios (VSWR) for each of the three ISM bands at 2.400 – 2.480 GHz, 5.150 – 5.350 GHz, and 5.725 – 5.825 GHz as well as the required miniaturization of antenna outermost size. These are essential requirements which can be represented in mathematical terms

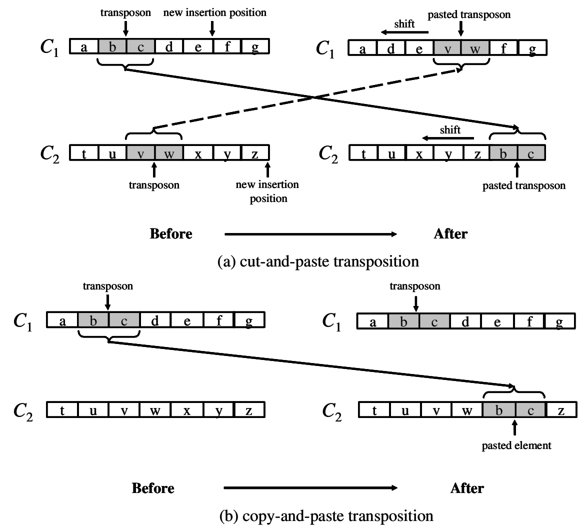


Figure 2. Jumping Genes Transposition

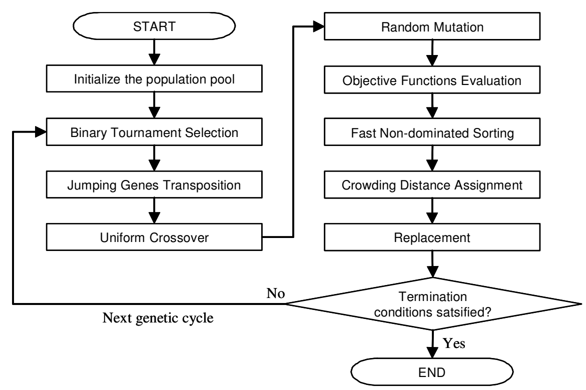


Figure 3. Flowchart of JGEA

for gauging the optimization procedures. The related objective functions for optimization are therefore given as follows:

$$F_1 = \left(\sum_{f=2.38\text{GHz}}^{2.50\text{GHz}} \text{VSWR} \right) \Big/ \left(\sum_{f=2.38\text{GHz}}^{2.50\text{GHz}} \text{number of frequency points} \right) \quad (1)$$

$$F_2 = \left(\sum_{f=5.13\text{GHz}}^{5.37\text{GHz}} \text{VSWR} \right) \Big/ \left(\sum_{f=5.13\text{GHz}}^{5.37\text{GHz}} \text{number of frequency points} \right) \quad (2)$$

$$F_3 = \left(\sum_{f=5.70\text{GHz}}^{5.90\text{GHz}} \text{VSWR} \right) \Big/ \left(\sum_{f=5.70\text{GHz}}^{5.90\text{GHz}} \text{number of frequency points} \right) \quad (3)$$

$$F_4 = l \times w \times h \quad (4)$$

where F_1, F_2, and F_3 are the objective functions for the minimization of the average VSWR value throughout the three ISM bands. F_4 is the measure in volume for the outermost size (length $l \times$ width $w \times$ height h).

The goal of the optimization should achieve an average VSWR ≤ 2 in all of the entire three ISM bands. It can be achieved by adapting the Pareto-ranking with goal information [12] by setting the goal of F_1, F_2, and F_3 to be smaller than 2. To calculate the average VSWR in a frequency band, the VSWR value is calculated by the summation of every 0.01 GHz frequency points in the band. The VSWR is evaluated by the electromagnetic simulation software IE3D [13] based on an infinite ground plane model so that the evaluation process can be greatly sped up.

The beauty of using JGEA is its speed of convergence as well as its capacity for yielding the wide spread solutions along the Pareto-optimal fronts. It usually requires a relatively small of number of generations to saturate the population pool with the desirable non-dominated solutions. In this optimization, a pool of 50 individuals were initially assigned and the obtainable non-dominated solutions, forty-two in total, were all satisfying the four individual objective functions in merely 45 generations. The result is tabulated in Table I. Each of these individual results indicates their respective objective values F_1, F_2, F_3 and F_4 which are all hardware implementable.

TABLE I
ANTENNA SOLUTION SET

Sol. No.	Objective Values				Sel. Criteria		Sel. Result	
	f_1	f_2	f_3	f_4	mean	var.	Index	Rank
1	1.568	1.341	1.243	6752	1.384	0.028	0.597	16
2	1.646	1.283	1.332	6752	1.42	0.039	0.632	23
3	1.43	1.667	1.495	6752	1.531	0.015	0.682	31
4	1.481	1.376	1.199	6752	1.352	0.02	0.567	10
5	1.428	1.703	1.325	6752	1.485	0.038	0.678	30
6	1.37	1.649	1.75	6752	1.59	0.039	0.863	42
7	1.48	1.44	1.225	6752	1.382	0.019	0.583	12
8	1.557	1.335	1.361	6752	1.418	0.015	0.599	17
9	1.373	1.443	1.575	6752	1.463	0.01	0.625	22
10	1.417	1.712	1.274	6948	1.467	0.05	0.693	33
11	1.361	1.342	1.725	6948	1.476	0.047	0.696	35
12	1.477	1.634	1.399	6948	1.503	0.014	0.67	29
13	1.416	1.359	1.515	6948	1.43	0.006	0.606	18
14	1.387	1.715	1.345	6948	1.482	0.041	0.693	32
15	1.332	1.434	1.475	6948	1.413	0.005	0.591	14
16	1.283	1.372	1.677	6948	1.444	0.043	0.664	27
17	1.282	1.392	1.721	6948	1.465	0.052	0.695	34
18	1.351	1.772	1.332	7046	1.485	0.062	0.735	39
19	1.269	1.407	1.66	7046	1.445	0.039	0.667	28
20	1.396	1.763	1.252	7046	1.47	0.069	0.732	37
21	1.368	1.739	1.305	7046	1.471	0.055	0.711	36
22	1.315	1.429	1.425	7046	1.39	0.004	0.575	11
23	1.343	1.395	1.343	7046	1.361	9E-04	0.541	3
24	1.398	1.358	1.488	7046	1.415	0.004	0.596	15
25	1.357	1.267	1.439	7187	1.354	0.007	0.562	7
26	1.133	1.418	1.706	7187	1.419	0.082	0.757	40
27	1.159	1.477	1.454	7187	1.363	0.032	0.609	19
28	1.357	1.31	1.485	7187	1.384	0.008	0.588	13
29	1.231	1.404	1.267	7187	1.301	0.008	0.522	2
30	1.178	1.387	1.583	7187	1.383	0.041	0.633	24
31	1.135	1.384	1.62	7187	1.38	0.059	0.656	25
32	1.159	1.412	1.377	7187	1.316	0.019	0.56	6
33	1.135	1.384	1.62	7187	1.38	0.059	0.656	25
34	1.291	1.357	1.253	7187	1.3	0.003	0.501	1
35	1.212	1.409	1.408	7187	1.343	0.013	0.566	9
36	1.197	1.725	1.294	7187	1.406	0.079	0.733	38
37	1.13	1.412	1.503	7396	1.348	0.038	0.618	21
38	1.253	1.738	1.204	7396	1.398	0.087	0.797	41
39	1.164	1.383	1.525	7396	1.357	0.033	0.618	20
40	1.155	1.453	1.218	7396	1.275	0.025	0.555	5
41	1.18	1.388	1.336	7501	1.302	0.012	0.548	4
42	1.146	1.464	1.208	7501	1.273	0.028	0.566	8

IV. FUZZY-BASED SOLUTION SELECTION

Since all these solutions can aptly be adopted for hardware implementation, it is difficult to pin-point an individual solution that may be considered as the most adequate solution for hardware fabrication. The difficulty remains from the abundance number of achievable objectives. The obtained non-dominated solutions may stretch to cover a whole range of design scenarios which signifies the significance of a smaller antenna outermost size (F_4) to the others with a low VSWR value within the three ISM bands (F_1, F_2, F_3).

Hence, some selection decision needed to be developed in order to justify the selected but most suitable solution. In this antenna design, a good antenna performance in VSWR must consist of two distinct attributes, (i) it must be able to achieve the lowest possible return loss in the three ISM bands and (ii) the antenna may allow the similar values of VSWR for the entire three ISM bands, and yet, avoiding one of the ISM bands to have a higher return loss than the other two ISM bands.

More importantly, a smallest possible antenna size (F_4) is advantageous for practical proposition. For these reasons, the selection criteria are based on three attributes would result to a desirable antenna design solution. After the much of the deliberation of the selection criteria based on the three aforesaid attributes, a fuzzy-based decision making scheme can be developed to select the most suitable antenna solution. First, fuzzy membership functions, Small and Large, are defined for describing the mean (M), variance (V) and the antenna size (S), as shown in Fig. 4. The mean_max, var._max and size_max in the membership function are the maximum value of the mean, variance and size of all antenna solutions obtained for the normalization of the membership functions. The ranking of antenna preference (A–F) can be defined for the classification of the overall antenna performance. The A class is the best grade while F is the worst grade. The membership values of the ranking (A–F) depends on the three attributes by fuzzy relations, and it is implemented as the fuzzy rules base in Table II. The general rule for calculation is:

$$\text{IF (Mean = M) AND (Variance = V) AND (Size = S)} \quad \text{THEN (Grade = G)} \tag{5}$$

In the design consideration, the mean (M) is more important than the variance (V) and the size (S). Hence, a Large Mean is not desirable. Thus, the fuzzy rule base listed in Table II has some priority settings for the three attributes of the antenna considered. For example, a Small Mean should has a higher ranking (A–C) than Large Mean (D–F) no matter what are the values of Variance and Size. It follows that the Variance (V) and the Size (S) will have the equal priority. The rule base is then defined as (V = Small AND S = Large) will have the same grade of (V = Large AND S = Small).

After the membership values of the grades (A–F) are established, the process of defuzzification may proceed to calculate a single performance index for a suitable solution selection. It can be given by the following weighted average formula:

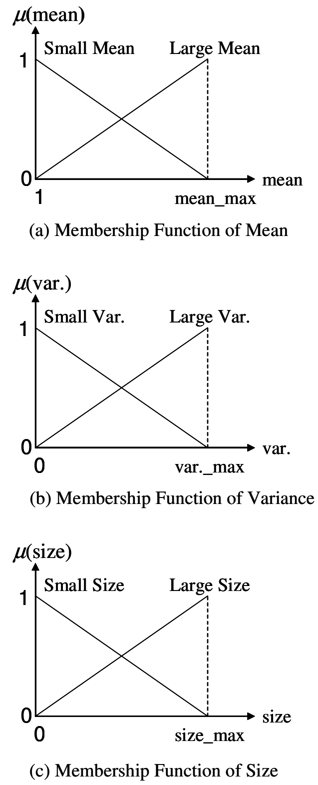
$$\mathit{Performance\ Index} = \frac{\sum_{Grade=A,\cdots,F} (\mu_{Grade}\, i_{Grade})}{\sum_{Grade=A,\cdots,F} \mu_{Grade}} \tag{6}$$

where μ_{Grade} is the membership values of the grades A–F, and the weighting of the grades i_{Grade} is constant values given in Table II corresponding to each grade.

Once the performance indexes of all solutions are calculated, the solution with the smallest performance index would be selected for the implemented antenna design. The following is to summaries the steps for obtaining a performance index for solution selection as listed as:

Step 1: Calculate the mean and variance of F_1, F_2 and F_3;
Step 2: Calculate the membership describing the mean (M), variance (V) and antenna size (S);
Step 3: Use the fuzzy rules to calculate the membership functions of the grade of performance A–F;
Step 4: Defuzzification on the grade of performance to obtain the performance index; and
Step 5: The solution with the least value of the performance index is selected as the implemented antenna solution.

The calculated results of the performance index are also listed in Table I. It is concluded that solution #34 has the least value of performance index (0.501), and so it is selected as the antenna solution. Fig. 5 compares its performance in VSWR



(a) Membership Function of Mean
(b) Membership Function of Variance
(c) Membership Function of Size

Figure 4. Membership Function

TABLE II
FUZZY RULE BASE

Mean (M)	Variance (V)	Size (S)	Grade (G)	Index (i_{Grade})
Small	Small	Small	A	0
Small	Small	Large	B	0.2
Small	Large	Small	B	0.2
Small	Large	Large	C	0.4
Large	Small	Small	D	0.6
Large	Small	Large	E	0.8
Large	Large	Small	E	0.8
Large	Large	Large	F	1

with other antenna solutions, for which they are the solution #10, #20 and #30 listed in Table I. It can be noted that solution #10 and #20 do not achieve good performance in the first and second ISM bands when comparing them with solutions #30 and #34. Also, the VSWR performance of solution #30 in the third ISM band is worse than that of solution #34. However, the solution #34 can achieve overall outstanding performance (VSWR ≤ 1.4) in the entire three ISM bands, showing the effectiveness of the solution selection methodology.

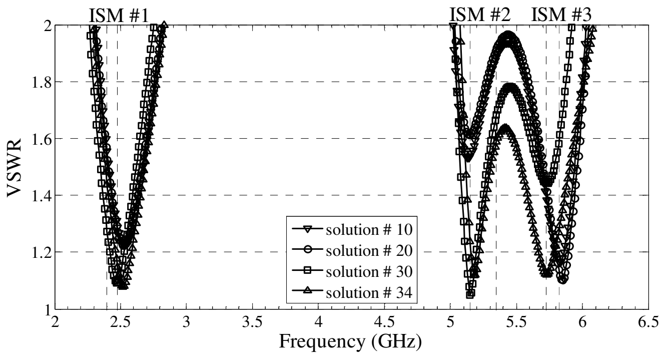


Figure 5. VSWR of the antenna solutions

V. CONCLUSION

A new dual band folded patch feed antenna configuration has been both computational optimized using JGEA. The antenna is able to cover three ISM bands at 2.400 − 2.480 GHz, 5.150 − 5.350 GHz, and 5.725 − 5.825 GHz, which satisfied the impedance bandwidth requirement (VSWR ≤ 2). The optimization results clearly show the effectiveness of JGEA scheme for the antenna design. It's a much more efficient methodology over the trail-and-error manually executed tuning method in term of time spent as well as for performance evaluation procedures.

Also, a fuzzy-based solution selection method is designed for selecting the most suitable antenna solution in the non-dominated solution set obtained though the JGEA optimization process. The selection results are compared with the other solutions, showing the effectiveness of the selection scheme.

REFERENCES

[1] C. L. Mak, K. M. Luk, K. F. Lee, Y. L. Chow, "Experimental study of a microstrip patch antenna with an L-shaped probe," *IEEE Transactions on Antennas and Propagation*, vol. 48, no. 5, 2000, pp. 777 – 783.

[2] C. Y. Chiu, K. M. Shum, C. H. Chan, and K. M. Luk, "Bandwidth enhancement technique for quarter-wave patch antennas," *IEEE Antennas and Wireless Propagation Letters*, vol. 2, no. 1, 2003, pp. 130 – 132.

[3] Y. X. Guo, K. M. Luk, K. F. Lee, "Dual-band slot-loaded short-circuited patch antenna," *Electronics Letters*, vol. 36, no. 4, 2000, pp. 289 – 291.

[4] C. Y. Chiu, C. H. Chan, and K. M. Luk, "Small dual-band antenna with folded-patch technique," *IEEE Antennas and Wireless Propagation Letters*, vol. 3, no. 1, 2004, pp. 108 – 110.

[5] T. M. Chan, K. F. Man, K. S. Tang, and S. Kwong, 2006 "A Jumping Gene Paradigm for Evolutionary Multiobjective Optimization," *IEEE Tran. on Evolutionary Computation*, (accepted for publication).

[6] T. M. Chan, K. F. Man, K. S. Tang, and S. Kwong, "Multiobjective optimization of radio-to-fiber repeater placement using a jumping gene algorithm," in Proceedings of *the IEEE International Conference on Industrial Technology (ICIT2005),* Hong Kong, China, Dec. 14 – 17, 2005, pp. 291 – 296.

[7] T. M. Chan, K. F. Man, K. S. Tang, and S. Kwong, "A Jumping gene algorithm for multiobjective resource management in wideband CDMA systems," *The Computer Journal*, vol. 48, no. 6, pp. 749 – 768, Nov. 2005.

[8] C. A. Coello Coello, D. A. Van Veldhuizen, and G. B. Lamont, *Evolutionary algorithms for solving multi-objective problems*. Boston, MA: Kluwer, 2002.

[9] H. Deng, C. –H. Yeh, "Simulation-Based Evaluation of Defuzzification-Based Approaches to Fuzzy Multiattribute Decision Making," *IEEE Trans. Syst. Man Cybernetic A*, vol. 36, no. 5, pp. 968–977, 2006.

[10] S. J. Chen and C. L. Hwang, *Fuzzy Multiple Attribute Decision Making: Methods and Applications*. New York: Springer-Verlag, 1992.

[11] K. Deb, A. Pratap, S. Agrawal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," *IEEE Trans. Evolutionary Computation*, vol. 6, pp. 182-197, April 2002.

[12] K. F. Man, K. S. Tang, and S. Kwong, *Genetic Algorithms: concepts and designs*. Berlin: Springer, 1999.

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