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A Review of Optimisation Techniques for Layered Radar Absorbing Materials

Including the Genetic Algorithm

Paul Saville

Defence R&D Canada – Atlantic

Technical Memorandum
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Canada

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Abstract

The absorption of microwaves by a material depends on the properties of the material and its structure. Broadband absorbers are can be fabricated by stacking resistive sheets separated by low dielectric spacers with a thickness of a quarter wavelength. This type of multilayered resonant absorber is called the Jaumann absorber. In this paper optimal design techniques for multilayer microwave absorbers are reviewed. These methods include analytical approximations, gradient optimisation routines, simulated annealing and the genetic algorithm. The genetic algorithm is a highly parallel stochastic technique that permits multi-objective optimisation and has a high probability of finding the global minimum.

Résumé

L'absorption des hyperfréquences par un matériau dépend des propriétés et de la structure de ce matériau. On peut fabriquer des absorbeurs large bande en empilant des couches résistantes séparées par des espaceurs faiblement diélectriques dont l'épaisseur équivaut à un quart de longueur d'onde. Ce type d'absorbeur résonant à couches multiples s'appelle un absorbeur de Jaumann. Le présent document porte sur des techniques de conception optimale pour les absorbeurs d'hyperfréquences à couches multiples. Ces techniques comprennent des approximations analytiques, des routines d'optimisation de gradient, des simulations de recuit et un algorithme génétique. L'algorithme génétique est une technique stochastique ultraparallèle qui permet une optimisation à objectifs multiples et qui présente une forte probabilité de trouver le minimum global.

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Executive summary

Introduction

The ability of a material to absorb radar, microwave radiation, depends on the permittivity and permeability of the material and its structure. A multilayer structure of alternating resistive sheets and low dielectric spacers has been found to make an effective radar absorber if the layers are spaced a quarter wavelength apart and the resistance of the sheets has specific values. To make an absorber with the widest possible bandwidth out of available materials, it is necessary to use an optimisation technique due to the complexity of the equations describing the reflectivity from an absorber. For this reason optimisation techniques that have been used for radar absorbers are reviewed with particular attention paid to genetic algorithm methods.

Results

The analytical and numeric methods of optimising absorber design have two short-comings. The first is that in general they do not use the properties of available materials, but they do predict the desirable properties. The second problem for the numerical methods is that they can converge to local optima. One solution to getting out of the local optimum trap is to use simulated annealing. Another solution is to use a technique that converges on a global optimum. Such a technique is the genetic algorithm. This method uses the properties of available materials and permits the optimisation of several design requirements at once, such as the minimum reflectivity over the widest bandwidth with the thinnest absorber.

Significance

The genetic algorithm will enable the design of the best possible thin multilayered broadband absorber with the materials that are available. It can also be used to predict the properties of materials for the optimum absorber and then the research chemist can use these properties as targets to achieve.

Future plans

A genetic algorithm code will be written for the optimisation of absorber design. Available material properties will be used in the design process and the optimum designs will be used for the fabrication of broadband absorbers.

Saville, P.. 2004. A Review of Optimisation Techniques for Radar Absorbing Materials: Including the Genetic Algorithm. DRDC Atlantic TM 2004-260, DRDC Atlantic.

Sommaire

Introduction

La capacité d’un matériau à absorber les rayonnements hyperfréquences (radar) dépend de la permittivité, la perméabilité et de la structure du matériau. On a découvert qu’une structure à couches multiples où des couches résistantes alternent avec des espaceurs faiblement diélectriques formait un absorbeur radar efficace si l’épaisseur des espaceurs équivaut à un quart de longueur d’onde et que les résistances des couches ont des valeurs spécifiques. Afin de fabriquer un absorbeur présentant la plus grande largeur de bande possible à partir des matériaux disponibles, il est nécessaire d’avoir recours à une technique d’optimisation à cause de la complexité des équations décrivant la réflectivité d’un absorbeur. Pour cette raison, les techniques d’optimisation qui ont été utilisées pour les absorbeurs radar sont examinées, particulièrement au niveau des méthodes à algorithme génétique.

Résultats

Les méthodes analytiques et numériques d’optimisation de la conception des absorbeurs présentent deux lacunes. D'une part, elles n’utilisent généralement pas les propriétés des matériaux disponibles, mais elles prédisent les propriétés souhaitables. D'autre part, elles peuvent converger vers des optima locaux. Une solution permettant de se sortir du piège des optima locaux est le recours au recuit simulé. Une autre solution possible est la technique qui converge vers un optimum global. Une de ces techniques est l'algorithme génétique. Cette technique fait appel aux propriétés des matériaux disponibles et permet l’optimisation de plusieurs exigences de conception à la fois, comme la réflectivité minimale sur la plus grande largeur de bande avec l’absorbeur le plus mince.

Portée

L’algorithme génétique permettra la conception du meilleur absorbeur mince large bande à couche multiple possible avec les matériaux disponibles. Il peut également être utilisé pour prédire les propriétés des matériaux correspondant à un absorbeur optimal, puis les chimistes de recherche peuvent utiliser ces propriétés comme objectifs.

Recherches futures

Un code d’algorithme génétique sera établi pour l’optimisation de la conception des absorbeurs. Les propriétés des matériaux disponibles seront utilisées dans le processus de conception, et les conceptions optimales seront utilisées dans la fabrication d’absorbeurs large bande.

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1. Introduction

The absorption of microwaves by a material depends on the properties of the material and its structure. One technique used to produce low reflectivity is to match the impedance of the electromagnetic radiation at the air-absorber interface, allowing the electromagnetic radiation to propagate into the absorber. Another technique used is to create destructive interference between the electromagnetic waves reflecting from different layers of the absorber. This class of absorbers are called resonant absorbers with examples being Dallenbach layers, Salisbury Screens and Jaumann layers. The reflectivity from these absorbers can be calculated if the thickness, permittivity and permeability of all layers are known. The procedure is to calculate the reflection and transmission coefficients for each layer, based on the permittivity and permeability, and then recursively propagate the electromagnetic field through the absorber. One technique used for microwave reflection from radar absorbers on perfect electrical conductors, PEC, is the recursion formulation.[1] In this case the recursion analysis starts at PEC surface and works back through the absorber to the air/absorber interface.

Although it is possible to calculate the reflectivity from an absorber, it is only feasible to analytically solve for the optimum absorber properties over a few layers.[2,3] Multilayer structures are described by a large number of variables and the mathematics become too complex to solve. Some strategies have been proposed for creating good absorbers by grading the impedance of the layers,[3,4] however, these are not the optimum absorbers that can be achieved, in terms of minimum reflection over the widest possible bandwidth.

Numerical optimisation techniques can be used for solving for the best absorber.[2,5] Techniques such as Conjugate Gradient, Quasi-Newton and Simplex methods tend to find local minima and do not work well if the objective functions are non differentiable or discontinuous. These methods tend to be dependent on the starting point/initial guess used. More global techniques include Random Walk, Simulated Annealing and Genetic Algorithm methods. These techniques do not take advantage of local solution-space information, resulting in slower convergence. The convergence, however, is near to the global minimum.

In this paper optimisation techniques for absorber design are reviewed with a focus on Genetic Algorithm methods. The Genetic Algorithm is reviewed along with objective functions that have been applied to absorber design. In the next sections three types of layered absorbers are reviewed. The simplest is the single Dallenbach layer, while the Salisbury Screen consists of two layers, a resistive sheet and a low dielectric spacer. Multiple Salisbury Screens stacked together form the Jaumann absorber.

2. The Dallenbach Layer

The Dallenbach layer is a resonant absorber that also uses the bulk of its material for absorption. A number of the dallenbach layers specifically incorporate magnetic materials, or a combination of conductive and magnetic. Design curves for permittivity and permeability values have been calculated.[6,7] The Kramers-Kronig relationship has been investigated to see if it places a limitation on the bandwidth of Dallenbach layers.[8] this study also attempted to use simulation to determine the maximum bandwidths achievable for multilayer (Dallenbach) absorbing structures. The ultimate thickness to bandwidth ratio for a radar absorber has been analytically calculated.[9]

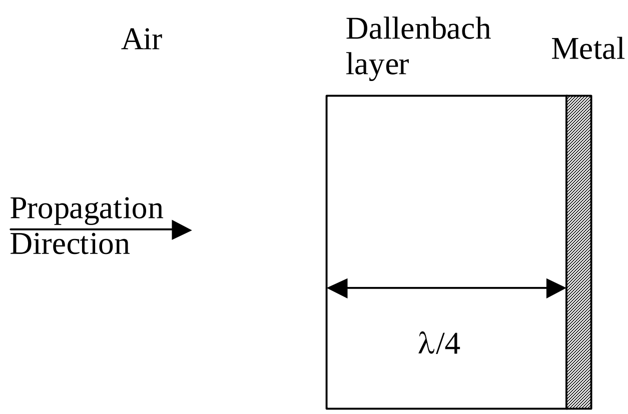

Figure 1. *Dallenbach Layer*

3. Salisbury Screen

The Salisbury Screen (patented 1952)[10] is the simplest layered resonant absorber consisting of a resistive sheet placed an odd multiple of ¼ wavelengths in front of a metal (conductive) backing, separated by an air gap (Figure 1). A low dielectric material is often used to replace the air gap, reducing the gap thickness at the expense of bandwidth. The Salisbury Screen has been examined in terms of transmission line theory. The quarter wavelength transmission line transforms the short circuit at the metal into an open circuit at the resistive sheet. The effective impedance of the structure is the sheet resistance. If the sheet resistance is 377 ohms/square (ie the impedance of air), then good impedance matching occurs and a reflective null appears at a frequency corresponding to the spacer thickness. The magnetic analogue of the electrical screen would place a magnetic layer on the metal surface, resulting in a thinner device.[3,11] Initial Salisbury Screens were made of canvas on plywood frames with a colloidal graphite coating on the canvas.[12]

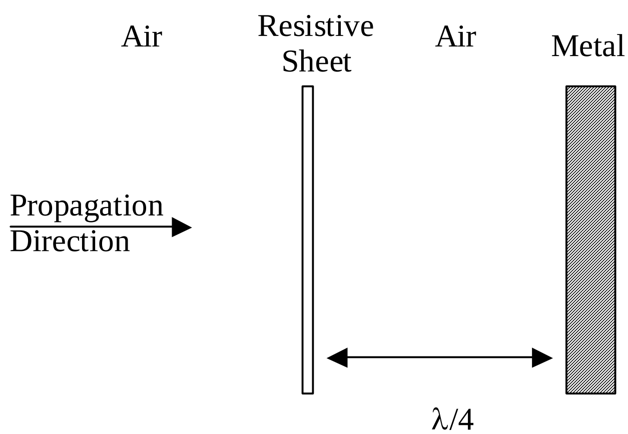

Figure 2. *Salisbury Screen*

3.1 Optimised Design of Salisbury Screens

Several strategies have been used for the design of the Salisbury screen.[3,13] The thickness of the optimal Salisbury screen can be calculated when the sheet resistance is equal to the impedance of free space (Z_o). The absorber thickness is given by

$$d = \frac{1}{Z_o \sigma} \qquad 1$$

where σ is the conductivity of the sheet. Two approximations are made regarding the resistive layer: The first is that the layer is electrically thin (1>> $k_o d\sqrt{|\varepsilon^*|}$ where k_o is $2\pi/\lambda_o$ and d is the resistive layer thickness), and the second approximation is that the loss in the layer originates from the conductivity and ε" >> ε'.[13] For practical devices these approximations may not be realistic with the result that the resonant frequency shifts to smaller values as the resistive sheet thickness, or ε' is increased. This was shown using a transmission line model with a RCL circuit representing the Salisbury screen.[13] The thickness of the resistive sheet for optimum absorption has an inverse relationship to the sheet conductivity.[14]

The bandwidth of Salisbury Screens can be maximised given the maximum acceptable reflectivity.[15] The optimum sheet resistance was calculated to be 377 ohms/sq for the lowest reflectivity, while the optimum resistance, R_{sopt}, for a given reflectivity limit is given by

$$R_{sopt} = Z_o \frac{1-\Gamma_{cutoff}}{1+\Gamma_{cutoff}} \quad (2)$$

where Γ_{cutoff} is the maximum acceptable reflectivity. Analytically it was also shown that bandwidth decreases with increasing permittivity of the spacing layer.

4. Jaumann Layers

Jaumann layers are a method of increasing the bandwidth of the Salisbury screen, the simplest form of a Jaumann device. The number of layers is proportional to the bandwidth of the absorber. For instance, a device consisting of two equally spaced resistive sheets in front of a conducting plane (Figure 2) was mathematically shown to produce two minima in the reflectivity, increasing the absorber's bandwidth over the Salisbury screen.[16] A seven layered Jaumann device consisting of resistive sheets, with increasing conductivity towards the metal plane, and separated by uniformly thick low loss dielectric sheets was also described and the reflectivity calculated.[16]

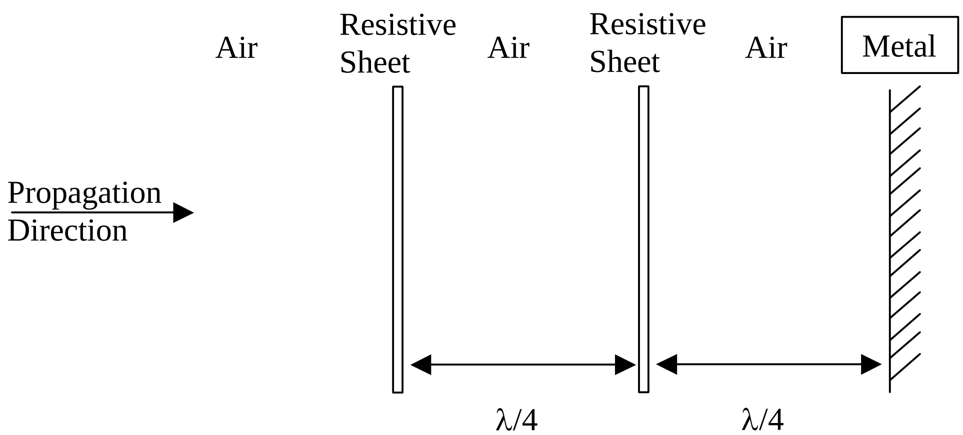

Figure 3. *Jaumann Layers*

4.1 Optimisation of Jaumann Layers

Optimisation of Jaumann absorbers is complex due to the number of parameters involved, which increase as the number of layers increase. Empirical procedures and numerical optimization techniques[4] have been used for designing Jaumann absorbers.

4.1.1 Analytical Techniques

Two analytical techniques have been used to optimise Jaumann absorbers up to a stack of three resistive sheets. These techniques are called the Maximally Flat or binomial design and the Tschebyscheff polynomial, or equal-ripple design after the shape of the reflectivity curve.

4.1.1.1 Maximally Flat Design

The objective of maximally flat design, or binomial expansion, is to have the flattest possible bandpass in the frequency region of interest. This is achieved by stacking up several Salisbury screens.[3] An approximate expression for such a quarter wave stack is

$$\Gamma = \Gamma_0 + \Gamma_1 e^{-2j\theta} + \Gamma_2 e^{-4j\theta} + \cdots + \Gamma_n e^{-2nj\theta} = \sum_{n=0}^{N} \Gamma_n e^{-2nj\theta} \qquad 3$$

where Γ_n is the reflection coefficient from an interface and

$$\theta = \beta_n d_n = \frac{2\pi}{\lambda_n}\frac{\lambda_{n_o}}{4} = \frac{\pi f}{2 f_o}$$

The summation on the right hand side of equation 3 can be expanded in a Taylor series in frequency so that the form is $\Gamma = A + Bf + \cdots$. It is desirable to have the reflectivity at the center frequency of the band equal to zero, and $\frac{dR}{df} = 0$ for the flat bandpass. The material properties are then solved for that set the coefficient A and B to 0. This technique has been extended to 3 resistive sheets and explored for magnetic and electric materials.[3] The bandwidth was found to increase over that of the Salisbury screen and with the bandwidth increasing as the admittance of the spacer decreases. The bandwidth of an absorber, with an outer magnetic and inner electric screen, increases with admittance. For this case the reflectivity does not necessarily reach a maximum (R=1). With two magnetic screens, one on the surface of the conductor and one a distance in front of the conductor plane, the reflectivity is independent of the separation of the second magnetic layer if the normalized complex magnetic impedance is 1/Y. This is due to the first screen absorbing all the radiation. However, there is a frequency dependence that requires the second screen for compensation and the bandwidth was calculated to increase. A three-screen Jaumann device was shown to have a larger bandwidth than the two-screen device. The three-screen device was also shown to reduce the reflectivity for incidence angles up to 60 degrees.

4.1.1.2 Tschebyscheff (Equal-Ripple) Design

In this design strategy the interference fringes from the quarter wavelength spaced resistive sheets are forced to approximate an equal amplitude ripple, with one ripple for each resistive layer. This is achieved by replacing the summation in equation 3 with a Tschebyscheff polynomial.[2]

$$\Gamma = e^{-jN\theta} \frac{T_N \sec\theta_m \cos\theta}{T_N \sec\theta_m} \qquad 4$$

where

$$T_N \sec\theta_m = p_m^{-1} \qquad 5$$

p_m is the ripple magnitude in dB, N is the number of ripples and layers,

$\theta = \dfrac{\pi}{2(1+F)}$ and $F = \dfrac{f - f_o}{f_o}$.

This method yields a wider bandwidth than the corresponding maximally flat solution. Tshebyscheff polynomials are also used to optimize the bandwidth of a Jaumann device.[17] This study showed that choosing the optimal spacer had a big influence on the bandwidth of the absorber. The Tshebyscheff technique has also been applied to the design of tapered absorbers.[18]

4.1.2 Gradient Methods

The analytical approach of using binomial, maximally flat design and polynomial, Tshebysheff design was only found to be suitable up to a stack of 3 and 5 resistive sheets, respectively. For larger stacks up to 20 resistive sheets a Newton-Raphson method is used to solve for maximally flat and equi-ripple designs.[4,5] The optimum maximum relative dielectric constant of the spacer tends to 1.0 as the number of layers increases.

The optimal control method has been used to optimise absorber design and has been compared to solutions from simulated annealing for the purpose of overcoming local optimum traps.[19] In simulated annealing the coating is subdivided into a large number of thin layers with fixed thicknesses. Each layer is assigned a material chosen from a predefined set of available materials. The optimal solution is found through iterative random perturbations of the material. Choices for each layer and evaluations are based on the metropolis criterion. This optimization technique usually leads to thinner, less reflective material than the optimal control approach.

A number of objective functions were formulated for optimizing the absorber properties. For instance the objective function for reflectivity performance of an absorber, *OF*, could be the mean reflectivity evaluated across the frequency band

$$OF = \frac{1}{n}\sum_{i=1}^{n} R(f_i) \qquad 6$$

where R is the reflectivity as a function of the frequency, f_i, and n is the number of frequency points across the band. A variation on this objective function is to optimise the reflectivity in comparison to a target reflectivity, R_c,

$$OF = \frac{1}{n}\sum_{i=1}^{n} \left| R(f_i) - R_c(f_i) \right| \qquad 7$$

A final objective function, includes weights for different regions of the frequency spectrum

$$OF = \sum_{i=1}^{n} p_i \left| R(f_i) - R_c(f_i) \right| \qquad 8$$

where $\sum p_i = 1$ and $p_i > 0$. This function permits the reduction in reflectivity for different frequencies.

If more than one objective function is to be optimised for then a weighting factor, α, is used to combine the weighting factors into a single expression,

$$OF = \alpha OF_1 + (1-\alpha) OF_2 \qquad 9$$

Modified Powell Algorithm (does not rely on explicit gradient information)

All these methods rely on local characteristics and so converge to local optima.

4.1.3 Optimisation of Jaumann Layers: Genetic Algorithm

The above optimization methods have produced significant increases in bandwidth and reduction in reflectivity. These methods, however, do not produce the optimal absorbing material, based on a number of factors such as minimum thickness or weight, or whether the solution is a local or global minimum. For these reasons, the Genetic Algorithm (GA) has been investigated as an optimization technique for RAM. Use of the GA is explored in this section and the GA method is reviewed in Section 5.

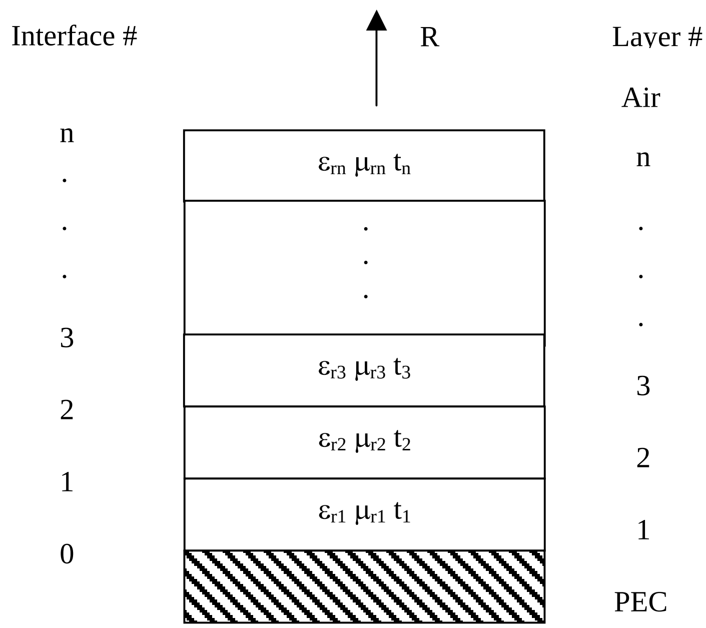

Figure 4. *Reflectivity from Jaumann absorber layers*

A review of the use of genetic algorithms in engineering electromagnetics provides a good description of the genetic algorithm with some examples including the design of microwave absorbers.[20] Genetic Algorithms were first used in 1993 for the optimization of Jaumann absorbers[21-23] and built on the approaches used for the optimal control method.[19] A set of available materials, their frequency dependent optical properties (permittivity and permeabiulity), and the layer thicknesses were used to define a population of absorbers. A genetic algorithm was used to optimise the absorber design against objective functions including reflectivity, thickness and weight. Both TE and TM polarisations of the reflection coefficient were calculated as well, in order to optimise the absorber as a function of incident angle as well. The reflectivity was calculated using a recursion relationship and the permittivity, permeability of the materials. Pareto fronts for the thickness vs reflectivity were presented.[1] Several Pareto Genetic Algorithms were compared with the non-dominated sorting genetic algorithm, NSGA, producing the best results.[1]

The genetic algorithm has also been used to optimise Jaumann absorbers based on transmission line theory.[24-28] Absorber bandwidth was shown to increase rapidly as a function of the number of resistive layers before asymptotically approaching the maximum bandwidth as the layer number approached infinity.[28] The optimum sheet resistance profile, assumed to have an exponential form,[29] was shown to have a sigmoid form with the resistance of the outer layers asymptotically approaching a maximum sheet resistance.[24,25,28] In these studies the bandwidth was studied as a function of both polarisations so that the absorbers could be optimized for incident angle as well. The bandwidth was defined as

$$BW = 2\frac{(f_u - f_l)}{(f_u + f_l)} \qquad 10$$

and the objective function for the combined polarisations as

$$OF = \frac{BW_{II} BW_{\perp}}{(|BW_{II} - BW_{\perp}| + 1)} \qquad 11$$

The optimised bandwidth for both polarisations was found to be less than that for normal incidence or one polarisation. At oblique incidences up to about 30 degrees the optimum bandwidth was found to remain fairly constant (near the value at normal incidence) before decreasing.[24] It was found that a two-stage strategy was useful in optimising absorber design. In the first stage an objective function based on the sum of the reflectivity below –20 dB was used to ensure that the –20 dB bandwidth was non-zero. Then in stage two, objective function sought to maximize the bandwidth and ensure that the reflectivity was still below –20 dB.[24] Absorbers with a protective skin were also optimised[24] and it was found that with proper choice of the outer layer material the absorber acted as if it had another resistive sheet and therefore had a wider bandwidth. With more than two resistive sheets, shinned absorbers could not be optimised below the –20 dB reflectivity limit, though the bandwidth could be improved for higher reflectivity targets.

The design of active (dynamic) radar absorbers has been investigated by using the genetic algorithm to optimise the absorption over different frequency bands by varying the sheet resistance, the spacer thickness or the spacer permittivity.[24]

Resistive sheets with capacitive properties have been used for making absorbers.[30] The optimal design of resistive-capacitive material based microwave absorbers has been studied using the genetic algorithm and transmission line theory.[31,32] The use of adaptive mutation has been explored to get out of local minima and to protect designs that are near the global minimum.[33] The genetic algorithm was also applied to the design of magnetic Dallenbach layers.[34]

A unique absorber design has been proposed and optimised using a genetic algorithm, where patches of material are organised to form a sheet.[35] These patches are either of the same material with different thicknesses or different materials with the same or different thicknesses.

A variant of the genetic algorithm, the microgenetic algorithm has been used for optimising frequency selective surfaces and circuit analog absorbers.[36-38] The microgenetic algorithm uses a small randomly generated population for optimisation in the usual manner for a genetic algorithm. Convergence occurs in a few generations and the fittest individual is added to those from previous generations. A new population is then randomly selected. Narrow band Salisbury Screens with circuit analog patterns replacing the resistive sheet have also been considered.[39-41]

4.1.4 Optimisation of Jaumann Layers: Other methods (Finite Element, FDTD and Taguchi Methods)

Scattering from cylindrical absorbers has been modelled using finite element method, FEM, and for single layer Jaumann (Salisbury Screen) the numerical method gives results similar to the analytic result.[42]

Preliminary FDTD calculations of the RCS of tapered Salisbury Screens and Jaumann layers have shown that the performance of these devices is not limited by resonant behaviour.[43]

The Taguchi method of optimization was used as a means of exploring less parameter space to explore the sensitivity and interaction of parameters in the design of planar and curved Jaumann Absorbers.[44]

5. The Genetic Algorithm

The Genetic Algorithm is a stochastic optimization routine based on Darwin's theory of evolution and genetics.[45,46] An evolutionary process arrives at the optimized solution over several iterations (generations), by selecting only the best (the fittest) solutions and allowing these to survive and form the basis for calculating the next round of solutions. In this manner the optimization routine evolves the initial solutions to the optimum. Table 1 gives an algorithm for a simple genetic algorithm.

Table 1. *Algorithm for a simple genetic algorithm*

STEP	ACTION
1	Initialize Population of size N, and Rank against fitness of objective functions
2	Start generation loop
3	Select fittest members of population for mating
4	Crossover properties from parents to create offspring
5	Mutate offspring
6	Rank offspring and parents, select fittest individuals for new population of size N.
7	Check for convergence
8	End generation loop

5.1 Initiation

In the first step a population of individuals of size N is randomly generated. Each individual is described by a set of variables (genes), which give rise to the overall characteristics of the individual. The set of variables for an individual is termed the chromosome. The chromosome of an absorber is made up of the permittivity, permeability and thickness of each layer of the absorber. The genes of an individual can be coded in a binary form, however, it has been found that using real variables leads to a faster algorithm since the binary format does not need to be coded and decoded.[24]

An objective function uses the chromosome (variable description) of an individual in order to calculate its characteristics (ie a solution for optimization). The characteristics are then used as a monitor of the fitness of an individual. Reflectivity, bandwidth and absorber thickness are examples of objective functions that can be used in absorber optimization. Generally the designer is trying to achieve the lowest reflectivity over the widest frequency range for the thinnest absorber possible.

The final step for the initial population is to rank the fitness of the individuals. This is accomplished by comparing the fitness of each individual. If there is only one objective function a simple sort of the fitness will rank the individuals. Now the initial population is created and the evolutionary loop is ready.

5.2 Selection

The first step in evolution is to select from the population members for mating so that their genes carried down to their children in the next generation. Darwin's theory of evolution states that the fittest members of a population will most likely to survive and hence propagate their genetic information to future generations. This has lead to several selection strategies that favour the fittest members of the population.

5.2.1 Decimation Selection

In this strategy the fitness obtained from the objective function is used to rank the superiority of the individuals in a population. Any individuals with fitness lower than a cut-off point are dropped from the population and the remainder are randomly paired for mating. The disadvantage of this simple method is that genes contained in the unfit individuals are lost early on and diversity is lost. This may cause the algorithm to converge to a good solution as determined by the good traits of the initial population, however, it may not be the optimal solution that may have been achieved by maintaining a diversity of genes in the population. This problem is circumvented in the following strategies.

5.2.2 Roulette Wheel Selection

The roulette wheel strategy is stochastic and is based on proportional selection. The probability of selecting an individual is determined by the relative fitness of an individual, (f_i), to the fitness of the whole population, $\sum_i f_i$.

$$p = \frac{f_i}{\sum_i f_i} \qquad 12$$

The probability of selecting an individual is then assigned a proportional space on a roulette wheel, so that all individuals have a chance to be selected with the fittest individuals having the highest probability of selection. Mating pairs are then obtained from two spins of the wheel.

5.2.3 Tournament Selection

Individuals are selected for mating by randomly picking several members from the population and comparing their fitness. The individual with the best fitness is then selected to become one of a mating pair. This strategy will drop the lowest ranked individual from the population, as it can never win the tournament. In all these strategies individuals may be selected for mating more than once.

5.3 Crossover

This is one of the operators in the genetic algorithm where the objective is to improve the fitness of the population. The principle is along the lines of genetics where the children of a mating pair will have chromosomes containing genes from each parent. For each mating pair a pair of children is created and these children will have a mix of the parent's genes as determined by the crossover routines and the crossover probability. There are a number of routines for producing crossovers at different points within the chromosome and each crossover event is controlled by a crossover probability. Generally a random number is chosen for the crossover event. If this is number is less than the crossover probability then a gene sequence from parent 1 is given to child 2 and the sequence from parent 2 is given to child 1. The result is children with genes from each parent and potentially a more fit population.

5.4 Mutation

The mutation operator is a means of introducing random variations into the population in order to explore new regions of the solution space. A consequence of this is that genes, which were lost earlier in the optimization, are brought back into the genetic makeup of the population. The mutation operator acts in response to a mutation probability, randomly changing a gene to a new value. The mutation probability needs to be kept fairly low ($p_{mutation}$ = 0.01-0.1) so that chromosomes with good fitness are not quickly lost. The mutation operator is applied to the children from the crossover step.

5.5 The New Generation

There are several methods for obtaining the individuals that will form the new population, each of which has implications for the convergence rate and robustness of the genetic algorithm.

5.5.1 Simple Genetic Algorithm

In the simple genetic algorithm, as outlined above, the children at each generation completely replace the parents in the population. A drawback of this technique arises as a result of the probabilistic nature of the selection, crossover, and mutation operators. It is quite possible that the fitness of the children may be lower than that of their parent's generation.

5.5.2 Elitism

Elitism addresses the problem of the children's generation having a lower fitness than their parents. If the highest-ranked individual in the children's generation has a lower fitness than the highest-ranked individual in the parent's generation, then the highest-ranked parent is copied into the new population. The process of preserving the best is elitism and ensures that the fitness increases.

5.5.3 Steady State Genetic Algorithms

The steady state genetic algorithm replaces a portion of the population at each generation with the children. This means that individuals can exist in the population over several generations. A number of techniques exist for the replacement of a portion of the population. The percentage replacement is a variable and various methods of selecting individuals for replacement exist. Replacement of the individuals with the lowest fitness in the parent generation adds elitism to the steady state algorithm.

5.6 Pareto Genetic Algorithms

The techniques discussed above are used to find the global optimum solution for a single objective. Often in design work several objectives need to be optimized and it is useful to be able to compare one objective against another. Solutions that present one optimized function against another optimized function are said to be Pareto optimal. Consider the design of a radar absorber. A design criterion will be the minimum thickness while a second criterion will be minimum reflectivity over a frequency band. The optimised result of both of these objective functions will be a line of points (the Pareto front) where for a given reflectivity, there will be no absorber design that is thinner. Armed with this information the designer can explore the trade-offs that will satisfy the design requirements. Any point that is not on the Pareto front is either not feasible or is an inferior design.

6. Conclusion

The design of wideband microwave absorbers requires the use of an optimisation technique due to the complexity of the reflectivity from a multilayered structure. For all the optimisation techniques, the biggest issue is finding the optimal solution without becoming stuck in a local minimum. The methods of simulated annealing and genetic algorithms have been shown to help in avoiding local optima traps. Another issue with the design of multilayer absorbers is the fact that conflicting constraints are placed on absorber design, such as having thinnest absorber with the lowest reflectivity over the widest bandwidth possible. These constraints are mutually exclusive and so an acceptable design is often a trade off between the constraints. The Pareto Genetic Algorithm calculates a family of optimised design solutions for more than one constraint and can be based on available materials, making it an attractive tool. The objective function in Equation 8 should be useful in optimising an absorber's bandwidth performance to a specific frequency region.

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List of symbols/abbreviations/acronyms/initialisms

DND	Department of National Defence
GA	Genetic Algorithm
FDTD	Frequency Domain Time Domain
FEM	Finite Element Method
RAM	Radar Absorbing Material
RCS	Radar Cross Section

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14. ABSTRACT (U) The absorption of microwaves by a material depends on the properties of the material and its structure. Broadband absorbers are can be fabricated by stacking resistive sheets separated by low dielectric spacers with a thickness of a quarter wavelength. This type of multilayered resonant absorber is called the Jaumann absorber. In this paper optimal design techniques for multilayer microwave absorbers are reviewed. These methods include analytical approximations, gradient optimisation routines, simulated annealing and the genetic algorithm. The genetic algorithm is a highly parallel stochastic technique that permits multi−objective optimisation and has a high probability of finding the global minimum.
15. KEYWORDS, DESCRIPTORS or IDENTIFIERS (U) Genetic Algorithm; Optimisation; multi−objective; Jaumann; Absorber; layered; Salisbury Screen; Dallenbach; microwave; radar; bandwidth; thickness; reflectivity

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