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Analysis of shielding effectiveness by optimizing aperture dimensions of a rectangular enclosure with genetic algorithm

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Abstract: Electromagnetic compatibility (EMC) becomes a substantial challenge than any other time since the number of electric vehicles (EV) is increased rapidly. The electric driving system in EV consists of power electronics components supplied by high voltage battery source. Those are both potential electromagnetic interference (EMI) source and victim since fast switching process occurs inside themselves. Electromagnetic shielding provides a significant protection against EMI for any electrical and electronic components inside the vehicle. In this paper, analysis of shielding effectiveness (SE) by optimizing aperture dimensions of a rectangular enclosure is investigated. Realistic dimensions of the shielding enclosure of an inverter component is employed. An optimization methodology based on genetic algorithm (GA) is carried out and applied to SE analytical model. It is aimed to keep total aperture area as large as possible inside a particular dimension range while improving SE of the enclosure comparing with the reference level. Obtained optimization results are presented by indicating optimum aperture length and width which satisfy both EMC and dimension requirements. Finally, it is concluded that through the optimization methodology designed in this study, SE of the enclosure is raised from poor level to average one while providing larger aperture area.

Key words: Electric vehicle, inverter, shielding effectiveness, genetic algorithm

1. Introduction

The fact that electronic components are getting into daily life more and more not only makes the life easier in many fields but also brings some problems with it. Maintaining the functionality of electronic devices and systems in an environment of electromagnetic interference (EMI) without affecting each other negatively, reveals the emphasis of electromagnetic compatibility (EMC). EMC is the ability of an electronic device to operate without generating EMI for other devices, as well as fulfilling its functionality in an environment of external EMI [1].

Vehicles have been in use for many years and it is observed clearly that they tend to have much more electrical and electronic components by following the development of technology. Due to new global regulations that aim to reduce CO_2 emissions, electric vehicles (EVs) entered a high speed developing period [2]. The integration of electrical driving systems into conventional vehicle electronic architecture makes EMC become a substantial challenge. EMI occurs generally by fast switching operations inside power electronic components such as inverter, onboard charger, DC/DC converter etc. that can affect the entire vehicle [3]. Beside this,

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wiring harness of high voltage (HV) components has a significant effect on generating EMI, unless groundings, length of cables, orientation of HV components are designed attentively [4–7].

Electromagnetic shielding is one of the major prevention to overcome EMI and improve the immunity of electrical and electronic components. Ideally, full protection of electronic devices against EMI could be achieved by placing them into a shielding enclosure consisted of high conductivity material without any aperture on itself [8, 9]. However, apertures are strictly required for various reasons such as power supply cables, connectors, I/O ports, mounting holes, ventilation and heat dissipation etc. Moreover, they can have different shape and dimensions. These apertures degrade the shielding performance of the enclosures by permitting EMI leakage onto the electronic devices [10]. The performance of a shielding enclosure is commonly expressed as shielding effectiveness (SE), which is defined as a ratio of field strengths in presence and absence of the enclosure [8–13].

There are many analytical and numerical methods for the investigation of SE in order to have an estimation during design phase of electrical and electronic components [8–20]. Numerical methods that have been used to calculate SE include finite difference time domain (FDTD) method [14], method of moments (MoM) [15], transmission line method (TLM) [16] and hybrid methods [12, 18]. Numerical methods can provide more accurate simulation results since they utilize large amount of data. However, they have major drawbacks such as the cost of large memory, longer computation time, necessity of detailed mesh. Despite that, analytical methods can be applied within a short space of time but they use various assumptions which may create validity problems unless physical phenomenon is taken into consideration deeply [8, 12, 13]. Whatever method is selected for investigation of SE, it is essential to find optimum solution since there are some design restrictions commonly that affect on the dimensions of shielding enclosure and its aperture.

Genetic algorithm (GA), which is an important branch of artificial intelligence research, is widely used for optimization studies in computer science, machine learning and neural networks [21]. GA includes stochastic searching techniques based on the idea that survival of strongest one similar to the natural selection and genetic mechanism. GA starts with selection of chromosomes, which represents a solution to problem, in an initial set of random solutions called population. It aims to get the highest fitness solution after many iterations of selection process in which chromosomes are evolved by applying genetic operators such as reproduction, crossover, mutation [22]. GA is applied to solve large scale problems efficiently since deterministic algorithms need longer computation time to access the most suitable solution. GA is also relatively easy to implement on account of searching for the solution without dealing with inner mathematical equations of the problem and therefore GA provides flexibility and modularity.

In this paper, analysis of shielding effectiveness by optimizing aperture dimensions of a rectangular enclosure with genetic algorithm has been investigated. SE analytical model obtained by Robinson et al. is used for the investigation [11]. Several studies are observed for the investigation of SE analytical model with deterministic optimization methods in the literature [8–11, 20]. However, there are limited optimization studies based on stochastic techniques. In one study, optimum thickness of an infinitely long multilayered cylindrical shield is obtained by using GA [23]. In another study, artificial neural network (ANN) is employed for the analysis of aperture size of metallic enclosure on SE [8]. Since there are not many studies about optimizing SE with GA that even focus on electrical and electronic components inside EVs, this study is the first, which employs realistic dimensions of shielding enclosure and intends to keep total aperture area as large as possible while improving SE of the enclosure. It provides optimum aperture dimensions for a particular design range defined by component designers.

The remainder of this study is as follows. Section 2 presents a benchmark study for the inverter component of EV. Then, analytical model is proposed to analyze SE of rectangular enclosure of the inverter. Section 3 covers optimization methodology based on genetic algorithm that is designed for providing optimum aperture dimensions of the enclosure. Section 4 presents optimization results and the findings. Finally, Section 5 presents the concluding remarks.

2. Materials and Methods

In this section, electromagnetic environment inside EV is mentioned and one of the critical components which belongs to EV driving system is analyzed. Then, an analytical model is proposed for SE investigation of the component enclosure. Finally, SE calculations are performed depending on enclosure dimensions and aperture dimensions respectively.

2.1. Electromagnetic environment inside EV

There are various components that require different voltage levels to operate inside EV. Beside low voltage components such as infotainment systems, advanced driving assistance systems etc., there are HV components which operate up to 900 V in some EV applications [2].

Electric driving system is mostly based on one central e-machine that is rotated and controlled by an inverter component. Due to usage of three-phase e-machine, the inverter is consisted of 6 insulated gate bipolar transistors (IGBTs), in which fast switching process occurs in many EV applications [3]. The inverter is therefore a great EMI source and a potential EMI victim which may lead driving safety problems unless EMC is taken into account properly. An inverter is generally composed of microcontroller unit and driver stage which are supplied by low voltage battery, IGBT stage supplied by HV battery, a shielding enclosure in which all of the circuits are placed as depicted in Figure 1.

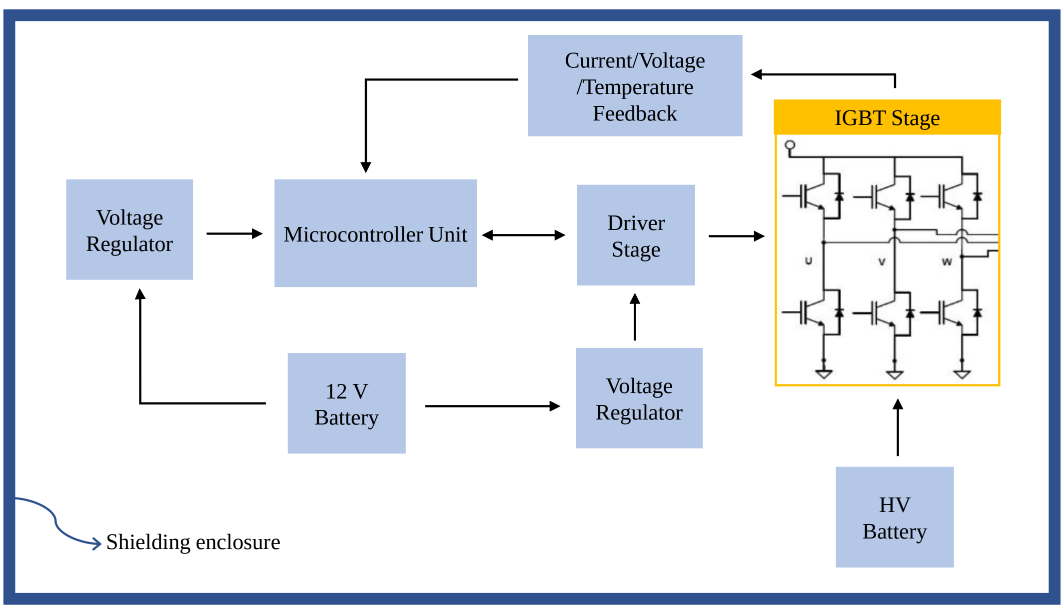

Figure 1. Inverter block diagram.

Shielding enclosure can have different dimensions depending on the complexity of internal circuits, coolant layout and mounting. Moreover, it can be produced by various materials such as aluminum or composites [19].

Table 1 illustrates inverter specific benchmark study for different brands and vehicle models in order to indicate common dimensions for the inverter. It is observed that the shielding enclosure tends to be smaller and lighter in the latest products while they have similar range for the operating voltage. Aluminum is still widely used to produce the enclosure.

Due to the necessity of aperture on the shielding enclosure for various reasons such as connector, power cable, ventilation etc., analyzing SE of the enclosure becomes crucial for EMC. Providing larger aperture area is essential to meet the requirements while keeping SE at desired EMC levels.

Table 1. Inverter specific benchmark study.

Type	Year	Vehicle Model	Inverter Dimension (mm)	Inverter Weight (kg)	Operating Voltage (V)	Enclosure Material
BEV	2019	Audi e-Tron	$300 \times 160 \times 310$	7.986	150-460	Aluminum
PHEV	2014	BMW i3 R.E	$202 \times 367 \times 128$	5.081	120-400	Composite
BEV	2018	Jaguar I-Pace	$275 \times 90 \times 435$	8.134	290-450	Aluminum
BEV	2013	Renault Zoe	$450 \times 200 \times 260$	10.108	240-420	Aluminum
BEV	2018	Hyundai Kona	$370 \times 120 \times 400$	9.193	200-400	Aluminum
BEV	2017	Opel Ampera	$247 \times 147 \times 405$	9.373	250-400	Aluminum

2.2. SE analytical model

Estimation of SE can be obtained by both analytical and numerical methods. It is observed that numerical methods are commonly employed for complex structures. They therefore require longer computation times, larger memory. Although they are successful on SE investigation of a particular enclosure, it is difficult to use them to investigate the impact of design parameters. Analytical methods provide quick results since they are mostly applied to basic structures by considering physical phenomenon [12, 13].

In this study, SE analytical model obtained by Robinson et al. is employed to investigate shielding performance of rectangular enclosure [8]. Figure 2 shows a rectangular enclosure with an aperture illuminated by a plane wave. Its equivalent circuit is depicted in Figure 3.

Electric shielding effectiveness at a distance P from the aperture is obtained by the voltage at point P. V_0 indicates the radiating source while $Z_0 = 377\ \Omega$ represents source impedance. The characteristic impedance and propagation constant of the waveguide are represented as Z_g and k_g respectively. To calculate SE, an equivalent impedance for the aperture is obtained initially and then transmission line theory is employed to transform all the voltages and impedances to point P [11].

The aperture is considered as a length of coplanar strip transmission line that represents the transition between free space and waveguide. The total width is equal to the height of enclosure b while the separation is equal to the height of aperture w. Its characteristic impedance is obtained by Gupta et al. as given by the following equation [24]:

$$Z_{0s} = 120\pi^2[ln(2\frac{1+\sqrt[4]{1-(w_e/b)^2}}{1-\sqrt[4]{1-(w_e/b)^2}})]^{-1}. \tag{1}$$

where w_e is the effective width of the aperture expressed in (2). $w_e < b/\sqrt{2}$ approximation is employed in (1).

Thickness of the enclosure wall is denoted as t that is used to define the effective aperture width in (2).

$$w_e = w - \frac{5t}{4\pi}(1 + ln\frac{4\pi w}{t}). \tag{2}$$

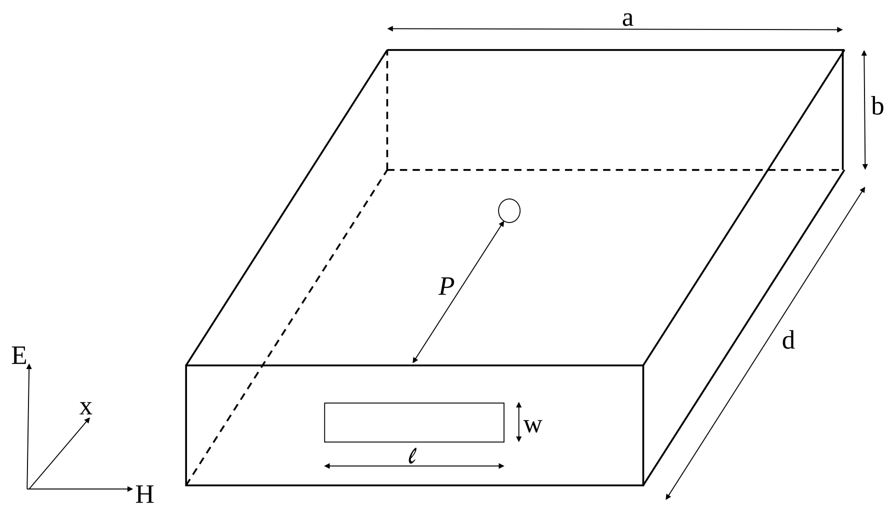

Figure 2. Rectangular enclosure with an aperture.

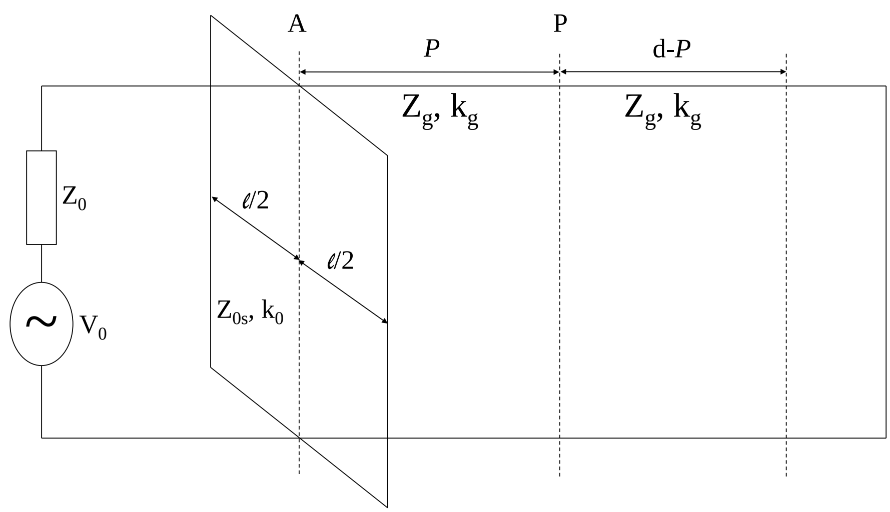

Figure 3. Equivalent circuit of rectangular enclosure with an aperture.

The short circuits at the ends of the aperture are transformed to an impedance Z_{ap} at point A obtained in (3) by including a factor l/a to take into account the coupling between the enclosure and the aperture [11].

$$Z_{ap} = \frac{1}{2}\frac{l}{a}jZ_{0s}tan\frac{k_0 l}{2}. \tag{3}$$

Z_{ap}, Z_0, V_0 are used to obtain equivalent voltage $V_1 = V_0 Z_{ap}/(Z_0 + Z_{ap})$ and source impedance $Z_1 = Z_0 Z_{ap}/(Z_0 + Z_{ap})$ by applying Thevenin's theorem. Transformation of V_1, Z_1 and the short circuit at the end of the waveguide to point P gives an equivalent voltage V_2, source impedance Z_2 and load impedance Z_3 expressed in the following equations respectively [11]:

$$V_2 = \frac{V_1}{cosk_g p + j(Z_1/Z_g)sink_g p}. \tag{4}$$

$$Z_2 = \frac{Z_1 + jZ_g tank_g p}{1 + j(Z_1/Z_g)tank_g p}. \tag{5}$$

$$Z_3 = jZ_g tank_g(d - p). \tag{6}$$

where $Z_g = Z_0/\sqrt{1-(\lambda/2a)^2}$, $k_g = k_0/\sqrt{1-(\lambda/2a)^2}$ and $k_0 = 2\pi/\lambda$ for TE_{10} mode of propagation.

The voltage at point P is expressed as $V_p = V_2 Z_3/(Z_2 + Z_3)$. The load impedance at P equals to Z_0 while the voltage is $V_p^{'} = V_0/2$ in the absence of the enclosure. Electric shielding effectiveness of a rectangular enclosure with an aperture at point P can be expressed as follows [11]:

$$S_E = -20log_{10}\left|\frac{V_p}{V_p^{'}}\right| = -20log_{10}\left|\frac{2V_p}{V_0}\right|. \tag{7}$$

2.3. SE calculation

SE calculations are performed depending on enclosure and aperture dimensions shown in Table 2 by employing the equation in (7). In general, a shielding range of 10 dB to 30 dB provides the lowest effective level of SE, while anything below that range is considered as no shielding. In many application, shielding between 30 dB to 60 dB is accepted average level of EMI protection. Any calculated SE much higher than 90 dB implies the material is essentially impenetrable [26].

Table 2. Enclosure and aperture dimensions.

Enclosures				
Enclosure	**a(mm)**	**b(mm)**	**d(mm)**	**t(mm)**
E1	275	90	435	2,5
E2	370	120	400	2,5
E3	490	240	350	2,5

Apertures		
Aperture	**l(mm)**	**w(mm)**
A1	100	5
A2	150	5
A3	100	10

Figure 4 illustrates SE calculations for rectangular enclosures $E1$, $E2$ and $E3$ shown in Table 2 while they have an aperture as $A1$. Point P is located at the center of each enclosure during the calculations. It is observed that resonance occurs at lower frequencies while enlarging dimensions of the enclosure. However, SE increases proportionally to enlarging dimensions of the enclosure at higher frequencies.

Figure 5 illustrates SE calculations for rectangular enclosure $E3$ while its aperture has different dimensions such as $A1$, $A2$, $A3$ shown in Table 2. It is observed that SE decreases by enlarging dimensions of aperture while the dimensions of the enclosure remain the same. However, higher SE is obtained with $A3$ dimensions although the total open area of aperture is larger for $A3$ than $A2$. At the same frequency sample point (200 MHz), SE is 5.82 dB higher when the aperture dimensions are modified from $A2$ to $A3$. Moreover, modifying aperture dimensions from $A1$ to $A2$ makes SE lower than $A1$ to $A3$ which shows that changing on length l of the aperture has significant influence on SE comparing with width w. Because, the electric field and the location of aperture length have the same direction, which indicates that high amplitude of electric field gets into the aperture of the enclosure by enlarging the length of aperture.

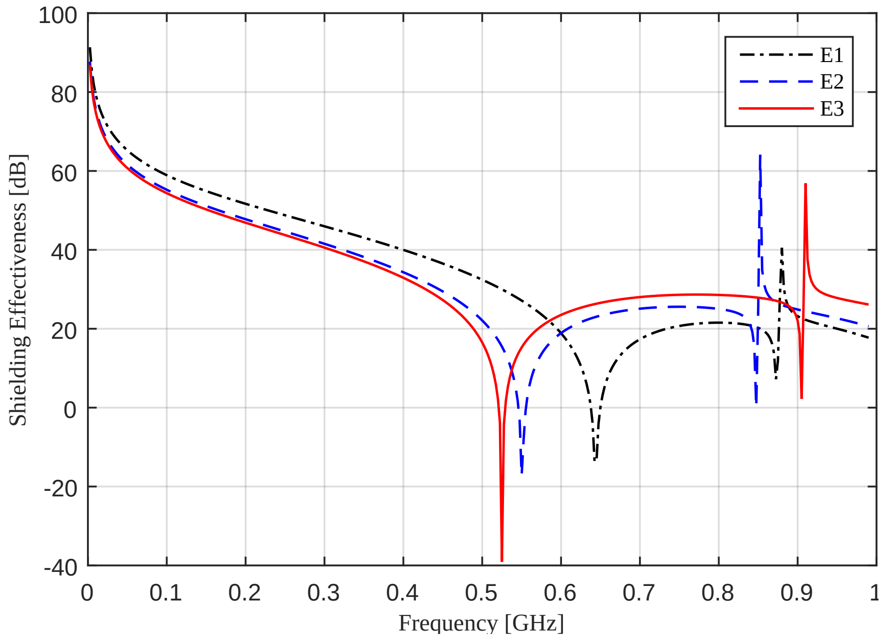

Figure 4. SE calculation for rectangular enclosures $E1, E2, E3$ with aperture $A1$.

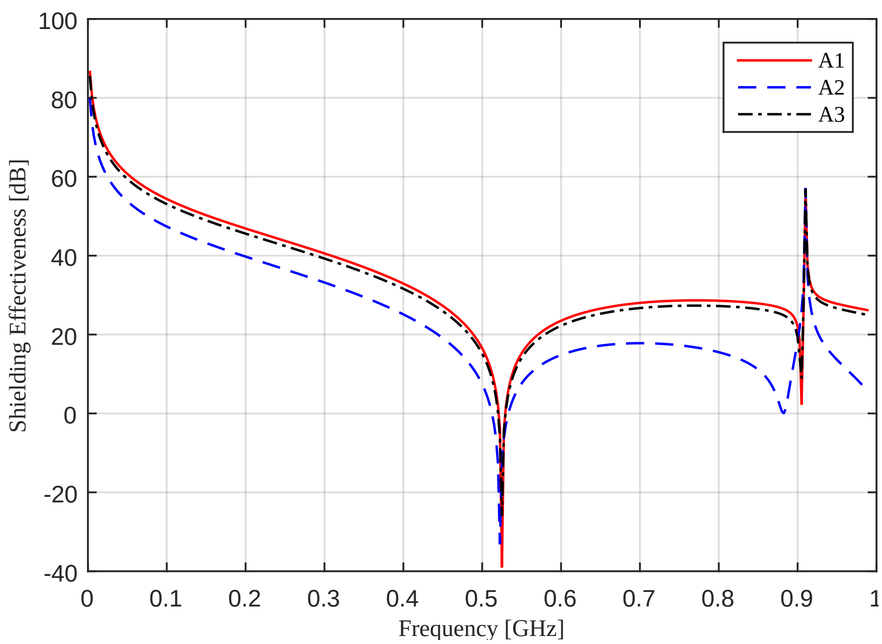

Figure 5. SE calculations for rectangular enclosure $E3$ with apertures $A1, A2, A3$.

3. Optimization with Genetic Algorithm

A structure similar to the natural selection is used in genetic algorithms due to having common terminology with the theory of evolution. In a population, individuals who adapt well to environmental conditions are able to survive and reproduce longer than weaker ones. Their characteristics are encoded in their genes which are transmitted to the next generations [21]. GA can be easily adapted to solve large scale problems by obtaining of objective or fitness functions regarding to each one. The main idea is to get the highest fitness solution after many iterations. However, deterministic algorithms frequently need inner mathematical requirements and have restrictions to adapt to other problems since they produce problem specific solutions.

The first step in GA is to have an initial set of random solutions called population. Each solution inside the population corresponds to a chromosome. The following steps include applying genetic operators such as crossover, mutation and reproduction to the population to generate the new one. Objective functions are calculated for every new populations [22].

One point crossover is applied to two chromosomes (parents) to create two new chromosomes (children) by picking a point on both parents' chromosomes and swapping genes between the chromosomes to the right of that point. In this way, each new chromosome carries some genetic information from both parents [25].

Mutation operator is widely used for increasing genetic diversity from one generation to the next. Applying only crossover operator to the chromosomes causes them to become too similar to each other after a while. Thus, stopping the iteration without getting the global optimum value is prevented [21].

Figure 6 shows genetic algorithm designed for optimizing aperture dimensions of a rectangular enclosure to have larger aperture area through a particular dimension range while keeping SE at desired level. The algorithm requires some input parameters such as rectangular enclosure dimensions, range for the dimensions of aperture as $w_{min} \leq w \leq w_{max}$ and $l_{min} \leq l \leq l_{max}$, some declarations used for SE calculation such as Z_0, V_0 etc. Then, it needs some probability constants such as $pcross$, $pmutation$ for crossover and mutation operators respectively.

As a first step, random w and l values inside the range of aperture dimensions are employed to create an initial population matrix sized as $psize \times d$ where $psize$ indicates the number of chromosomes in the population while d expresses the number of genes for the chromosomes. In this study, $d = 2$ is taken due to reducing the solution parameters to the pairs of w and l which represent a chromosome. SE is calculated for each pair of w, l and stored in $obj(i,j)$ matrix. The selection criteria of each pair of w, l for the fitness function $objit(i,j)$ is providing maximum SE by intending to keep it higher than $SE\_threshold$ (30 dB) as much as possible while applying the largest values for both w and l in every iteration.

After obtaining fitness function in an iteration step, genetic operators such as the natural selection, crossover, mutation are applied to the population matrix to sustain the survival of strongest chromosome. Then, SE is calculated for each chromosome in the next generation again and the previous steps are followed to obtain fitness function. Finally, the iteration is stopped when $iter\_threshold$ is achieved and the strongest chromosome is used to plot optimum SE.

The natural selection permits chromosomes to be copied for possible inclusion in the next population. The possibility of a chromosome that makes it to propagate into the next generation is based on chromosome's fitness value, obtained from fitness function. There are various methods to define possibility. One of the easiest method is fitness proportionate selection to assign a probability to each chromosome as follows:

$$P_i = \frac{f_i}{\sum_{i=1}^{psize} f_i}. \tag{8}$$

where f_i is fitness value of chromosome i while $\sum_{i=1}^{psize} f_i$ indicates the total population fitness. After that, a cumulative probability is obtained for each chromosome by adding the probability value as follows:

$$c_i = \sum_{i=2}^{psize} c_{i-1} + P_i. \tag{9}$$

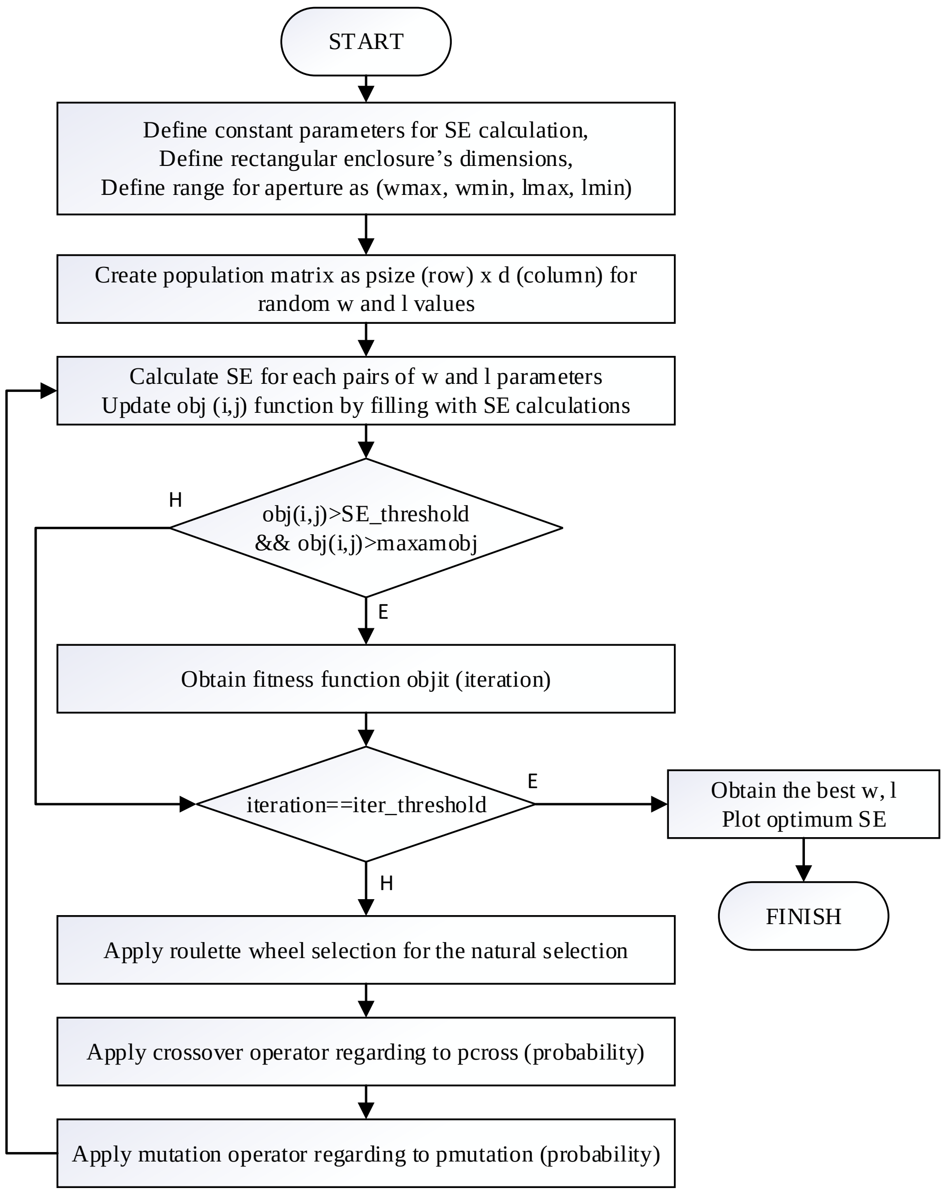

Figure 6. Optimizing aperture dimensions of a rectangular enclosure by using genetic algorithm.

Random number rs_i, uniformly distributed in [0,1] is drawn $psize$ times and cumulative probabilities of chromosomes are checked each time to identify the first one that satisfies $rs_i < c1$ condition. Then, selected chromosome is replaced to i_{th} place in the population. This process is named as roulette wheel selection [25].

All pairs of chromosomes are not selected for the crossover. Crossover probability $pcross = 0.95$ is used to decide which pairs of chromosomes are to undergo crossover. It is typically defined between 0.6 and 1. If crossover is not applied, then selected chromosomes are copied to the next generation without any change. [22].

After crossover operator, mutation is applied to each chromosome. It modifies genes in the chromosomes randomly regarding to mutation probability $pmutation = 0.005$ which can vary from 0.001 to 0.01. It rarely alters genes depending on quite low probability. However, it is a very useful operator to avoid having similar chromosomes after several iterations.

4. Optimization Results and Findings

In this study, one of the critical EMC issue for automotive inverter components, SE analysis of rectangular enclosure with an aperture is investigated. It is aimed to obtain the best SE values while keeping aperture area as large as possible for a particular design range since larger aperture area is needed for additional cables, connectors, ventilation etc. SE analytical model for the enclosure obtained by Robinson et al. is employed to build the object of the problem [11]. Then, an optimization methodology based on GA is designed to get optimum dimensions for width w and length l of the aperture which provide higher SE values and larger aperture area.

It is observed clearly in Figure 4 that enlarging the enclosure size provides better SE while the aperture dimensions remain the same. However, it is strongly intended to have enclosures as small as possible especially for automotive components since extra space for any component may be quite significant for the vehicle body size. Component designers mostly deal with sustaining EMC requirements in a very limited dimension range, so optimization activity always stays as one of the popular subjects.

Figure 5 represents the effect of aperture dimensions while keeping enclosure dimensions the same. It is obtained obviously that enlarging the aperture area decreases SE. In this case, the change on aperture length l has bigger impact on SE than changing of aperture width w. Thus, optimization based on GA is designed by taking into account the priority for increasing the aperture width w initially in order to provide larger aperture area while keeping SE at desired level.

Optimization algorithm is executed 5 times as shown in Table 3 to investigate the outputs and estimate the efficiency of such a stochastic optimization methodology. SE optimization results, obtained for a particular design range such as $5\ mm \leq w \leq 10\ mm$ and $50\ mm \leq l \leq 150\ mm$ are compared with the previous result indicated as $A1$ in Figure 5.

Table 3. Comparison of SE optimization results with the reference result $A1$.

Result ID	**Width** (mm)	**Length** (mm)	**Area** (mm^2)	**SE (dB) @200 MHz**	**SE (dB) @400 MHz**	**SE (dB) @600 MHz**	**SE (dB) @800 MHz**
A1	5	100	500	41,72	27,69	18,47	23,18
O1	9,9	52,80	522,72	+9,83	+10,18	+10,57	+11,8
O2	10	53,5	535	+9,61	+9,96	+10,34	+11,57
O3	9,9	51	504,9	+10,46	+10,83	+11,22	+12,48
O4	9,9	51,50	509,85	+10,29	+10,66	+11,04	+12,3
O5	9,9	55,60	550,44	+8,95	+9,3	+9,67	+10,86

It is observed that SE gets better significantly despite keeping population size $psize = 1000$ and iteration size $iter\_threshold = 100$ which are quite low numbers to generate more precise results. However, the results are obtained less than a minute to provide a design decision. Designed optimization methodology is very flexible that can be modified easily to process more data by increasing $psize, iter\_threshold$ numbers. It can be applied to determine larger aperture area for any rectangular enclosure inside EV while keeping SE at desired level.

The comparison of each result with the reference one is performed for four different frequencies such as 200 MHz, 400 MHz, 600 MHz and 800 MHz respectively. Since the aperture length l is more significative than aperture width w for SE calculation, it is observed that the algorithm tends to identify w value inside random populations initially. The reason is mentioned in Section 2.3. In this study, aperture width varies from $9,9$ mm to 10 mm which is the largest value. Beside this, aperture length varies from 51 mm to $59,26$ mm. The total aperture area varies from $504,9$ mm^2 to 535 mm^2 which is higher than the reference value 500 mm^2 while keeping SE gets $\geq +8,85$ dB better.

Figure 7 depicts the comparison of reference result $A1$ with the best optimization result $O3$ shown in Table 3. Since it has the lowest aperture area comparing with other obtained results, it provides the best SE values at selected frequencies. SE gets $\geq +10,46$ dB better with $O3$ that makes the total SE of the enclosure to raise from poor level to average one for EMI protection.

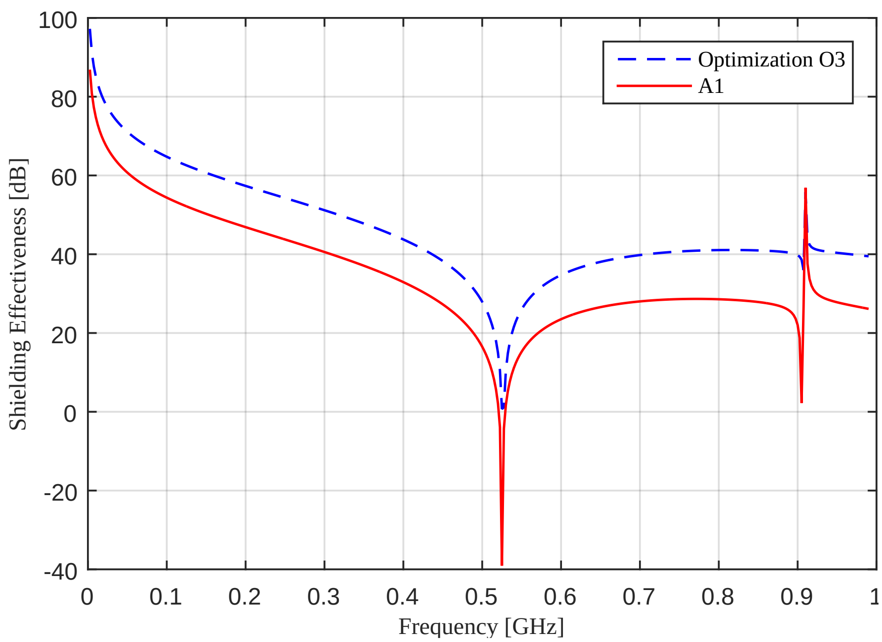

Figure 7. SE optimization result obtained by $O3$.

Figure 8 illustrates the change of aperture width w and aperture length l for each iteration step during obtaining $O3$ result. It is observed that $9,50$ mm is reached for w by 15^{th} iteration step where the oscillation starts and continues between $9,51$ mm and 10 mm until the iteration is stopped. l value also starts to oscillate after 15^{th} iteration step, the oscillation continues between $50,96$ mm and $51,36$ mm. It shows that designed algorithm gets the largest w initially due to less impact on SE comparing with l.

Figure 9 shows the change of aperture area obtained by $O3$ result. The oscillation starts after 19^{th} iteration step. Finally, it reaches to $504,9$ mm^2 while providing $\geq +10,46$ dB improvement on SE.

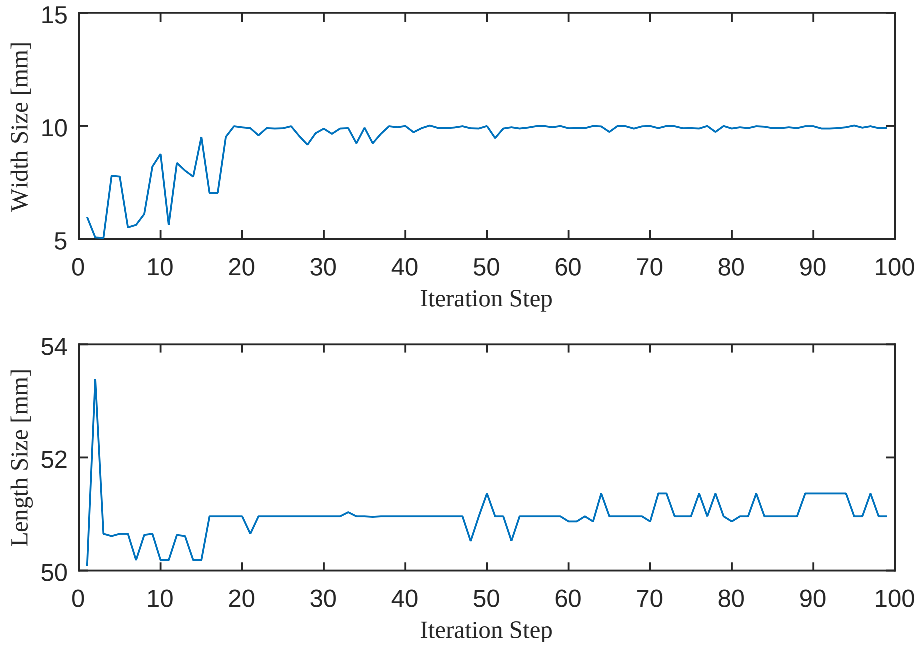

Figure 8. The change on aperture dimensions for each iteration step of $O3$ result.

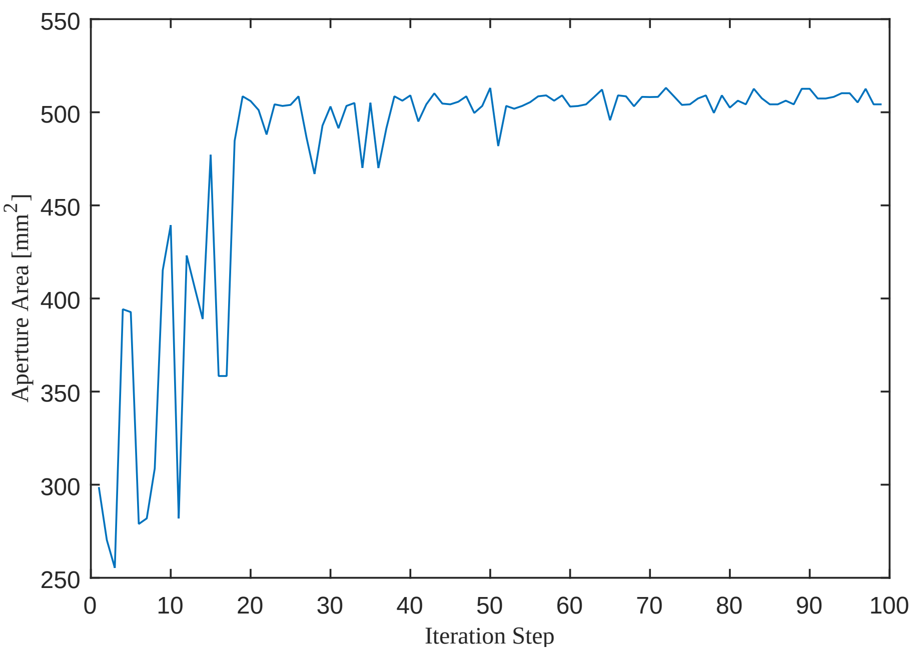

Figure 9. The change on aperture area for each iteration step of $O3$ result.

5. Conclusions

Due to new strict regulations for the standardization of emission, EVs have entered a high speed developing period. The integration of electrical driving systems into conventional vehicle electronic architecture makes EMC design one of crucial point to be investigated deeply. Fast switching process, supplied by HV battery occurs inside power electronics components such as inverter, DC/DC converter which makes them to become both great EMI source and victim.

Electromagnetic shielding is one of the fundamental parts of electrical and electronic components in the vehicle. The performance of shielding enclosure can be degraded by an aperture. Thus, the enclosure of components must be designed to keep SE above average level $\geq$ 30 dB. However, larger aperture area is frequently needed to add additional cables, I/O connections, ventilation hole etc. which causes SE to get lower.

In this paper, analysis of SE by optimizing aperture dimensions of a rectangular enclosure with GA has been investigated. Realistic dimensions of shielding enclosure of the inverter component are employed. An optimization methodology based on GA is designed to keep total aperture area as large as possible for a particular dimension range while improving SE of the enclosure comparing with the reference one. It is obtained that enlarging enclosure dimension makes SE get higher. However, extra space for any enclosure may affect the total dimensions of vehicle body. Thus, it is crucial to optimize aperture dimensions while keeping SE at desired level. The optimization methodology provides larger aperture area while fulfilling both EMC and dimension requirements of a rectangular enclosure for electrical and electronics components inside EV.

It is obtained that the change on aperture length l has bigger impact on SE rather than changing of aperture width w. Optimization algorithm is designed to find the largest w value in a random population initially. In this study, optimization algorithm is executed 5 times to investigate the efficiency. It is observed that optimization makes SE of the enclosure raise from poor level to average one for EMI protection despite increasing aperture area.

Consequently, optimum aperture dimensions are obtained for a particular dimension range by the optimization methodology based on GA. It is very applicable while dealing with providing efficient solutions that fulfill both EMC and dimension requirements. As a future work, optimizing the effect of enclosure and aperture shapes will be proposed.

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