IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 3 Ver. IV (May. – Jun. 2016), PP 65-70
www.iosrjournals.org

Optimum Design of Bi-Layer Perforated Electromagnetic Shield Using Improved Particle Swarm Optimization Algorithm

J. Tewary[1], D. Mandal[2], K.S.Kola[3], V.P.Roy[4]
[1,2,3,4]*Department of Electronics and Communication Engineering, Bengal College of Engineering and Technology, Durgapur, West Bengal, India,*

Abstract: *The disturbance of the sensitive measurement and the control equipment by Electromagnetic field is a central problem in electromagnetic compatibility, removal or reduction of such a disturbance is achieved by Electromagnetic Shielding sheets. Electromagnetic shields play a very significant role in the modern power and electrical industry. Efficient shields are also used in medicine, physics, and when making high-sensitivity electric and magnetic measurements to shield them from electromagnetic interference. In this paper an optimization method based on improved Particle Swarm Optimization (IPSO) algorithm for design of Bi layer perforated Electromagnetic Shield has been proposed. This can be used in any shape or form. The method of particle swarm optimization is used to determine the optimum Effective mass (mass/sqare cm) of the bilayer perforated electromagnetic shield that provides Shielding effectiveness which is very much acceptable as compare to standard value for the same.The simulation results for shielding effectiveness (SE) of the Bi layer Electromagnetic shield obtained by our proposed method has been compared with the desired value to illustrate the effectiveness of our proposed method.*

Keywords: *EMI/EMC; Electromagnetic Shield; Shielding effectiveness (SE); Improved Particle Swarm optimization Algorithm (IPSO),*

I. Introduction

Electromagnetic pollution levels are now reaching alarming proportions; highlighted by numerous studies conducted by scientists from all over the world, including many from India. It is very easy to understand water, air or noise pollution or contamination. However electromagnetic (EM) pollution is very much esoteric; it is not easily seen, tasted, smelled or felt; but it can be more damaging, something like a 'silent killer'. Now a days the International Standards (for example the European EMC Directive 89/336/EEC) calls for the severe and stringent requirement for the Electromagnetic (EM) radiated emission from electric and electronic devices. These regulations span from the magnetic field Emission at power frequency (related to human health issue) to the EM field Emissions in the radio frequency range, directly related to EMC parameters of the Electrical system considered [1-4].

Shielding the source or the victim system is still one of the effective ways to mitigate the effects of these electromagnetic emissions due to which the design of electromagnetic shield and its EMC applications have drawn the attention of researchers in the last few years [5]. B. D. Mottahed et al. proposed design methodology based on the electromagnetic shielding effectiveness capabilities [6]. The source can also be modified to reduce the interference generated proposed by J.Colotti [7]. A procedure for the optimization of planar multilayered shielding structures for magnetic fields, at frequencies for which the quasimagnetostatic description can be adopted, is presented by A. Massarini et al. [8]. Shielding is the process or technique which can be used to reduce or eliminate the effect of such Electromagnetic (EM) radiations. There are different techniques such as analytical [9], numerical [10], hybrids [11] have been incorporated to obtain the Expression of the Shielding Effectiveness (***SE)*** of the EM fields in presence of shielding structures. These functions relate SE to the geometrical (dimensions, thickness, distance from the source etc) and to the electrical (conductivity, permeability etc.) parameters of the shield in the form of multivariate function in which the number of the independent variables increases even more if multilayered structures are taken into account. Furthermore, practical design constraints such as limitations on weight, cost etc. fixed boundaries to the choice of the Shield's parameters and fixed implicit relationships among them. Thus the evaluation of the maximum EM field attenuation becomes a constrained optimization problem. Particle swarm optimization (PSO) is an evolutionary algorithm and has been successfully implemented in the design of Electromagnetic Shield. The PSO algorithm has been shown to be an effective alternative to other evolutionary algorithms such as Genetic Algorithms (GA), Ant Colony Optimization (ACO) etc. in handling certain kinds of optimization problems. This paper proposed a Shield having a number of air holes (perforated) for reducing mass [12]. To prevent the electric and magnetic fields a Bi layer shield has been designed. After that the usage of the recently developed improved particle Swarm Optimization (IPSO) algorithm [13-16] has been incorporated for finding the optimum effective mass of the Bi layer Electromagnetic Shield taking into account all the existing constraints.

II. Problem Formulation

The purpose of shielding is to confine radiated energy to a specific region or to prevent radiated energy from entering a specific region. Shield type include Solid, non-solid, braid as is used in cables .In all cases shield can be characterized by its shielding effectiveness (SE).

The shielding effectiveness is defined as:

For *E* field

$$SE = 20\log_{10}\left(\frac{E_0}{E_s}\right) dB \tag{1}$$

For *H* field

$$SE = 20\log_{10}\left(\frac{H_0}{H_s}\right) dB \tag{2}$$

Where E_0 and H_0 represents quantities at the receptor without shielding body, E_s and H_s denote quantities at the receptor with a shielding barrier between the emitter and the receptor. These expressions assume that the wave impedance is the same before and after the shield .The shielding effectiveness is sometimes called Shielding Loss. The greater is its value the better its Shielding abilities.

For a nonsolid material such as screen (perforated) Shielding effectiveness

$$SE = (A + R + B + K_1 + K_2 + K_3)\, dB \tag{3}$$

Where, the first term of equation (3) $A = 1.314\, t\sqrt{f\mu\sigma}\, dB$ represents attenuation caused by the discontinuity. $t = t_{cu} + t_{per}$ is the equivalent thickness of the bi layer Shield and f is the frequency of the radiated electromagnetic wave. The subscripts "*cu*" and "*per*" signifies for Copper and Permalloy respectively.

$$\mu = \frac{\mu_{cu} t_{cu} + \mu_{per} t_{per}}{t_{cu} + t_{per}} \tag{4}$$

μ is the equivalent relative permeability .

$$\sigma = \frac{\sigma_{cu} t_{cu} + \sigma_{per} t_{per}}{t_{cu} + t_{per}} \tag{5}$$

σ is the equivalent relative conductivity.

Second term of equation (3) represents $R = 168 - 10\log_{10}\frac{f\mu}{\sigma}\, dB$ loss due to single reflection.

Third term represents $B = 20\log_{10} e^{-\delta} dB$ which is Multiple reflection loss here δ is the skin depth.

$$\delta = \frac{1}{\sqrt{\pi f \sigma}} \tag{6}$$

The fourth term K_1 is Correction term to account for the number of like discontinuities and

$$K_1 = -10\log_{10}(an)\, dB \tag{7}$$

Here *a* is the area of each hole (cm^2) and n is the number of holes per cm^2.

The next term of equation (3) K_2 which is low frequency correction term to account for the skin depth may neglect at higher frequencies.

The last term of equation (3) K_3 is also a correction term to account for coupling between the adjacent holes.

$$K_3 = 0.20\log_{10}\left\{\coth\left(\frac{A}{8.686}\right)\right\} dB \tag{8}$$

The equation for the effective mass (Z) which has been minimized to get optimum light weight low cost shield using improved Particle Swarm Optimization algorithm (PSO) is as follows:

$$Z / cm^2 = (1 - an)(t_{cu}\rho_{cu} + t_{per}\rho_{per}) \tag{9}$$

Where ρ_{cu} and ρ_{per} are densities of copper and Permalloy respectively.

Here we have considered Copper and Permalloy for the design of Bi layer electromagnetic shield for the protection against electromagnetic field.

The values of the parameters taken are given below:

Table I. Values of the parameters

μ_{cu}	μ_{per}	σ_{cu}	σ_{per}	$f\,(GHz)$
1	2×10^4	1	0.027	1

In this paper, the optimization of the effective mass (mass/cm^2) of the Bi layer Electromagnetic shield with respect to shielding effectiveness is carried out; initially the following parameters have been considered.
(a) Shielding effectiveness of the shield (b) Effective mass of the shield (c) Cost of the shield
(d) Flexibility and (e) Softness of the shield.

After that the optimization technique using improved PSO algorithm to solve the constrained minimization problem among shielding effectiveness (SE) and mass of the shield have been incorporated. The design has been carried out considering that the shield having a numbers of air holes for flexibility and reduction of mass. To prevent electric and magnetic fields a Bi layer (copper and Permalloy) shield has been designed. The cost function to be minimized with improved PSO for optimal synthesis of bi-layer electromagnetic shield is given below:

$$Z = (1-an)(8.96t_{cu} + 8.6t_{per}) \tag{10}$$

Subject to

$$SE = 1.314\sqrt{10^3\left(t_{cu} + 2\times10^4 t_{per}\right)(t_{cu} + 0.027t_{per})} + 168 - 10log_{10}\left\{10^9\,\frac{(t_{cu} + 2\times10^4\,t_{per})}{(t_{cu} + 0.027)}\right\} - \frac{20(t_{cu} + t_{per})}{\sqrt{3.14\times10^9\left(t_{cu} + 2\times10^4 t_{per}\right)(t_{cu} + 0.027t_{per})}} - 10\log_{10}\left(\text{an}\right) + \tag{11}$$

$$0.20\log_{10}\left[\coth\left\{\frac{1.314\sqrt{10^3(t_{cu} + 2\times10^4\,t_{per})(t_{cu} + 0.027t_{per})}}{8.686}\right\}\right] \geq 80$$

Where,

$$0 \leq a \leq 176.625$$
$$0 < n \leq 1$$
$$0.1 \leq t_{cu} \leq 3$$
$$0.005 \leq t_{per} \leq 0.1$$

Now for carrying out the simulation, PSO algorithm has been considered for solving the above problem.The results of Shielding effectiveness for some standard values are given in Table II. Table II shows that as Shielding effectiveness (SE) increased the attenuation ratio increased which can provide much better protection against electromagnetic radiation.

Table II Results of shielding effectiveness for some standard values

SE (dB)	Attenuation ratio	Results
20	10:1	Normal acceptable shielding
40	100:1	Normal acceptable shielding
60	1000:1	Normal acceptable shielding
80	10000:1	Normal acceptable shielding
100	100000:1	Above average shielding
120	$10^6:1$	Above average shielding

III. Algorithm Overviews

Overview of Improved Particle Swarm Optimization Algorithm

Particle swarm optimization emulates the swarm behavior of insects, animals herding, birds flocking and fish schooling where these swarms search for food in a collaborative manner. Each member in the swarm adapts its search patterns by learning from its own experience and other member's experiences. These phenomena are studied and mathematical models are constructed. In PSO [13-16], a member in the swarm, called a particle, represents a potential solution which is a point in the search apace. The global optimum is regarded as the location of food. Each particle has a cost value and a velocity to adjust its flying direction according to the best experiences of the swarm to search for the global optimum in the *D*- dimensional solution space. The PSO algorithm is easy to implement and has been empirically shown to perform well on many optimization problems.

The PSO algorithm is an evolutionary algorithm capable of solving difficult multidimensional optimization problems in various fields. Since its introduction in 1995 by Kennedy and Eberhart [13], the PSO has gained an increasing popularity as an efficient alternative to GA and SA in solving various optimization design problems in shielding.

As an evolutionary algorithm, the PSO algorithm depends on the social interaction between independent agents, here called particles, during their search for the optimum solution using the concept of cost. PSO emulates the swarm behavior and the individuals represent points in the *D*-dimensional search space. A particle represents a potential solution. The particle swarm optimization used in this paper is a real-coded one. The steps involved in this algorithm are given below:

Step 1: Initialize positions and associated velocity of all Particles (potential solutions) in the population Randomly in the D-dimensional search space.

Step 2: Evaluate the cost value of all particles.

Step 3: compare the personal best (P_{best}) of every particle with its current cost value. If the current cost value Is better, and then assign the current cost value to P_{best} and assign the current coordinates to P_{best} coordinates.

Step 4: Determine the current best cost value in the whole Population and its coordinates. If the current best Cost Value better than global best (g_{best}), then assign the current best cost value to g_{best} and assign the current coordinates to g_{best} coordinates.

Step 5: Velocity (V_{id}) and position (X_{id}) of the *d-th* Dimension of *i-th* particles are updated using the following Equations:

$$V_{id}^{t} = w * V_{id}^{t-1} + c_1 * rand1_{id}^{t} * (pbest_{id}^{t-1} - X_{id}^{t-1}) + c_2 * rand2_{id}^{t} * (g_{d}^{t-1} - X_{id}^{t-1}) \quad (12)$$

$$V_{id}^{t} = \min(V_{\max}^{d}, \max(V_{\min}^{d}, V_{id}^{t})) \quad (13)$$

$$X_{id}^{t} = X_{id}^{t-1} + V_{id}^{t} \quad (14)$$

If $X_{id}^{t} > X_{\max}^{d}$, then,

$$X_{id}^{t} = X_{\min}^{d} + rand\,3_{td}^{t} * (X_{\max}^{d} - X_{\min}^{d}) \quad (15)$$

If $X_{id}^{t} < X_{\max}^{d}$, then,

$$X_{id}^{t} = X_{\min}^{d} + rand\,4_{td}^{t} * (X_{\max}^{d} - X_{\min}^{d}) \quad (16)$$

Where c1, c2 = acceleration constants =1.4945, w=inertia weight shown in Fig. 1 linearly damped with iterations starting at 0.9 and decreasing linearly to 0.4 at the last iteration, rand1, rand2, rand3 and rand4 denote uniform random numbers between 0 and 1, different value in different dimension, and t is the current generation number .Eqn. (13),(15) and (16) have been introduced to clamp the velocity and position along each dimension to maximum $(V_{\max}^{d}, X_{\max}^{d})$ and minimum $(V_{\min}^{d}, X_{\min}^{d})$ value if they try to cross the desired domain of interest. These clipping techniques are sometimes necessary to Prevent particles from explosion. The maximum velocity is set to the upper limit of the dynamic range of the search $(V_{\max}^{d} = X_{\max}^{d})$ and the minimum velocity is set to $-V_{\max}^{d}$.

Step 6: Repeat steps 1–5 until a stop criterion is satisfied or a pre specified number of iteration is completed, usually when there is no further update of best cost value.

IV. Simulation Results

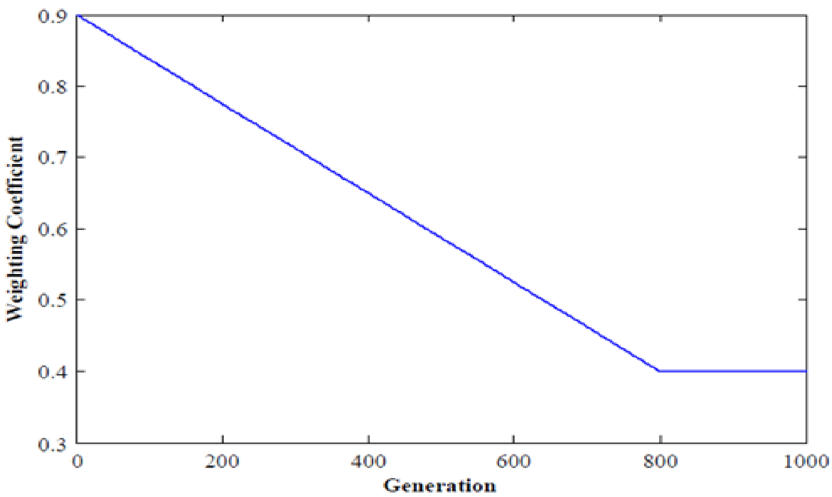

Figure 1: Change of weighting coefficient with Generation

The simulated results for the mass and shielding effectiveness of the shield considering the area of the shield is $3805 cm^2$ is shown in Table III. This design theoretically results 380.5gm of mass of the Shield provides 321.047 dB as the shielding effectiveness.

Table III Mass and shielding effectiveness

Area to be Shied (cm^2)	**Area of each hole /cm^2**	**No. of hole/cm^2**	t_{cu} **(cm)**	t_{per} **(cm)**	**Effective mass (gm/ cm^2)**	**Additional mass of the shield (gm)**	**Shielding effectiveness (SE) dB**
3805	9.6686	0.0955	0.1286	0.0172	0.1	380.5	321.047

The comparison between desired and obtained results of proposed method are shown in Table IV. Table IV shows that the desired values of shielding effectiveness has a value always greater than or equal to 80 dB but using the proposed method 321.047 dB of shielding effectiveness have been achived which is much higher as compare to the desired one. Similarly the obtained result for the effective mass is also very much adequate with the desired values.

Table IV Desired and obtain values of shielding effectiveness (SE) and Effective mass

Shielding Effectiveness (SE) in dB		**Effecti vemass (gm/cm^2)**	
Desired	**Obtained**	**Desired**	**Obtained**
≥ 80	321.047	As minimum as possible	0.1

The obtained results clearly shows the effectiveness of the proposed method and also established a very good agreement between the desired and obtained parameters. The convergence curve of improved PSO algorithm has been illustrate in Fig. 2.

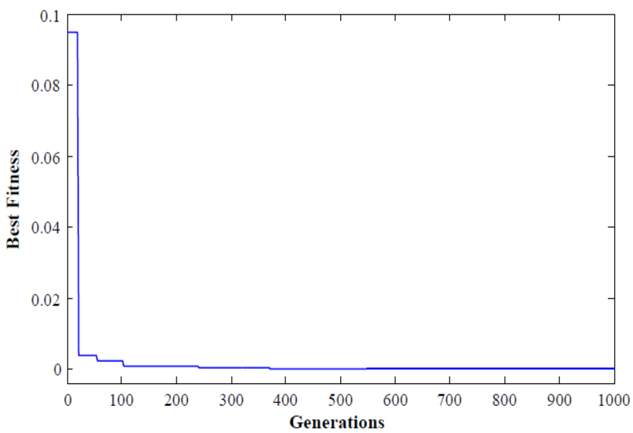

Figure 2: Convergence curve using improved PSO

V. Conclusion

A procedure to find the optimum mass of Electromagnetic Shield under the constraint of a minimum threshold value for the shielding effectiveness is presented in this paper. The Optimization in the design of shield is carried out by adopting the recently proposed improved PSO algorithm considering the minimization should be difference squared between calculated values -0.1.The method is reliable and fast in performing its task. By using particle swarm optimization algorithm we evaluate the optimum values for area of each holes (a), the number of holes per square cm (n), thickness of copper sheet (t_{cu}) and the thickness of permalloy sheet (t_{per}) which will minimize the Effective mass (mass/sqare cm) of the bilayer perforated electromagnetic shield that provides Shielding effectiveness which is very much acceptable as compare to standard value for the same. This paper proposed an optimization and designing method of perforated Electromagnetic Shield which provides optimum Shielding effectiveness (SE), optimum mass of the shield and has relaxation that can be used in any shape or form which is suitable for protection of equipments, devices or human being from harmful effects of Electromagnetic Interference (EMI).

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