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Antenna Electromagnetic Compatibility Layout Optimization Simulation Based on CST-PSO Hybrid Method

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Introduction

With the increasing demand of communication, the modern electronic equipment is equipped with more and more wireless communication devices. However, due to the complex electromagnetic characteristics of different devices and the limited space of the carrier, the antenna of the device is usually closely installed on the surface of the carrier, which makes the electromagnetic compatibility (EMC) problem between the antennas more and more prominent. Coupling degree between antennas is the most important index for evaluating electromagnetic compatibility of multi-antenna systems. The smaller the coupling degree, the better the electromagnetic compatibility of the antennas. Therefore, in order to make the wireless device can communicate normally, it is necessary to optimize the layout of the antenna system to reduce the coupling degree of the entire antenna system.

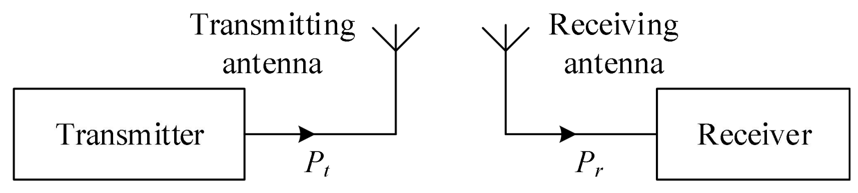
In this paper, a hybrid CST-PSO method is proposed to solve the layout optimization problem of antenna system. In this hybrid method, the simulation calculation of coupling degree is based on the electromagnetic simulation software CST, which is widely used to analyze different electromagnetic problems. The layout optimization simulation of antenna system is based on the particle swarm optimization (PSO), which has been widely used to solve antenna optimization problems because its simple principle and strong universality. The effectiveness of the hybrid method is proved by the simulation analysis of a typical multi-antenna system. The simulation results show that the hybrid method can effectively optimize the layout and reduce the coupling degree of multi-antenna systems through the interactive simulation of PSO and CST.

Theory of CST-PSO Hybrid Method

CST Simulation of Antenna Coupling

Coupling degree between antennas can be typically described by the ratio of the antenna's received power P_r and the antenna's transmitting power P_t:

$$C = 10\log\left(\frac{P_r}{P_t}\right)$$



According to the microwave network theory, a multi-antenna system can be regarded as a generalized multi-port network, each antenna corresponding to one port of a generalized network, and the coupling degree between antennas can be represented by transmission parameter S_{ij} of multi-port network:

$$C = S_{ij}(\text{dB}) = 10\log\left(\left|S_{ij}\right|^2\right)$$

where S_{ij} indicates the transmission coefficient of port j to port i when all ports except port j are connected to match load.

By establishing the whole model of system platform and antenna structure using CST, the transmission parameters S_{ij} can be solved, which are used to measure the coupling degree of the two antennas.

Optimization Model of Antenna Layout

The goal of the antenna layout optimization is to reduce the coupling degree of the entire antenna system, which is a typical multi-objective optimization problem. Multi-objective optimization problems can be described as the following mathematical model:

$$\begin{cases} F(x) = \min\left[F_1(x), F_2(x), \cdots F_L(x)\right]^T \\ s.t. x \in X \\ X \subset R^m \end{cases}$$

The most important factor affecting the coupling of the antenna is the geometric position between the antennas. Therefore, based on the geometric position of the antenna as the independent variable and the total coupling degree of the antenna system as the dependent variable, an optimization model of antenna layout is established in this paper. Simultaneously considering the optimization layout of antennas in various frequency bands, the weight coefficient variation method is adopted to transform the multi-objective optimization problem into a single objective problem. The final optimization model is as follows:

$$\min F(\Phi, FB_n) = \sum_{n=1}^{N} w_n F_n(\Phi, FB_n)$$

$$F_n(\Phi, FB_n) = \sum_{k=1}^{K} \sum_{i=1, j=1, i\neq j}^{M} a_{ij} S_{ij}(FB_n^k)$$

$$\Phi = (P_1, P_2, \cdots, P_m)^T = \left\{(x_1, y_1, z_1), (x_2, y_2, z_2)\cdots, (x_m, y_m, z_m)\right\}^T$$

CST-PSO Hybrid Method

In the hybrid method, the PSO method program is based on the MATLAB, and the PSO is utilized to control the CST to solve the antenna electromagnetic compatibility layout problem.

According to the PSO method, the collection Φ of antenna positions to be optimized corresponds to the particle number, the number of optimization variables is equal to dimension of particle, and the target function $F_n(\bullet)$ corresponds to the fitness value of particle. The specific steps of CST-PSO method are as follows:

Step 1: Simulation model preprocessing in CST. The position coordinates of the CST antenna simulation model are set as parameter variables to be optimized.

Step 2: PSO algorithm initialization. According to the position coordinate variable in CST, it mainly includes dimension (the number of optimization variables), the range of optimization variables, maximum speed, the number of iterations, particle number and so on.

Step 3: Running the PSO algorithm program, recording the settings and parameters.

Step 4: MATLAB calls the CST simulation through ActiveX. According to the current position of the particle, the simulation model is updated to calculate the coupling degree of the antennas.

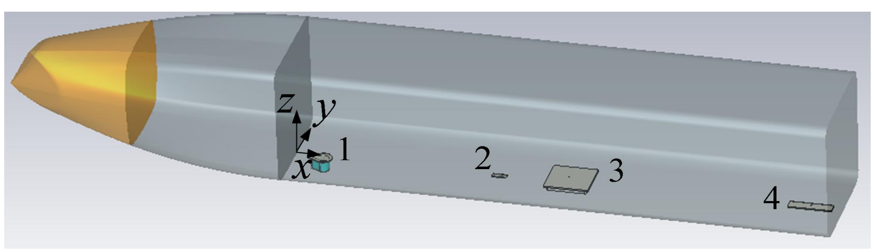
Step 5: Reading the coupling degree results from CST. PSO algorithm calculate the fitness value of the corresponding particle position.

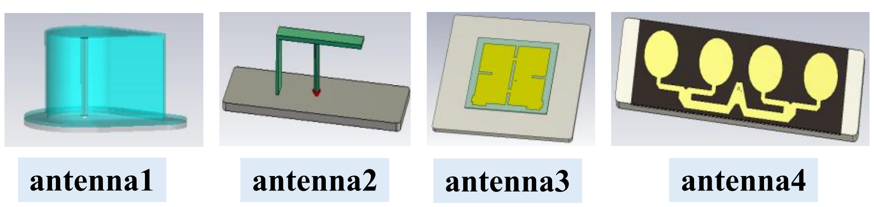
Step 6: Determining whether it satisfies termination conditions of the program depending on the fitness value and the current number of iterations. If it satisfies conditions, stop the program. If it doesn't satisfy conditions, update the particle position and return to step 4.

Antenna Electromagnetic Compatibility Layout Optimization Simulation

The Simulation Model

Four antennas are installed in the bottom area of the carrier cabin, and all the antennas are installed in the middle of the surface (antenna positions can only move along the x-axis) to prevent affecting the antenna performance.





Working characteristics of antennas

Antenna	Working frequency	Working mode	Initial position coordinate
Antenna 1	1.35GHz~1.55GHz	Receiving and transmitting	(100，0，0)mm
Antenna 2	1.65GHz~1.85GHz	Receiving and transmitting	(800，0，0)mm
Antenna 3	2.2GHz~2.3GHz	Only transmitting	(1080，0，0)mm
Antenna 4	4.2GHz~4.4GHz	Only receiving	(2000，0，0)mm

Potential interference antenna pairs

Transmitting antenna	Receiving antenna	Simulation frequency bands
Antenna 1	Antenna 2	1.65GHz~1.85GHz
Antenna 1	Antenna 4	4.2GHz~4.4GHz
Antenna 2	Antenna 1	1.35GHz~1.55GHz
	Antenna 1	1.35GHz~1.55GHz
Antenna 3	Antenna 2	1.65GHz~1.85GHz
	Antenna 4	4.2GHz~4.4GHz

Layout Optimization Simulation Analysis

Due to the fact that all antennas can only move along the x-axis, there are four position variables to be optimized, namely $\Phi = \{x_1, x_2, x_3, x_4\}$. There are three optimized frequency bands, namely FB_1(1.35GHz~1.55GHz), FB_2(1.65GHz~1.85GHz), FB_3(4.2GHz~4.4GHz). The antenna coupling degree to be optimized are $S_{21}(FB_2)$, $S_{41}(FB_3)$, $S_{12}(FB_1)$, $S_{13}(FB_1)$, $S_{23}(FB_2)$, $S_{43}(FB_3)$. Considering the equal importance of the coupling degree of each antenna pairs and frequency band, the weighting coefficient w_n and a_{ij} are evenly distributed. Target function to be optimized can be simplified as follows:

$$\min F(\Phi, FB_n) = \frac{1}{6}\left[S_{21}(FB_2) + S_{41}(FB_3) + S_{12}(FB_1) + S_{13}(FB_1) + S_{23}(FB_2) + S_{43}(FB_3)\right]$$

In the PSO program, the range of x_i(i=1, 2, 3, 4) is set to be [50, 2100]mm. The particle number is equal to 8, the dimension of each particle is equal to 4 and the number of iterations is equal to 30. The minimum value of objective function is calculated by PSO program. The comparison results of coupling degree between the initial layout and the optimal layout are shown in table. The optimized x coordinates of antenna 1, 2, 3, 4 are1350, 150, 2000, 590 respectively.

Transmitting antenna	Receiving antenna	Simulation frequency bands	Initial layout	Optimal layout
Antenna 1	Antenna 2	1.65GHz~1.85GHz	-35dB	-55dB
Antenna 1	Antenna 4	4.2GHz~4.4GHz	-70dB	-60dB
Antenna 2	Antenna 1	1.35GHz~1.55GHz	-37dB	-60dB
	Antenna 1	1.35GHz~1.55GHz	-65dB	-55dB
Antenna 3	Antenna 2	1.65GHz~1.85GHz	-36dB	-90dB
	Antenna 4	4.2GHz~4.4GHz	-70dB	-72dB
	Summation		-313dB	-392dB

Through the above optimization simulation analysis, it can be seen that compared with the initial antenna layout, antenna pairs with high initial coupling degree have been greatly optimized, and the total coupling degree of the layout after optimization decreases by 79dB, significantly improving the electromagnetic compatibility of antenna system.

Conclusion

In this paper, aiming to analyze the electromagnetic compatibility layout optimization of the multi-antenna system, a hybrid CST-PSO method is proposed. The CST is used to calculate the coupling degree by simulating the S parameters of multi-antenna system, and the PSO method program based on MATLAB is used to control the CST to carry out iterative optimization simulation. The hybrid method has been successfully applied to a typical carrier antenna layout case. By iterative optimization simulation, the total coupling degree of the entire antenna system decreased by 79dB compared with the original layout, which proves that the hybrid method has certain significance for guiding the layout optimization design of multi-antenna system.