Frontiers in Power and Energy Systems (2024) **DOI: 10.23977/fpes.2024.030106**
Clausius Scientific Press, Canada **ISSN 2516-2926 Vol. 3 Num. 1**

Intelligent Ship Antenna Electromagnetic Compatibility Analysis and Optimal Placement

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Keywords: Electromagnetic compatibility, Coupling effects, Antenna, Layout

Abstract: The rapid development of technology has led to the integration of more and more electronic information equipment on the same carrier platform. Due to the limited space area of aircraft, ships, vehicles, ground rescue robots and other carrier platforms, the coupling effect between equipment and equipment and complex platforms may lead to a significant decline in equipment performance, and even affect its normal work. Therefore, whether to ensure the electromagnetic compatibility of electronic information equipment in a limited space area, and improve its performance as much as possible, it becomes a key issue to determine the performance of the platform. Combined with the basic principles of antenna layout, this paper distinguishes and describes them with whip mobile communication 1#antenna, microstrip 2#antenna and rubber respectively. For the three antennas, different coupling degrees are derived by changing the distance between the antennas. The absolute value of the coupling degree is required to be no less than 35dB. The spacing coupling degree of 1# and 2#antennas, the 1# and 3#antennas, and 2# and 3#antennas are analysed at 2-4GHz and 8-12GHz or 0.8-1.5GHz respectively, and the optimal position distance is finally obtained.

1. Introduction

In recent decades, the rapid development of science and technology has promoted the upgrading and strengthening of the information technology level of various application platforms[1]. In order to improve performance, save power consumption and facilitate use, more and more electronic information equipment is integrated into the same carrier platform, but the space area of these carrier platforms is limited, and the electromagnetic environment has become more and more complex, thus requiring the continuous high-speed development of electronic information equipment.

New technologies in modern society continue to develop, and more and more electronic equipment is installed on a limited number of work platforms. There are many antennas on this limited working platform, and these antennas have many different types and operate in many frequency bands, etc. Differences will make the electromagnetic environment on the platform more complex[2]. Therefore, how to improve the electromagnetic compatibility[3] for the intelligent boat platform is an inextricable problem. In order to solve this problem, electromagnetic compatibility technology is widely used, there are space layout, frequency control and other methods. Among them, for the EMC problem of antenna system, space isolation is an effective solution. Through reasonable antenna layout and spatial isolation, the mutual interference between antennas can be minimized, so as to effectively achieve electromagnetic compatibility between antenna systems. In practical applications, the space of the antenna carrier platform is limited, which requires that the antenna layout must be highly compact and flexible. Therefore, while considering the electromagnetic compatibility of the antenna system, it is also necessary to ensure that the space utilization between the antennas is maximized, especially in the space-constrained environment, it is more necessary to design the antenna position distance carefully.

2. Inter-Antenna Coupling Analysis

The same two pairs of antennas are placed on the surface rescue robot as shown in Figure 1, and the distance between the two pairs of antennas is 100mm.

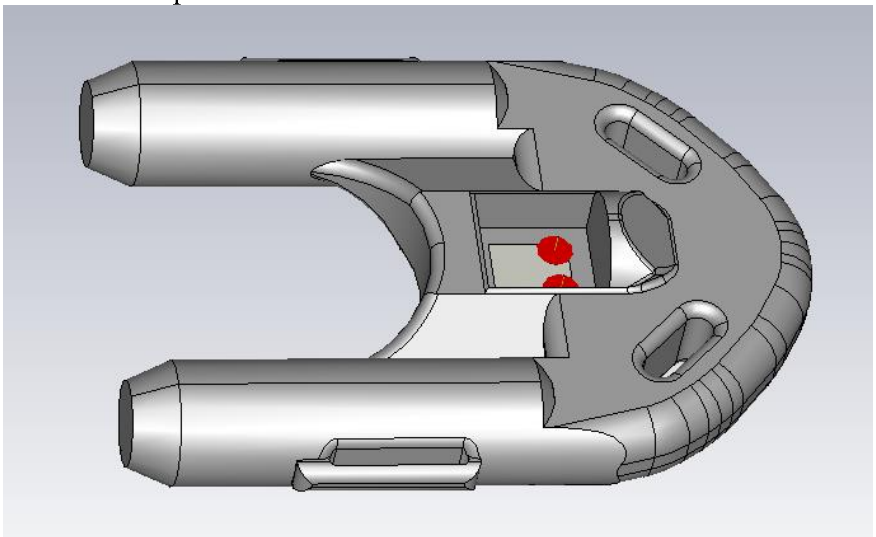

Figure 1: Antenna placement on the surface rescue robot

Since most of the antenna frequencies in this study are above a few GHz, at this time, the size of the surface rescue robot is much larger than the antenna wavelength, which belongs to the electrically large size, which requires high computational power of the computer during the simulation process and takes more time. In order to facilitate the processing, the high-frequency asymptotic solver of CST is selected, and the simulation results can be obtained accurately and efficiently by using the combination of the method of bouncing ray (SBR) and the equivalent field source

The biggest advantage of the field source is that all the closed surface is placed as a vacuum, without considering the internal structure, as if the circuit theory of Davignan's theorem, for a number of independent voltage sources, any number of independent current sources and any number of resistors composed of a one-port network, the network of all the characteristics of the external circuit can always be used in the port at both ends of an independent voltage source and a resistor in series to be completely equivalent. .

The use of equivalent field sources in electromagnetic simulation software allows the field sources to be seen as a link between the small and large electric algorithms, i.e., between the full-wave and high-frequency algorithms. In CST, the full-wave algorithm is used to calculate the field source first, and then the high-frequency algorithm is used to calculate the full-field problem of a complex three-dimensional structure, so that after structural segmentation, two simulations of the two structures are carried out, and two independent algorithms are flexibly combined to obtain the simulation results efficiently and accurately.

The biggest advantage of the field source in the principle of equivalence is that all the closed surface is placed in a vacuum, without having to consider the internal structure, as if the circuit theory of Davignan's theorem, for a number of independent voltage sources, any number of independent current sources, as well as any number of resistors composed of a one-port network, all the characteristics of the network to the external circuit can always be used in the port at both ends of an independent voltage source and a resistor in series to be completely equivalent.

According to the relevant requirements of electromagnetic compatibility design, when multiple antennas are placed on the same platform, there should be strong compatibility between antennas, and in order to prevent interference, the absolute value of spatial attenuation between one transmitting antenna and another receiving antenna should not be less than 35dB, and it is better to reach 45dB.In this paper, we take the upper limit of the coupling degree of -50dB, and analyze the coupling between antennas of the water surface lifesaving robot.

There are three kinds of antennas studied in this paper. Three sets of antennas do the experiment in pairs.

3. Antenna System Coupling Simulation Calculation

Electromagnetic coupling between antennas refers to the existence of mutual inductance between two or more pairs of antennas, which makes the electromagnetic energy changes between antennas affect each other. As shown in Fig.2, when the receiving antenna receive the electromagnetic wave emitted by the transmitting antenna, electromagnetic coupling exists between the two pairs of antennas. This is usually expressed in terms of the coupling degree:

$$C = 10log\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) \tag{1}$$

In Eq. 1, C (dB) is the electromagnetic coupling between antennas; the net output power of the receiving antenna; and the net input power of the transmitting antenna.

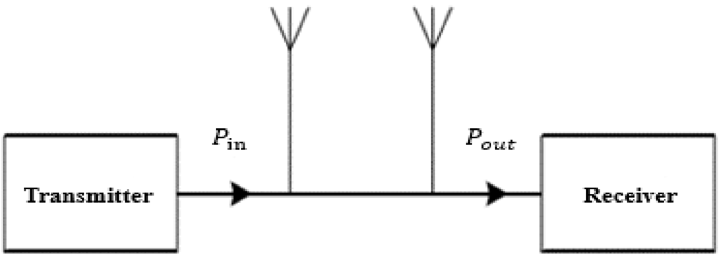

Figure 2: Schematic diagram of antenna coupling.

As shown in Fig. 3, according to the knowledge of microwave network, the two pairs of antennas (transmitting and receiving antennas) system (Fig.1) can be equivalent to a two-port network. The transmitting antenna is connected at port 1 and the receiving antenna is connected at port 2, when the antenna at port 2 has a network matching state[4-6].

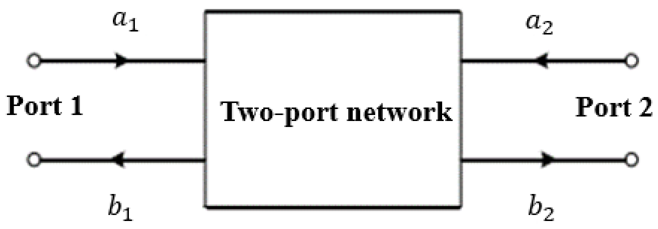

Figure 3: Two-port equivalent network.

From Fig. 3, the S-parameter matrix of the two-port network is:

$$\begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = \begin{pmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \end{pmatrix} \tag{2}$$

The output power of port 2 is:

$$P_{\text{out}} = \frac{1}{2}|b_2|^2 \tag{3}$$

The output power of port 1 is:

$$P_{in} = \frac{1}{2}|a_1|^2 - \frac{1}{2}|b_1|^2 \tag{4}$$

Since port 2 is in impedance matching state:

$$\frac{P_{\text{out}}}{P_{\text{in}}} = \frac{\frac{1}{2}|b_2|^2}{\frac{1}{2}|a_1|^2 - \frac{1}{2}|b_1|^2} = \frac{|S_{21}|^2}{1-|S_{11}|^2} \tag{5}$$

When port 1 is also matched, $S_{11} = 0$, the resulting coupling between the antennas is

$$C = 10log\left(|S_{21}|^2\right) \tag{6}$$

The derivation process of the above formula is completed under ideal conditions, and its setting condition is the ideal matching of port impedance. However, the ideal matching state in engineering practice is not achievable, there will be some energy reflection between the antenna and the port, and the coupling between antennas calculated by the formula has some errors. However, when using CST software to simulate the coupling between antennas[7], it is equivalent to the mutual coupling of the receiving antennas in the range of its operating band, and the default antenna is in the ideal matching state, so the coupling can be obtained directly by using the formula[8-9].

4. Antenna Coupling Analysis

4.1. 1# and 2# Antenna Coupling Analysis

In order to better grasp the effect of different antenna spacing on antenna coupling, by analyzing the antenna coupling at different distances, the distance between 1# and 2# antennas is set as x. The data and curves shown in Table 1 and Fig. 4 are obtained, and the relationship between 1# and 2#

antenna spacing and coupling is as follows.

Table 1: Relationship between 2-4GHz 1# and 2# antenna spacing and coupling (dB)

Frequency /GHz	Interval /mm					
	30	40	50	60	70	80
2	-48.82	-51.45	-53.80	-56.14	-58.76	-59.57
2.2	-44.56	-47.27	-49.88	-52.42	-55.28	-57.57
2.4	-41.38	-43.76	-46.32	-48.92	-51.57	-55.02
2.6	-39.03	-41.07	-43.44	-46.04	-48.31	-51.85
2.8	-37.33	-39.17	-41.46	-44.17	-46.37	-48.68
3	-36.39	-38.15	-40.44	-43.43	-45.91	-47.61
3.2	-36.04	-37.61	-39.78	-43.01	-46.56	-48.51
3.4	-32.26	-37.23	-38.76	-41.50	-45.38	-50.64
3.6	-37.62	-37.73	-38.24	-39.94	-42.74	-47.13
3.8	-39.19	-39.35	-39.16	-40.08	-42.08	-45.69
4	-39.41	-40.75	-40.54	-40.99	-42.40	-44.90

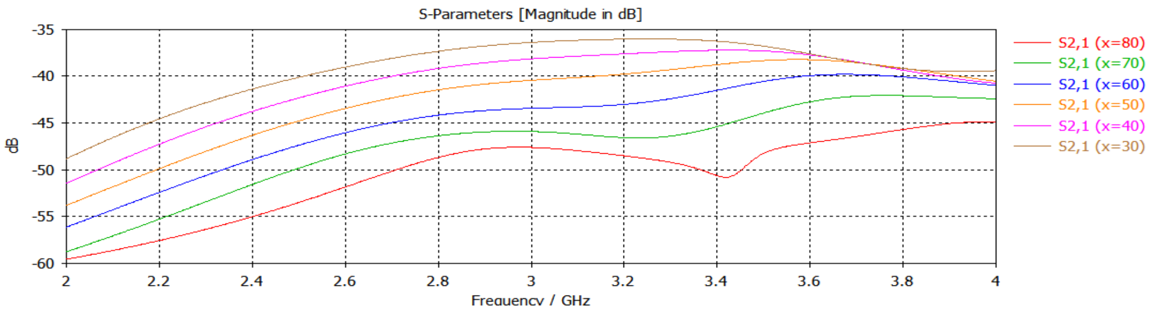

Figure 4: Relationship between 2-4GHz 1#and 2# antenna spacing and coupling degree graph.

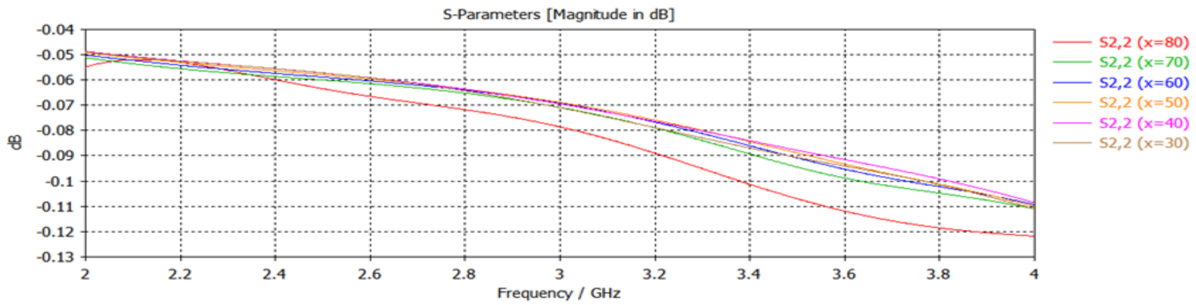

Figure 5: 2-4GHz2# antenna sparameter diagram.

According to the coupling degree change curves of 1# and 2# antennas at different distances in Fig. 4, it can be seen that the coupling degree is decreasing with the increase of distance in the 2-4 GHz band. In the full frequency band with a distance of 30mm to 80mm, the coupling degree of the two antennas is less than -35dB, indicating that the mutual interference between them has been relatively small. When the distance is increased to 80mm, the curve in Fig. 4 tends to stabilize, and the coupling of the two antennas is basically less than -50dB, which has basically met the relevant coupling requirements. In addition, the coupling degree of the two antennas in Fig. 4 is relatively small, which is related to the electromagnetic characteristics of the antenna. The sparameters of antenna #2 in the 2-4 GHz band in Fig. 5 also confirm this conclusion. It can be seen that the sparameter of 2# antenna is basically in this frequency band, and basically does not radiate electromagnetic waves. Therefore, the coupling between 2# antenna and other antennas is relatively small and basically meets the coupling requirements.

Table 2: Relationship between 8-12GHz 1# and 2# antenna spacing and coupling (dB)

Frequency /GHz	Interval /mm					
	30	40	50	60	70	80
8	-43.07	-45.96	-48.04	-47.40	-47.95	-49.53
8.5	-48.79	-47.65	-53.53	-59.25	-54.76	-53.63
9	-61.25	-55.53	-58.44	-70.34	-60.87	-56.88
9.5	-47.28	-49.52	-53.36	-68.51	-56.28	-51.42
10	-47.95	-51.68	-56.33	-61.43	-52.99	-52.05
10.5	-53.60	-59.02	-61.74	-72.33	-58.11	-58.75
11	-54.19	-58.98	-77.60	-64.44	-60.28	-61.33
11.5	-56.48	-57.76	-63.37	-68.07	-63.56	-64.90
12	-59.52	-59.63	-61.04	-70.55	-68.29	-62.45

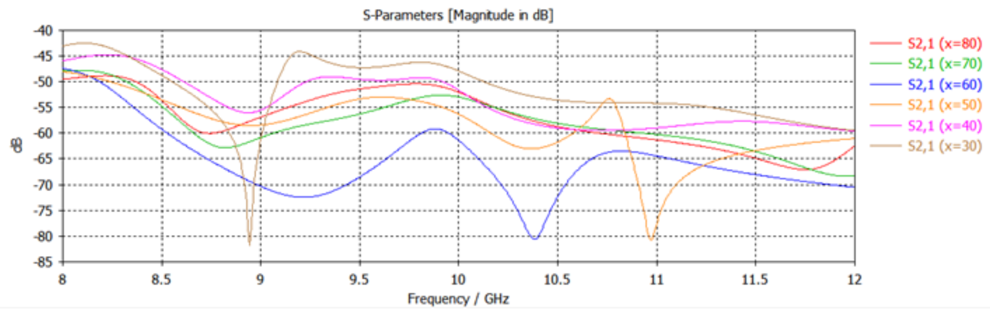

Figure 6: Relationship between 8-12GHz 1# and 2# antenna spacing and coupling degree graph.

In Table 2 and Fig. 6, the coupling of antenna #1 and antenna #2 in the 8-12 GHz band is depicted. The coupling between these two pairs of antennas is small relative to the 2-4 GHz band. However, unlike the monotonically decreasing coupling with distance in the 2-4 GHz band, the coupling varies slightly in the 8-12 GHz band, which is not only affected by the distance of the antennas, but also by the frequency. When the distance between the two is greater than 30mm, the frequency in 9-12GHz, the coupling of the two antennas is strictly less than -50dB, from the figure can also be seen, when the distance between the two antennas is 60mm, the coupling between the two antennas in the full band reaches the minimum, to meet the requirements.

4.2. 1# and 3# Antenna Coupling Analysis

Table 3: Relationship between 2-4GHz 1# and 3# antenna spacing and coupling (dB)

Frequency /GHz	Interval /mm					
	30	40	50	60	70	80
2	-23.08	-24.83	-27.70	-27.73	-26.57	-25.20
2.2	-20.47	-24.20	-26.39	-27.91	-26.89	-24.35
2.4	-19.46	-23.05	-25.84	-27.00	-26.31	-24.40
2.6	-19.35	-22.96	-25.86	-28.61	-28.76	-26.25
2.8	-18.58	-21.44	-23.43	-25.68	-29.03	-28.40
3	-17.72	-20.25	-22.24	-24.16	-26.92	-28.59
3.2	-17.73	-20.25	-22.23	-25.17	-26.91	-28.59
3.4	-19.32	-20.97	-23.02	-25.94	-28.13	-28.66
3.6	-21.14	-22.32	-24.13	-27.27	-30.23	-29.74
3.8	-20.87	-21.30	-23.92	-27.19	-29.51	-30.01
4	-22.60	-23.46	-25.71	-29.51	-30.20	-32.16

By analyzing the antenna coupling at different distances and setting the distance between antennas 1# and 3# as x, the data and curves shown in Table 3 and Fig. 7 are obtained, and the following is the relationship between antenna spacing and coupling between antennas 1# and 3#.

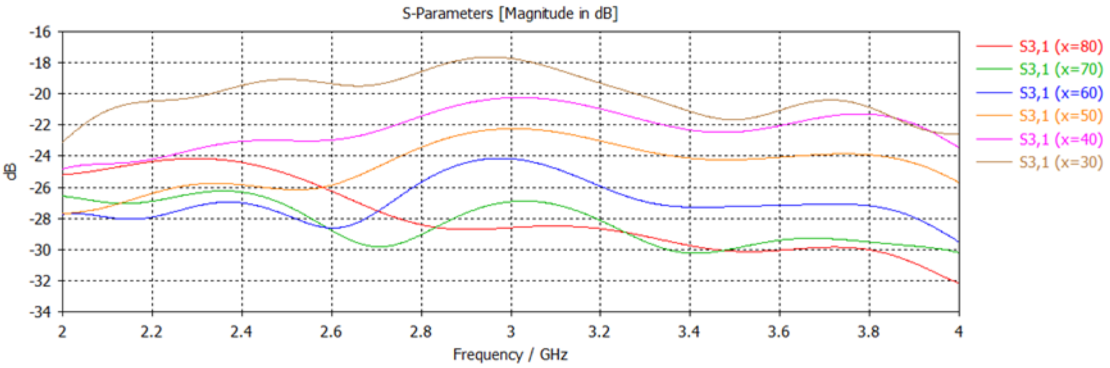

Figure 7: Relationship between 2-4GHz 1# and 3# antenna spacing and coupling degree graph.

According to the above simulation results Table 3 as well as Fig. 5, it can be seen that the coupling phenomenon between 1# antenna and 3# antenna in the frequency band of 2-4GHz should not be neglected, and the coupling gradually decreases with the increase of distance. Although the interaction between them is weakened as the distance increases, the relative positions between them still have a significant effect on their interaction, and the coupling between these two pairs of antennas is still quite serious. Especially at the resonance point of the 1# whip antenna at 3 GHz, the coupling between the two antennas is -17.72 dB when the distance is 30 mm, and the coupling further decreases to -28.58 dB when the distance is increased to 80 mm. although the coupling between the two antennas has reached its minimum value of -32.16 dB when the distance is 80 mm, the coupling does not reach the standard of -35 dB, and there is still a serious mutual interference problem.

The analysis of the above simulation results shows that the coupling between the two antennas is more serious, and the reason is mainly related to the performance of the two antennas. Firstly, the whip antenna and the rubber antenna have similar electro-magnetic characteristics. Secondly, the distance of 80 mm is small relative to the wavelength in the frequency band, which leads to more significant mutual interference between the two antennas. In addition, the frequency and type of antenna also have an effect on the level of mutual interference.

Table 4. Relationship between 0.8-1.5GHz 1# and 3# antenna spacing and coupling (dB)

Frequency /GHz	Interval /mm					
	30	40	50	60	70	80
0.8	-28.14	-31.29	-33.83	-36.02	-37.11	-37.72
0.9	-26.34	-29.16	-31.37	-33.15	-34.58	-35.51
1	-24.85	-27.15	-28.88	-30.27	-31.30	-32.04
1.1	-23.19	-24.76	-25.89	-26.77	-27.44	-27.91
1.2	-21.97	-22.99	-23.68	-24.24	-24.66	-24.98
1.3	-21.61	-22.50	-22.90	-23.13	-23.28	-23.38
1.4	-21.59	-22.80	-23.07	-23.02	-22.82	-22.61
1.5	-21.34	-23.25	-23.64	-23.30	-22.81	-22.27

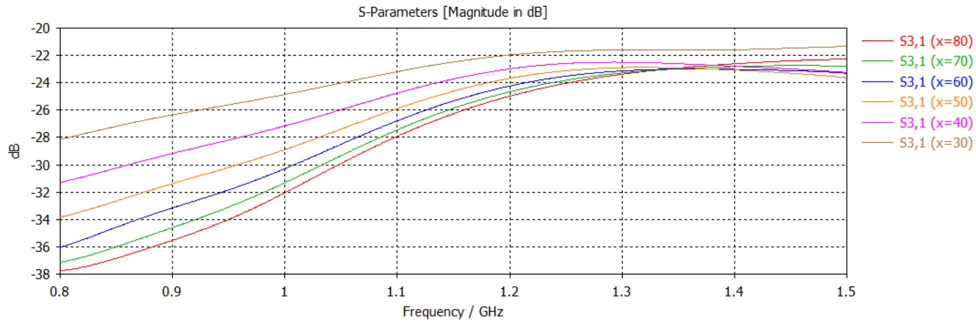

Figure 8: Relationship between 0.8-1.5GHz 1# and 3# antenna spacing and coupling degree graphs.

Table 4 and Fig. 8 give the relationship between antenna spacing and coupling between antenna 1# and antenna 3# in the 0.8-1.5GHz band. When the distance between the two is 70mm and 80mm, the coupling degree is below -35dB, which shows that the mutual interference of antennas in the 0.8-1GHz band is small, and the other bands still cannot meet the standard requirements.

Through the results of the above data analysis, it can be concluded that in the intelligent ship platform, simply increasing the distance between antennas 1# and 3# cannot effectively reduce the degree of coupling between them, because the interaction between them is still quite significant at a distance of 80mm. Therefore, in order to reduce the level of mutual interference, other measures are needed to ensure the stability and performance of the system. One possible solution is to utilize the harmonic suppression capability of the transmitter.

In addition, spectrum management techniques can be utilized to avoid frequency interference. By adjusting and planning the frequency and power of individual antennas, it is possible to minimize their interactions and to keep them operating independently of each other while maintaining system performance.

4.3. 2# and 3# Antenna Coupling Analysis

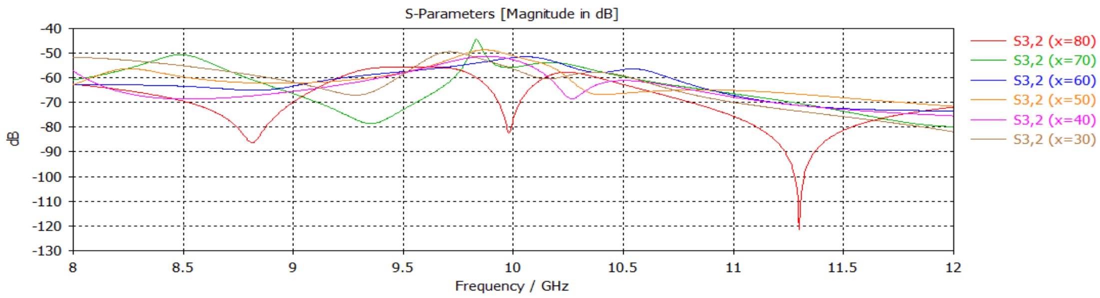

Figure 9: 8-12GHz2# and 3# antenna spacing and coupling relationship graph.

Table 5: Relationship between 8-12GHz 2# and 3# antenna spacing and coupling (dB)

Frequency/GHz	Interval /mm					
	30	40	50	60	70	80
8	-51.68	-58.31	-62.89	-62.97	-60.91	-62.63
8.5	-55.18	-68.65	-59.66	-63.47	-50.71	-69.50
9	-61.83	-65.54	-62.18	-63.40	-66.49	-69.85
9.5	-58.53	-58.08	-57.86	-57.53	-72.88	-55.79
10	-56.50	-52.76	-51.15	-51.84	-55.80	-76.90
10.5	-59.24	-61.16	-66.32	-56.69	-59.59	-62.78
11	-69.97	-67.83	-65.11	-67.18	-66.49	-75.64
11.5	-75.75	-72.84	-68.12	-72.48	-73.59	-81.29
12	-81.94	-75.48	-71.60	-73.46	-79.84	-71.90

Table 6. Relationship between 0.8-1.5GHz 2# and 3# antenna spacing and coupling (DB)

Frequency /GHz	Interval /mm					
	30	40	50	60	70	80
0.8	-52.96	-54.68	-56.26	-58.05	-59.08	-58.98
0.9	-52.62	-53.92	-55.24	-56.77	-57.95	-58.59
1	-53.26	-53.93	-54.85	-55.96	-56.80	-57.51
1.1	-54.07	-53.63	-53.62	-53.66	-53.53	-53.11
1.2	-51.60	-52.37	-52.15	-51.55	-50.40	-49.04
1.3	-48.32	-50.68	-51.85	-51.92	-50.38	-48.34
1.4	-46.51	-48.91	-50.90	-52.39	-51.69	-49.45
1.5	-45.59	-47.52	-49.37	-51.29	-51.81	-50.52

The distance between antennas 2# and 3# as x, the data and curves shown in Table 5 and Fig.7 were obtained, and the following is the relationship between antenna spacing and coupling between antennas 2# and 3#.

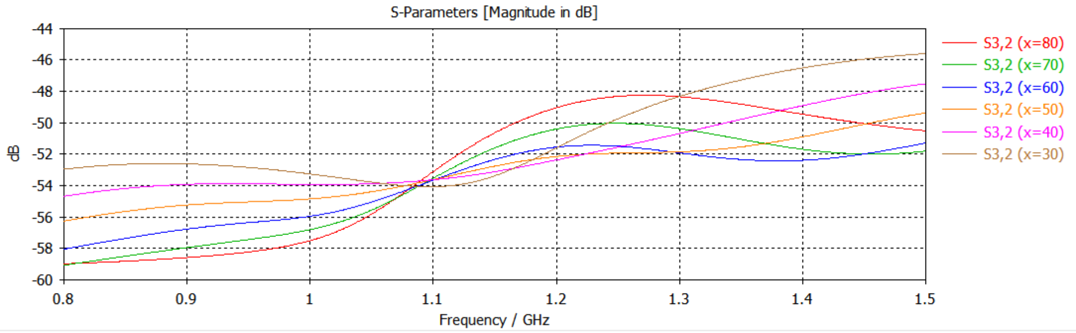

Figure 10: Relationship between 0.8-1.5GHz 2# and 3# antenna spacing and coupling degree graphs

The simulation results in Table 5 and Fig.9 show that the coupling between antenna 2# and antenna 3# is not monotonically decreasing with increasing distance in the frequency band. But the coupling between both antennas is less than. The coupling between the two antennas is much less than -35 dB in the distance range of 30 mm to 80 mm, which indicates that the mutual interference between antennas 2# and 3# is relatively small in the frequency band of 8-12 GHz, and the distance between the two antennas does not have a great influence on the mutual interference. Although the coupling degree may vary in different distance ranges, in general, the interaction between them does not greatly affect the performance of the system[10-11].

According to the simulation results in Table 6 and Fig.10, we can find that the antenna coupling in the 0.8-1.5 GHz band is more significant compared to the coupling between the two antennas, 2# antenna and 3# antenna, in the 8-12 GHz band. In this band, the coupling between the two antennas is not monotonically decreasing with increasing distance, but slightly undulating with frequency. However, the coupling decreases with increasing distance in the 0.8-1.1 GHz band, and the values of the coupling are all strictly less than -50dB.

According to the data shown in Table 6, when the two antennas are separated by 60 mm and 70 mm, the coupling between them is less than -50dB, which is in accordance with the coupling requirements.

5. Conclusions

Firstly, the equivalent source method is introduced, which can greatly reduce the simulation time and computer memory resources under the premise of guaranteeing the accuracy in electromagnetic simulation software; then the changes of the directional map when the antenna is placed in different carriers and the influence of different materials on the antenna gain are analyzed; finally, taking the inter-antenna coupling degree of less than -50dB as the criterion, the study of the change of two-two antenna coupling degree with the distance is made, and the minimum limiting distance to satisfy the criterion is given.

According to the above antenna system coupling simulation analysis, it can be seen that: 1# antenna and 2# antenna in 2-4GHz, the distance between the two antennas is 80mm when the coupling degree reaches the minimum, in the 8-12GHz, the two antennas distance of 60mm when the coupling degree is the minimum; 1# antenna and 3# antenna in the 2-4GHz, the distance between the two antennas is 70mm when the coupling degree is the minimum, in the 0.8-1.5GHz, the two antenna distance of 80mm when the minimum coupling; 2 # antenna and 3 # antenna in 8-12GHz and 0.8-1.5GHz, the two antennas at any distance coupling is less than -50dB, any distance coupling is very small to meet the requirements.

Acknowledgements

Research on key technologies for improving energy efficiency of green intelligent electric tugboats (Grand T4023)

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