Designed of a Broadband Multi-Layered Absorber using an NSGA-II Multi-Objective Optimization Algorithm

Ki-Bum Jung, Hyun-Su Shin, Yeon-Choon Chung, and Jae-Hoon Choi

Senior Member of Technical Staff /P.L, EMC Center
901, Hogye-2dong, Dongan-gu, Anyang-si, Kyunggi-do, 430-082, Korea
E-mail: kbjung@rapa.or.kr
School of Engineering, div . Of Electrical and Computer, Hanyang University
17 Haengdang-dongs, Seongdong-gu, Seoul, 133-791, Korea
E-mail: hssshinhyu@ihanyang.ac.kr
Department of Information and Communication Engineering, Seokyeong University
16-1 Jungneung-Dong Sungbuk-Ku Seoul, 136-704 Korea
E-mail: ycchung@skuniv.ac.kr
Div . Of Electrical and Computer, Hanyang University
17 Haengdang-dongs, Seongdong-gu, Seoul, 133-791, Korea
E-mail: choijh@hanyang.ac.kr

Abstract : In this paper, we purpose multi-objective optimization genetic algorithm implementation for optimum design of slim multilayer absorber. Among multi-objective optimization technique, applied by first in NSGA-II(Non-dominated Sorting Genetic Algorithm) genetic algorithm slim multilayer absorber field that is attested that performance is excellent. Slim multilayer absorber composes insulator in incidence angle within 30 angle and limited extent by number of layers within total 5 layers including top floor. Numerical analysis algorithm embodied optimization algorithm to use material information collected actually considering manufacture. Here after, is going to compare and examine measurement through manufacture and numerical analysis result.

1. Introduction

In this paper, multi-objective evolutionary algorithms(MOEA) are used to optimize the structure of electromagnetic wave absorbers. These optimization problems involve multiple conflicting objectives, such as simultaneous minimization of production cost and maximization of durability. Under this conflicting situation, it is intuitive that less costly objective is usually less durable and vice versa, therefore multi-objective optimization technique has to be adapted and slim multilayer absorbers are to be optimized by using NSGA-II which is able to find much better spread of solution and better convergence near the true pareto-optimal front compared to any other MOEAs. Given a predefined set of available-existent and virtual-materials with frequency-dependent permittivity and permeability, the proposed technique simultaneously determines the optimal material choice for each layer, its thickness, and fractional bandwidth. This optimal choice results in more excellent multilayer absorbers, which maximally absorbers TE and TM incident plane waves for the prescribed range of frequencies and incident angle, than those of previous studies.

2. Reflection Coefficient of a Slim Multi-Layer Absorber Medium

The Propagation wave of a flat multi-layered isotropic medium is described by a scalar wave equation in TE and TM respectively. Such a two scalar wave equations are described very simple with think of one dimensional problem. To begin with, accepted field from source excitation in flat multi-layer type medium can be expression a form of an integral equation. This is represented better of the simple equation through asymptotic expansion method.

2.1 Induced of Scalar Wave Equations

We have induced in this case TE and TM. On the basis of orthogonal coordinates, propagation of direction z-axis suppose to TE wave. In this case electrical field must be presence x-y plane. If considering to arbitrary y-axis direction element, then electrical field is presented at E = Ey.

$$\mu\nabla \times \mu^{-1}\nabla \times E_y - \omega^2 \mu\varepsilon E_y = 0 \qquad (1)$$

Here, if $\partial/\partial y\, E_y = 0$ is concluded, therefore next some condition is achieved.

$$\nabla \cdot \varepsilon E_y = \frac{\partial}{\partial y}\varepsilon(z)E_y = 0 \qquad (2)$$

If arrange y-axis direction element, equation forms as following.

$$\left[\frac{\partial^2}{\partial x^2} + \mu(z)\frac{\partial}{\partial y}\mu^{-1}(z)\frac{\partial}{\partial z} + \omega^2\mu\varepsilon\right]E_y = 0 \qquad (3)$$

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Magnetic field equation about TE wave can derive applying condition($E_z = 0,\ H_z \neq 0$) about TE wave. The following is vector wave equation about magnetic field in inhomogeneous medium.

$$\varepsilon \nabla \times \varepsilon^{-1} \nabla \times H_z - \omega^2 \mu \varepsilon H_z = 0 \qquad (4)$$

And if permittivity and permeability say that is variable z function, can arrange as following.

$$\left[\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \mu(z) \frac{\partial}{\partial z} \mu^{-1}(z) \frac{\partial}{\partial z} + \omega^2 \mu \varepsilon \right] \mu H_z = 0 \qquad (6)$$

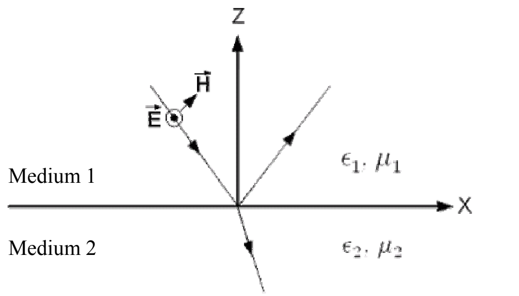
We can be derived boundary condition of scalar wave equation if basic boundary condition $\hat{n} \times E$, $\hat{n} \times H$ is continuity in two medium. The following is boundary condition of electric field and magnetic field about y component in border between medium 1 and medium 2.

$$e_y \ ; \ e_{1y} = e_{2y}, \ \ \mu_1^{-1} \frac{d}{dz} e_{1y} = \mu_2^{-1} \frac{d}{dz} e_{2y} \qquad (9\text{-a})$$

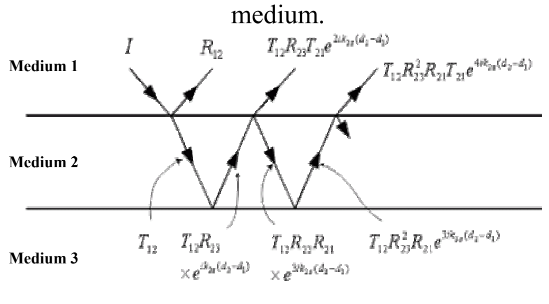
$$h_y \ : \ h_{1y} = h_{2y}, \ \ \varepsilon_1^{-1} \frac{d}{dz} h_{1y} = \varepsilon_2^{-1} \frac{d}{dz} h_{2y} \qquad (9\text{-b})$$

2.2 Reflection coefficient in Half-Space

We suppose that TE wave with below Fig. 1 propagation in different two mediums.



(a) Transmission and reflection coefficient between medium.



(b) Multiple reflection in 3 layers medium

Fig. 1. Multiple reflection principle in between medium

Reflection coefficient and transmission coefficient in two medium is as following if express y-component electric field.

$$e_{1y}(z) = e_0 e^{-ik_{1z}z} + R^{TE} e_0 e^{ik_{1z}z} \qquad (10)$$

$$e_{2y}(z) = T^{TE} e_0 e^{-ik_{2z}z} \qquad (11)$$

Eq. (10) expresses electric field by linear reiteration principle of $\exp(\pm ik_{1z}z)$ from upper part half space, and eq. (11) expresses electric field from below part half space. Here, R^{TE} and T^{TE} mean TE wave reflection coefficient and transmission coefficient each. Subscript 1y, 2y, 1z, and 2z mean medium and direction. Therefore, reflection coefficient and transmission coefficient of transverse electric wave can express as following.

$$R^{TE} = \frac{-\mu_1 k_{2z} + \mu_2 k_{1z}}{\mu_1 k_{2z} + \mu_2 k_{1z}}, R^{TM} = \frac{-\varepsilon_1 k_{2z} + \varepsilon_2 k_{1z}}{\varepsilon_1 k_{2z} + \varepsilon_2 k_{1z}} \qquad (12\text{-a})$$

$$T^{TE} = \frac{2\mu_2 k_{1z}}{\mu_1 k_{2z} + \mu_2 k_{1z}}, T^{TM} = \frac{2\varepsilon_2 k_{1z}}{\varepsilon_1 k_{2z} + \varepsilon_2 k_{1z}} \qquad (12\text{-b})$$

We can become expressed briefly as follows if generalize little more eq. (12).

$$\overline{R}_{i,i+1} = \frac{R_{i,i+1} + \overline{R}_{i+1,i+2} e^{2ik_{i+1,z}(d_{i+1} - d_i)}}{1 - R_{i+1,i} \overline{R}_{i+1,i+2} e^{2ik_{i+1,z}(d_{i+1} - d_i)}} \qquad (13)$$

Finally, we can save reflection coefficient of multi-layer medium applying circulation expression with eq. (13) if find out frequency, properties of matter (permittivity, permeability), thickness of medium. We can puts air on first layer and puts PEC on last layer and saves reflection coefficient if apply to multi-layer absorber material of this study.

3. Multi-objective optimization genetic algorithm

Genetic algorithm is algorithm that based on choice of natural world and mechanism of genetics. Usually, evolution algorithm can divide by genetic algorithm and evolution strategy. Optimization searching process of genetic algorithm is consisted of greatly subsequent 4 steps. The first is initialization, and second fitness estimation, third reproduction (use of heredity operator), fourth by END condition examination and loop consist. Since VEGA that multi-objective most suitable algorithm is first gene algorithm for multi-objective problem by Schaffer in 1988 is announced, there were a lot of developments until present. In this paper, embodied multi- objective algorithm of pareto base in optimum design of multi-layer absorber. But, multi-objective algorithm complexity of calculation is big, and does not use elit strategy, and have uncomfortable though set share parameter. To supplement this weak point, K. Deb proposed multi-objective evolutionary algorithm of non-dominated sorting. We that apply this evolution-ary algorithm completed numerical analysis algorithm of slim multi-layer absorber structure.

Table 1. Fast non-dominated sorting procedure

```
fast-non-dominated sort (P)

for each p ∈ P
  S_p = ∅
  n_p = 0
  for each q ∈ P
    if (p ≺ q) then           If p dominates q
      S_p = S_p ∪ {q}         Add q to the set of solutions dominated by p
    else if (q ≺ p) then
      n_p = n_p + 1           Increment the domination counter of p
  if n_p = 0 then             p belongs to the first front
    p_rank = 1
    F_1 = F_1 ∪ {p}
i = 1                         Initialize the front counter
while F_i ≠ ∅
  Q = ∅                       Used to store the members of the next front
  for each p ∈ F_i
    for each q ∈ S_p
      n_q = n_q − 1
      if n_q = 0 then         q belongs to the next front
        q_rank = i + 1
        Q = Q ∪ {q}
  i = i + 1
  F_i = Q
```

Table 2. Optimization algorithm main loop that elitism is applied

```
Main Loop (elitism)

R_t = P_t ∪ Q_t
                      - combine parent and offspring population
F = fast-non-dominated-sort(R_t)
                      - F = (F_1, F_2, ...), all nondominated fronts of R_t
P_t+1 = ∅ and i = 1
until |P_t+1| + |F_i| ≤ N   - until the parent population is filled
  crowding-distance-assignment(F_i) - calculate crowding-distance in F_i
  P_t+1 = P_t+1 ∪ F_i   - include ith nondominated front in the parent pop
Sort(F_i, ≺_n)        - sort in descending order using ≺_n
P_t+1 = P_t+1 ∪ F_i[1 : (N − |P_t+1|)]
                      - choose the first (N − |P_t+1|) elements of F_i
Q_t+1 = make-new-pop(P_t+1)
                      - use selection, crossover and mutation
                        to create a new population Q_t+1
t = t + 1             - increment the generation counter
```

Table 1 shows calculation of O (MN2) that is reduction than calculation of fast nondominated sorting procedure and existing. Elitism applied in this optimization algorithm compares population of present with non-dominated solution of good quality in ago generation. It is Table 2 that explains this.

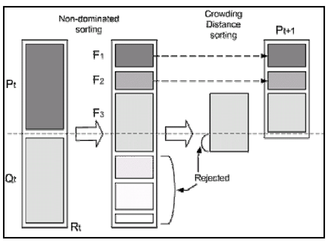


Fig. 2. NSGA-II procedure

Also, this Table 2 and Fig. 2 display NSGA-II's procedure. Three advantages of NSGA-II are fast nondominated sorting procedure, fast crowded distance estimation procedure, and simple crowded comparison operator.

4. Optimum design of slim multilayer absorber

Fig. 3 displays slim multilayer absorber composition. Least significant layer puts metal material. Arrange absorption material that get thin n-1 more from 1 layer. And top-level layer locates insulator.

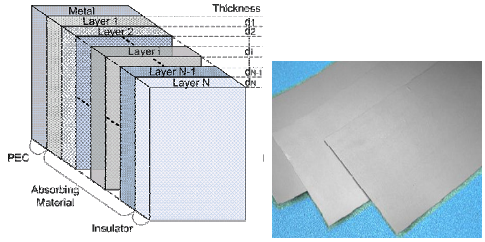
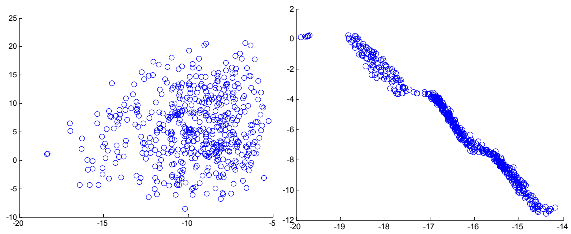


Fig. 3. Structure of slim multilayer absorber

4.1 Numerical analysis result

Estimated accuracy of algorithm that is embodied in this study through test function used in KUR's study.



(a) Early generation (b) 10 generation

Fig. 4. KUR's test function

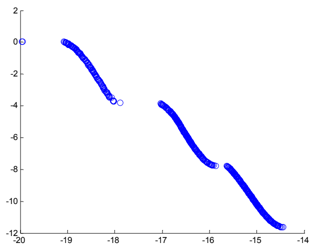


Fig. 5. 50 generation of KUR test function

Expected pareto front of this test function is non-convex's type.

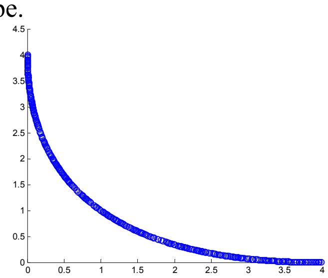


Fig. 6. 50 generation of Schaffer (SCH) test function

In this study, material of kind that displayed material property used total 28.

Table 3. Most suitable design variables that do not consider insulation

Designed Number #53		
Layer Number	Material Number	Thickness(μm)
1	20	312.06
2	13	369.45
3	15	654.21
4	6	323.47
Best reflection coefficient in bandwidth (dB)	-23.042(TE), -15.1(TM)	
Total Thickness(μm)	1659.2	

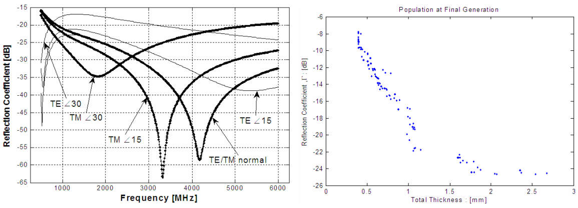


Fig. 7. Reflection coefficient property by incidence angle of designed number #53 absorber.

Table 4. Optimization designed variable of 500 MHz ~ 6 GHz band absorber

Designed Number # 71		
Layer number	Material number	Thickness(μm)
1	19	250.45
2	17	250.05
3	12	919.86
4	26	604.94
5	permittivity (4.0073+j0)	254.21
Best reflection coefficient in bandwidth (dB)	-9.5697	
Total thickness(μm)	2279.5	

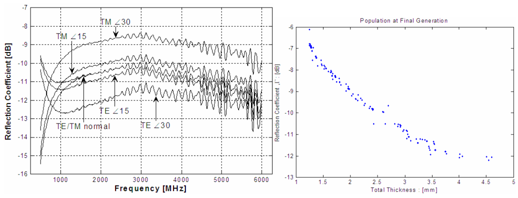


Fig. 8. Reflection coefficient property by incidence angle of design number #71 absorber

5. Conclusion

In this paper, we designed broadband multi-layered absorber using proposed a computationally fast and elitist multi-objective evolutionary algorithm based on non-dominated sorting approach. In most objective functions, NSGA-II has found a better spread of solution than general proposed multi-objective algorithm. We will study a slim multi-layered broadband absorber practice technology to solve EMI problem of PCB level.

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