Antenna Position Optimal Design for Reducing Interference

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Abstract: In this paper, a novel antenna position optimization method in EMC design by utilizing Space Mapping Algorithm(SMA) together with Genetic Algorithm.(GA) is presented. This technique involves two kinds of EM models for antenna coupling: coarse for fast computation of the coupling between each antenna, and the corresponding fine for MOM simulation. Finally, the numerical results show the effectiveness of this method.

Index Terms: EMC, optimization, coupling, antenna, SMA, GA

1. Introduction

The electromagnetic compatibility of the antennae on the top of vehicle should be treated as a very important question. Because antennae work in open air, so conventional shielding technique is unusable to reduce the interference among antennae and we have to utilize position optimization design to deal this problem. In early project we optimized the antenna position via experience and probing together with numerical computation method. Usually, the numerical computation method may take several hours, even one or several days to implement one computation. Therefore, if it need M steps to get convergence in the optimization, the total CPU time should be M×N hours. Actually the time cost is prohabitively large.

In EMC technique antenna coupling is the parameter to weigh the interference among antennae so we firstly give two kinds of antenna coupling model in this paper, then introduce a new double-quick and precise antenna position optimal method via Space Mapping Algorithm and Genetic Algorithm by using the antenna coupling models we have given firstly.

2. Antenna Coupling Model

2.1 Antenna Coupling Definition

Antenna coupling is defined as

$$C = 10\lg\left(\frac{P_{out}}{P_{in}}\right)\ (\mathrm{dB}) \qquad (1)$$

P_{in} is the power input into transmitting antenna and P_{out} is the output power of receiving antenna.

2.2 Fine Model of Coupling – based on MOM

MOM is a very accurate numerical method to execute electromagnetic calculation. When we use MOM to solve EFIE and MFIE we get the matrix equation

$$[I]=[Y][V]$$

where $[I]$ is the general current matrix to be solve, $[Y]$ and $[V]$ are the general conductance matrix and voltage matrix that have been known.

In MOM two segments on different antennae can be seen as a two port network like shown in figure 1.

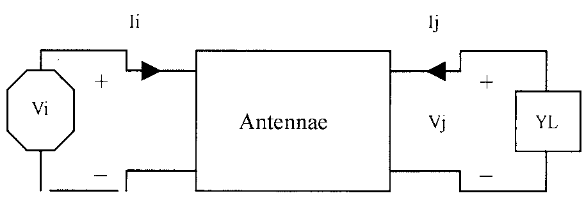

Figure1. two port network of segments

When we want to calculate the coupling between ith segment and jth segment we can choose the corresponding elements from matrix $[Y]$ to form the conductance matrix of the equivalent tow port network and we can get the expression of antenna coupling.

$$C = \frac{P_j}{P_i} = \frac{|Y_{ji}|^2 \cdot \mathrm{Re}(Y_L)}{|Y_{jj} + Y_L|^2 \cdot |\mathrm{Re}(Y_{in})|} \quad (2)$$

In expression (2) $Y_{in} = Y_{ii} - \frac{Y_{ij}Y_{ji}}{Y_{jj} + Y_L}$.

2.3 Coarse Model of Coupling–based on MOM

The fine model of antenna coupling based on MOM is a numerical model and this model has high precision, but it needs more computer time. Sometime we needn't to get high precision result but need to get approximate result use little computer time, so we need to find a coarse model.

Two segments like shown in figure 1, in MOM their impedance can also be calculated use formula (3)

$$Z_{ij} = j\omega\mu\Delta l_i \cdot \Delta l_j \cdot \Phi(i,j) + \frac{1}{j\omega\varepsilon}[\Phi(i1,j1)$$

$$-\Phi(i2,j1) - \Phi(i1,j2) + \Phi(i2,j2)] \quad (3)$$

in this formula

$$\Phi(i,j) = \frac{1}{4\pi\Delta l_i}\int_{j1}^{j2}\frac{e^{-jkR_i(z)}}{R_i(z)}dz \quad (4)$$

and R is the distance between tow antenna segments. According to different precision request we can get varied approximate formation of formula (4). Substituting those approximate formulas of (4) into formula (3) we may work out the impedance between any two antenna segments. Finally we can use the expression

$$Y_{ij} = \frac{1}{Z_{ij}}$$

to calculate the corresponding conductance and then can use expression (2) to calculate approximate antenna coupling.

3.Model of Antenna Position Optimization

In 2th section we have introduced two kinds of models of antenna coupling via MOM. Now we should give the model of antenna position optimization. When we optimize the positions of antennae our intention is to keep the coupling of the whole multi-antenna system at the lowest level. Basing on the coupling models we can constitute the position optimal model shown as follows.

$$\begin{cases} f(\Psi) = \sum_{i=1}^{m} w_i C_i(\Psi_1^i, \Psi_2^i, \Psi_3^i......) \\ \Psi_{1\min}^i \le \Psi_1^i \le \Psi_{1\max}^i \\ \Psi_{2\min}^i \le \Psi_2^i \le \Psi_{2\max}^i \\ \Psi_{3\min}^i \le \Psi_3^i \le \Psi_{3\max}^i \\ .... \end{cases} \quad (5)$$

In expression (5) $C_i(\Psi^i)$ is the coupling of a couple of antennae and it's the function of the coordinate variables of antenna location. w_i is the weigh function relating to $C_i(\Psi^i)$ and $\Psi = \{\Psi_1, \Psi_2, \Psi_3......\}$ is the vector of the solution we are seeking for.

4.Optimal Algorithms

From section 3 we may find that if we choose the fine model of antenna coupling as $C_i(\Psi^i)$ the optimal process may take too much computer time or the process can not be realized at all. If we choose coarse model as $C_i(\Psi^i)$ the optimal process can be realized easily but may has low precision. To deal with this problem we have find a new effective optimal algorithm called Space Mapping Algorithm(SMA). In SMA the fine model and coarse model are both taken into account so this kind of algorithm have not only high precision but also speediness. SMA should be executed in the follow steps:

step 0: Find optimal solution in coarse domain

Φ_c^* and go to step 1 or step 4.

step 1: Generate base points of fine model

$$B_f = \{\Phi_f^1, \Phi_f^2 ......\Phi_f^m\}$$

and find fine model responses

$$R_f(\Phi_f^i) \quad i = 1,2,......,m.$$

step 2: Extract base points of coarse model

$B_c = \{\Phi_c^1, \Phi_c^2 ......\Phi_c^m\}$ and evaluate

the expression $\left\| R_f(\phi_f) - R_c(\phi_c) \right\| \le \varepsilon$,

(R_c is the response of coarse model).

step 3: Find the transformation

$\Phi_c = P_j(\Phi_f)$, Φ_c is an vector of coarse model parameters and Φ_f is of fine model. Φ_c and Φ_f have the same physical sense as Ψ in expression (5).

step 4: Find $\Phi_f^{m_j+1}$ from $\Phi_f^{m_j+1} = p_j^{-1}(\Phi_c^*)$.

step 5: Find $R_f(\Phi_f^{m_j+1})$.

step 6: If $\left\| R_f(\Phi_f^{m_j+1}) - R_c(\Phi_c^*) \right\| \le \varepsilon$ go to step 7

else add $\Phi_f^{m_j+1}$ to B_f and go to step 2.

step 7: $\overline{\Phi}_f = \Phi_f^{m_j+1}$.

step 8: Stop.

According to the theory about SMA have been introduced above we can see the key technique of SMA is to find the mapping P from coarse domain to fine domain by interactive process.

In SMA optimal coarse model solution Φ_c^* should be found firstly. In this paper we find it by using Simple Genetic Algorithm. While using SGA we implement follow principles:

(1). Binary coding.

(2). Roulette wheel selection.

(3). One-point crossover.

(4). Binary mutation.

5.Numerical Example

There is an example of antenna optimization process. The target antenna system is going to be installed on the top of a communication cabin fixed on vehicle. The cabin dimension is $4 \times 3 \times 2\, m^3$ and 3 VHF antennae will be fixed on its top. Because some other electronic devices have been installed in the interior and 2 of the 3 antennae have been installed at one edge of the top so we should find the optimum site to fix the *3*th antenna to keep the coupling of this 3-antenna system at the lowest level. We assume the antenna system work at 200MHz(at other frequency the optimal process is same as this one). The optimal variables are the coordinates x and y of antenna sites.

Using the execution parameters shown in table 1 SGA can work out

$$\Phi_c^* = (-1.50, -2.00)$$

in one generation and spend 2-4 seconds.

Table 1.SGA execution parameters

Population size	
Maximum	30
generation	100
Cross rate	0.6
Mutation rate	0.03
Chromosome	20
length	

In general the optimal solution of coarse model Φ_c^* is very close to the optimal solution of fine model so we can choose original bases of fine model in the vicinity of Φ_c^*. We choose the original base of fine model as

$$\Phi_f^1 = (-1.40, -1.90)$$

and $\varepsilon = 0.1$ then SMA take 2 interactive steps to get the optimal solution of fine model

$$\bar{\Phi}_f = (-1.48, -1.98)$$

. We can see that this solution meet the request

$$\left\| R_f(\bar{\Phi}_f) - R_c(\Phi_c^*) \right\| = = 0.098 < 0.1 .$$

Table 2 shows the optimal process, in table 2 the length is expressed in meter and coupling is expressed in dB.

Table 2:optimal process

	x	y	C12	C13	C23	$f(\Phi)$
Step0	-1.40	-1.90	-28.886	-35.192	-29.666	-93.744
Step1	-1.47	-1.97	-28.861	-35.036	-30.340	-94.237
Step2	-1.48	-1.98	-28.871	-34.628	-31.099	-94.598

In fact the steps that the interactive process of SMA takes depend mostly on the choice of the original base of fine model and the precision of the two models. For example, if we choose Φ_c^* as the original base of fine model then SMA will use only one step to find out the optimal solution of fine model

$$\bar{\Phi}_f = \Phi_f^1 = \Phi_c^* = (-1.50, -2.00)$$

and this solution meets the request

$$\left\| R_f(\bar{\Phi}_f) - R_c(\Phi_c^*) \right\| = = 0.087 < 0.1 .$$

If the coarse model has poor precision and the original base of fine model is badly chosen the interactive steps may become more.

Earlier we found an optimal antenna position of the same case use probing method by executing the program of fine model should spend some days but use SMA only spent 4 hours. When we use SMA because the fine model of MOM is a numerical model so it spent 99% computer time. We realized the optimal process on the computer which has intel processor P III 700 MHz.

Finally we show data of the optimal position and some other positions in table 3.By studying the data shown in table 3 we can see that the optimal position we have got by using SMA is the best one.

Table3: optimal position and comparative positions.

	X	y	C12	C13	C23	$f(\Phi)$
op	-1.48	-1.98	-28.871	-34.628	-31.099	-94.598
p1	1.50	-2.00	-28.861	-31.099	-34.618	-94.578
p2	0.00	-2.00	-28.618	-32.496	-32.496	-93.610
p3	-1.50	0.00	-28.539	-31.654	-26.733	-86.926
p4	0.00	0.00	-29.202	-27.743	-28.234	-85.179

6.Conclusions

In this paper we firstly give two models of antenna coupling, based on those two models we gave an antenna position optimization method. To the author's knowledge, this method is a novel antenna position optimization technique.

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