Design of Broadband Radar Absorbers with Genetic Algorithm

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Introduction

Accompanying development of a new organic polymers [1], there has been a revival of interest in design of broadband radar absorbers. The new materials can be used as very thin sheets forming Jaumann transformers, or in multi-layer Dallenbach transformers. Genetic algorithms (GA) have been previously shown to offer advantages in design of multi-layer absorbers [2 – 4]. Pareto GA permits to obtain a family of designs with two or more design objectives, e.g. reflection coefficient and absorber thickness [3, 4]. However, efficient optimization of absorbers for a range of angles of incidence still poses challenges. In this work, we explore how selection of the GA objective function can increase the absorber bandwidth without increasing the thickness for a range of angles of incidence.

Methods

Reflection coefficients for oblique incidence of uniform plane waves for the TE and TM polarization are computed from well-known formulae cited in [4]. For very thin sheets whose properties are defined in terms of resistivity per square R_s and have $\mu = \mu_o$, the loss factor (ε'') can be found as equal to:

$$\varepsilon'' = \frac{1}{2\pi f R_s t} \tag{1}$$

where f is the frequency and t is the actual thickness of the layer (0.05 mm).

A fast elitist multi-objective (Pareto) GA is used [5]. This is an improved version of the Pareto GA used earlier for optimization of radar absorbers [4]. Few objective (performance) functions are investigated in this work. For comparison purposes the previously used objective function is also used:

$$R = 20 \; \log \; \left\{ \max\left[R(f)\right], f \in B \right\}. \tag{2}$$

which minimizes the highest reflection in the frequency band B, where

$$B = \frac{\left(f_{max} - f_{min}\right)}{f_o} \quad . \tag{3}$$

and f_o is the desired center frequency. The new objective functions include application of the weight coefficients in sub-bands of frequency. This approach is based on the fundamental properties of transformers and empirical observations. If the desired maximum $R = 0.1$, corresponding to –20 dB, the objective function to be minimized is:

$$F = w_1 \sum_{n=1}^{N_1} \left[0.1 - R(f_n) \right] + w_2 \sum_{n=N_1+1}^{N_2} \left[0.1 - R(f_n) \right] +$$
$$w_3 \sum_{n=N_2+1}^{N_3} \left[0.1 - R(f_n) \right]$$

(4)

where w_1, w_2, w_3 are weight coefficients generally between 1 and 2 allocated in the three sub-bands. For oblique incidence, there are 6 summations, three for each polarization. If the optimization is to be performed for multiple angles of wave incidence, the objective function is constructed as an envelope of the reflections at all angles of incidence considered and both polarizations. For each angle of incidence weight coefficients are applied in sub-bands. The second objective function is as previously [4] the total thickness of the absorber.

Results

Figure 1 compares the results for a multi-layer transformer optimized for the normal incidence and $f_o = 6$ GHz. The reflection coefficient as a function of frequency is shown in Fig. 1a for the previous design [4], and two designs using the objective function with weight coefficients (eq. 4). Pareto fronts for the designs are shown in Figs. 1(b) and 1(c), and summary data are given in Table 1. The same database of absorbing materials has been used as in [4]. The previously optimization reported has been obtained by setting the same materials as those in the design in [4]. The same materials are selected for our design #1, and in our design #2 the materials are selected by the GA. The use of the weight coefficients in the objective function facilitates faster convergence and provides means of fine tuning the frequency response.

Table 1. Comparison of three designs of five-layer Dallenbach transformer for $f_o = 6$ GHz and normal incidence, max reflection -20 dB.

Design	Bandwidth	Thickness
From [4]	129 %	4.134 mm
# 1	150%	3.975 mm
# 2	145%	3.850 mm

Optimization for a range of angles of incidence presents a much more challenging task, despite the fact that GA is particularly well suited for this complex optimization that uses simple and fast computations of the functions optimized.

Figures 2 and 3 show results of optimization of 4 layer transformers. Three basis transformer structures have been optimized with $f_o = 6$ GHz (Fig. 2) and $f_o = 12$ GHz (Fig. 2). The angle of incidence ranges from 0 to 40^0 and both TE and TM polarizations. The structures are the Jaumann transformer consisting of resistive sheets only, and a hybrid consisting of resistive sheets and lossy materials. Table 2 summarizes the results. In all optimizations $R_{max} \leq -20dB$ is the goal within the bandwidth, and the envelope objective function is used. We have not been able to obtain the required R_{max} with Dallenbach transformer. This is in agreement with previously reported large reflection coefficients for a range of angles of incidence [4] using the materials from the database.

Figure 4 illustrates the reflection coefficient for the hybrid transformer with f_o = 12 GHz for various angles of incidence and polarizations. Computations have indicated that for other angles of incidence from 0 to 40°, the reflection coefficient is below the envelope shown. (This is achieved during the optimization process.)

Table 2. Design of 4-layer transformers for 0 - 40° angle of incidents, TE and TM polarizations.

Type	Center Frequency	Bandwidth	Thickness
Jaumann	6 GHz	90 %	44 mm
ε'=1.1	12 GHz	96 %	16.8 mm
Hybrid	6 GHz	98 %	38 mm
	12 GHz	125 %	16.0 mm

Conclusions

Two main goals have been achieved in the research reported. First, by knowledge-based selection of a better performance function of a fast elitist multi-objective GA superior designs of multi-layer radar absorbers can be obtained for relatively wide range of angle of incidence. Second, a hybrid transformer that utilizes lossy materials and resistive sheets gives superior performance in terms of the reflection coefficient for a range of angles of incidence. Further investigation will include capacitive reactance in addition to resistance for the thin layers, and thin layers with periodic structures.

[1] V.-T. Truong, S.Z. Riddell and R. F. Muscat, "Polypyrrole based microwave absorbers", *J. Materials Sci.*, **33**, 4971-4976, 1998.
[2] E. Michielssen, J. M. Sajer, S. Ranjithe and R. Mittra, "Design of lightweight, broadband microwave absorbers using genetic algorithms", *IEEE Trans. Microwave Theory Tech.*, **41**, 1024-1031, 1993.
[3] B. Chambers and A. Tennant, "Optimized design of Jaumann radar absorbers using a genetic algorithm", *IEE Proc. Radar, Sonar, Navig.*,**143**, 23-29, 1996.
[4] D. S. Weibe, E. Michielssen and D. H. Goldberg, "Genetic algorithm design of Pareto optimal broad band microwave absorbers", *IEEE Trans. Electrom. Compat.*,**38**, 518-524, 1996.
[5] K. Deb, S. Agrawal, A. Pratap and T. Meyarivan, "A fast elitist non-dominated sorting genetic algorithm for multi-objective optimization: NSGA-II", KanGAL Report No. 200001.
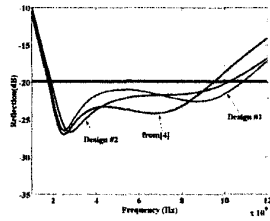
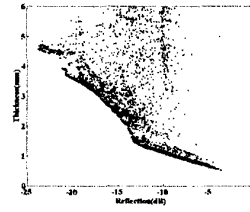Fig. 1a. Reflection coefficient for 3 absorbers, each 5 layers, normal incidence, f_0 =6 GHz.
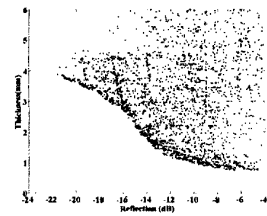

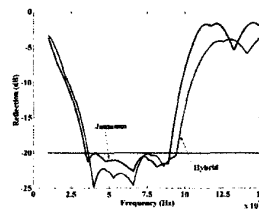Fig. 1b. Pareto front for design # 1.

Fig. 1c. Pareto front for design # 2

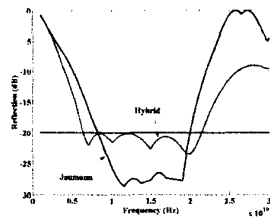Fig. 2. Four-layer absorber, f_0 =6 GHz, angles of incidence 0 - 40^0, TE and TM polarization.

Fig. 3. Four-layer absorber, f_0 =12 GHz angle of incidence 0 – 40^0, TE and TM polarizations

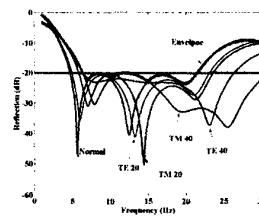

Fig. 4 Reflection coefficient for various angles of incidence and two polarizations; f_0 = 12 GHz.

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