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Bin Xiao

Lidong Chi

Fuhai Li

James L. Drewniak
Missouri University of Science and Technology, drewniak@mst.edu

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/5170

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Passive Testing of Electrically Small Antennas in Electronic Systems

Bin Xiao
Hunan University
Changsha, China
xbsxy007@hnu.edu.cn

Lidong Chi, Student Member, IEEE
LinkE Technologies Co., Ltd.
Zhuhai, China
565548254@qq.com

Fuhai Li, Senior Member, IEEE
Hunan University
Changsha, China
lifuhai@hnu.edu.cn

James L. Drewniak, Fellow, IEEE
Missouri University of Science and Technology
Rolla, MO, USA
drewniak@mst.edu

Gang Feng, Member, IEEE
LinkE Technologies Co., Ltd.
Zhuhai, China
gang.feng@linketech.cn

Yihong Qi, Fellow, IEEE
LinkE Technologies Co., Ltd.
Zhuhai, China
yihongqi@gmail.com

***Abstract*—In this paper, a measurement scheme, which eliminates the interference of the common mode current, for electrically small antennas is proposed. Firstly, the causes and effects of common mode currents appearing in passive testing are analyzed. Then, the influence of different outlet points of coaxial cable on the passive testing of antenna is studied experimentally and numerically. According to the distribution of the common mode currents on the ground plane when the coaxial cable feeds the antenna, the minimum current point is selected as the outlet point of the coaxial cable to reduce the influence of common mode current. Additionally, the influence of the coaxial cable's arrangement and the soldering area between coaxial cable and ground plane on the antenna under test is studied. Finally, considering the output point, arrangement and soldering area of the coaxial cable, a measurement scheme to improve the passive measurement accuracy of the electrically small antenna is proposed.**

Key Words—passive test, common mode current interference, coaxial cable

I. Introduction

In the design of wireless system, four points need to be considered: 1) antenna selection, 2) antenna layout, 3) the layout of other sensitive electronic systems, and 4) size, industrial design and aesthetics of antennas and systems. Once the system and antenna design are complete, it is essential to conduct passive testing of the antenna to verify and evaluate its performance.

However, inaccurate passive measurement can lead antenna designers to design the wrong antenna solution. Therefore, improving the accuracy of the passive test of the antenna can provide early verification for the design of the wireless system, improve the confidence of the system design, and provide a basis for the decomposition of system indicators.

Antennas that fed by unbalanced feeding structures can introduce common mode currents flowing outside the grounded structure. These common mode currents can degrade the antenna's performance, leading to an offset int the operating frequency and a deterioration of radiating performance. A dipole antenna fed by an ideal lumped port is shown in Fig. 1(a). In this case, I_{b1} equals to I_{b2}, where the antenna functions well. Fig. 1(b) shows the other case of an unbalance fed dipole antenna, which is fed by a coaxial cable. As shown in the figure, a part of I_{b2} flows along the shielding layer of the coaxial cable and becomes the common mode current I_{b3}.

When measuring an antenna, the passive measurement value obtained in the relatively complete whole machine environment (including the ground plane) is closer to the value under the actual working conditions of the antenna. It is important to ensure that the actual measurement is conducted in the whole environment to obtain accurate results. However, due to the influence of common mode current, different measurement methods will destroy the original electromagnetic environment. Therefore, there is a large deviation between the test results and the results in actual working situation.

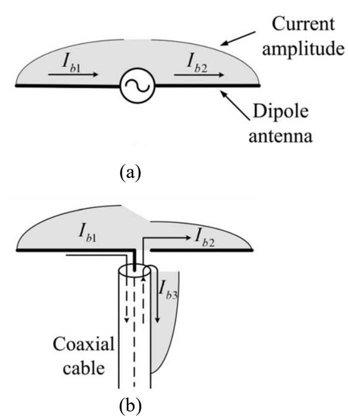


Fig. 1. Generation of common mode current.

Several measures have been proposed to reduce common mode current interference. For example, the ferrite chokes were used around the front end of the cable to absorb the energy on the outer surface of the cable, so as to reduce the additional radiation of the cable [1]. However, the disadvantage of the chokes is that they reduce the radiated power of the antenna. Alternatively, current baluns were used to suppress the induced current flowing onto the outer surface of the cable [2]-[4]. Furthermore, L-shaped slotting on both sides of the phone ground plane was used to suppress the common mode current [3]. The handset antenna is a kind of electrically small antenna. which suffers from the interference of common mode current in passive measurement. A measurement method of handset antennas was proposed in [5], where the influence of outlet points of feeding coaxial cable on the tested mobile phone antenna under test was investigated. The cell phone antenna test solution with the least influence by the transmission cable was finally obtained after experimental comparison.

However, it does not explain how to select the optimum outlet point of transmission lines.

For this point, an accurate measurement scheme, which can eliminate the influence of the common mode current, for electrically small antennas is proposed in this paper. The arrangement of feeding coaxial cable is to be investigated based on the current distribution on the ground plane.

II. Description of Testing Scheme

Taking a 2.4 GHz inverted-F antenna as a test object. The short point of the antenna is connected to the ground plane on the dielectric substrate. The feeding point is connected to the inner core of the coaxial cable, while the outer surface of the coaxial cable is soldered to the ground plane near the feeding point. The current distribution on the ground plane when the antenna is fed by the coaxial cable at 2.4GHz is simulated in HFSS software. A 50 mm × 90 mm × 1 mm copper-clad printed circuit board (PCB) is used to simulate the ground plane of the system, and the current distribution is shown in Fig. 2. According to the different outlet point of the coaxial cable, the antenna feeding scheme is divided into Feeding Scheme 1 (FS1) and Feeding Scheme 2 (FS2). In FS1, the coaxial cable takes the point of maximum current on the ground plane as the exit point. In FS2, the coaxial cable takes the point of minimum current on the ground plane as the exit point. In both the FS1 and FS2, the shielding layer of the coaxial cable is soldered only on the feeding point and the exit point.

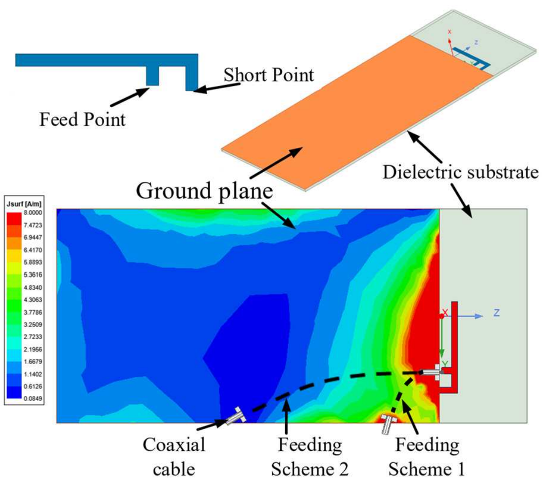


Fig. 2. Feeding schemes of the inverted-F antenna.

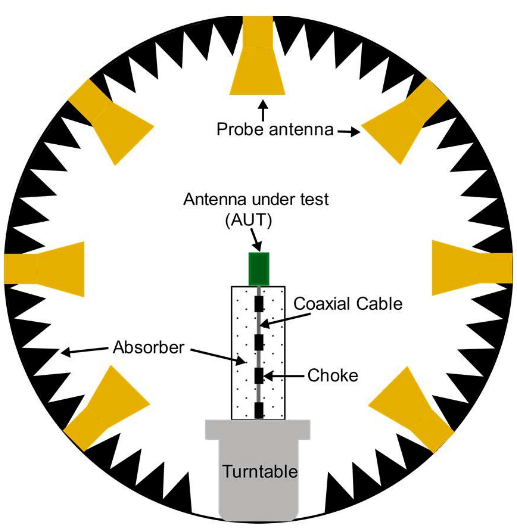


Fig. 3. Multi-probe antenna measurement anechoic chamber.

Table I . Study of the Effects of the Test Scheme on the AUT

	FS*	Return Loss	Current Distribution	Radiation Pattern
AUT	0	Simulated	Simulated	Simulated
	1	Measured		Measured
	2	Measured		Measured

* FS: Feeding Scheme (Fig. 1)— 0: simulation.

The return loss of the antenna is measured with an E5071C network analyzer. The SMA output port is calibrated. The length of signal cable is 2 m. The far-field radiation patterns, gain and efficiency are measured in a anechoic chamber ($3\,m \times 3\,m \times 2.97\,m$), which is a multiprobe test system as shown in Fig. 3, ranging from 0.4 GHz to 7.5 GHz. The chokes and absorbing materials in the dark room serve to prevent additional radiation from the signal cable and avoid the uncertainty of the cable on the AUT (antenna under test).

In addition, to verify the measurement results, HFSS software based on FEM (finite element method) is used to simulate the return loss and radiation performance of AUT. An ideal lumped port is used to excite the coaxial cable which feeds the antenna.

III. Results and Discussion

In the study, the effects of the testing schemes on the performances of the AUT, such as operating frequency, radiation pattern, gain, and efficiency are investigated.

A. Operating Frequency Versus Feeding Schemes

Fig. 4 shows the measured and simulated return loss ($|S_{11}|$), where the S_{11} minimum point frequency is 2.3 GHz for FS1, 2.39 GHz for FS2, and 2.4 GHz for the simulation. FS2 is consistent with the simulation, while FS1 is shifted by 100MHz compared to the simulation results.

Hence, selecting the outlet point of the coaxial cable on the ground with minimum current can reduce the impact of common mode current on the antenna operating frequency.

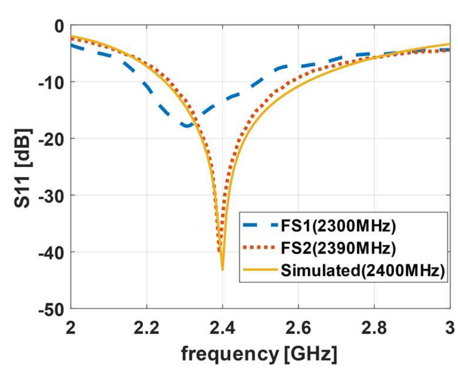


Fig. 4. Measured and simulated return losses of AUT (FS1 versus FS2).

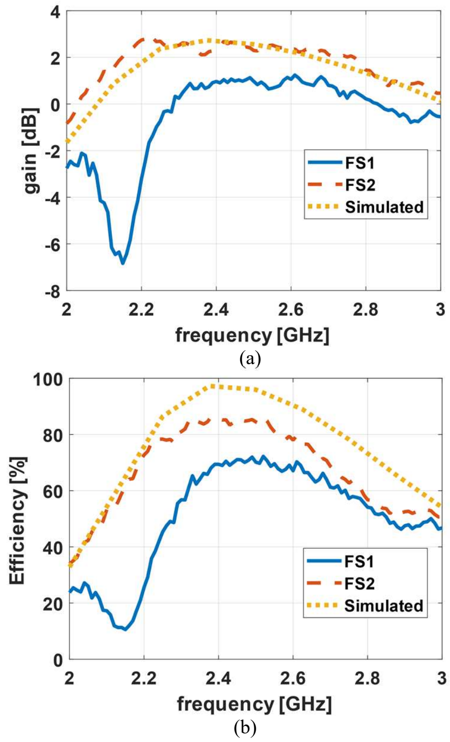


Fig. 5. Variation of antenna efficiency with frequency for different feeding schemes (FS1 versus FS2).

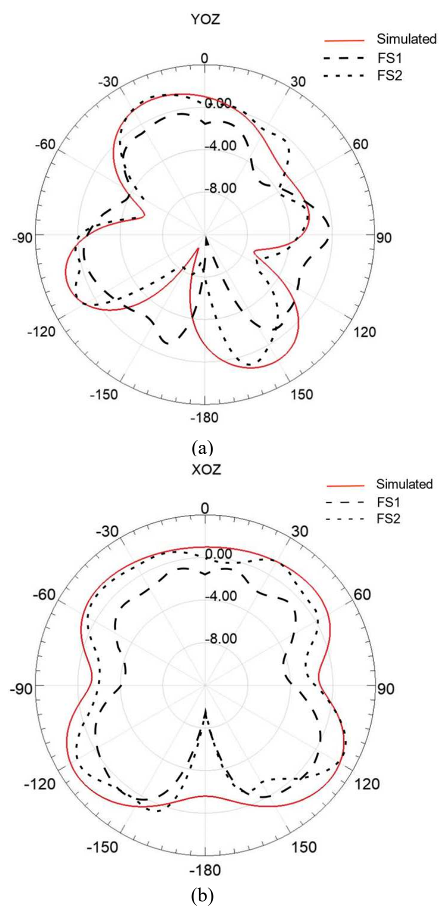


Fig. 6. Radiation patterns of different feeding schemes of AUT (FS1 versus FS2).

Table II. COMPARISON OF THE EFFECTS OF TEST SCHEMES ON EFFICIENCIES AND GAINS

	FS*	Efficiency (%) of AUT/ f(MHz)	Gain (dB) of AUT/f(MHz)
AUT	0	96.98%/2400	2.69/2400
	1	65.8%/2300	0.66/2300
	2	82.4%/2390	2.50/2390
	3	76.7%/2360	1.36/2360
	4	66.2%/2335	3.17/2335

* FS: Feeding Scheme (Fig. 1)— 0: simulation.

B. Radiation Performance

Fig. 5(a) and (b) show the efficiency and gain results of AUT under different feeding schemes. Compared with FS1, FS2 has higher gain and efficiency in the range from 2 GHz to 3 GHz. The curve of FS2 is closer to the simulation than FS1. Meanwhile, it can be seen from Table II that FS2 has 82.4% efficiency and 2.5 dB gain at the antenna operating frequency, while FS1 has 65.8% efficiency and 0.66 dB gain respectively. The simulation has an efficiency of 96.98% and a gain of 2.69 at the operating frequency. From the results, the efficiency and gain of FS2 are closer to the simulated value compared to FS1.

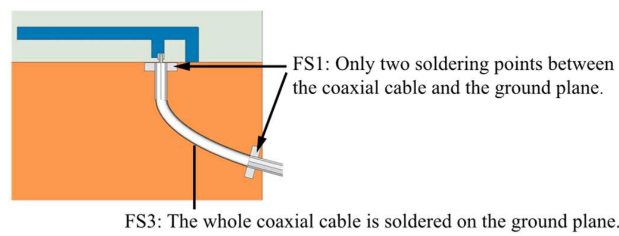


Fig. 7. Differences between FS1 and FS3.

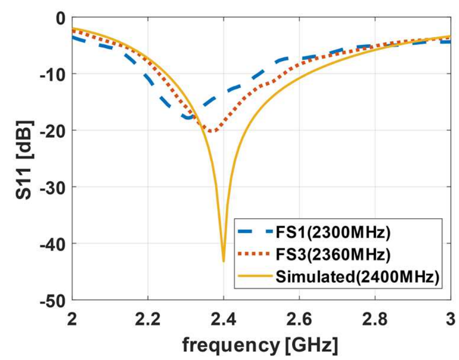


Fig. 8.Measured and simulated return losses of AUT (FS1 versus FS3).

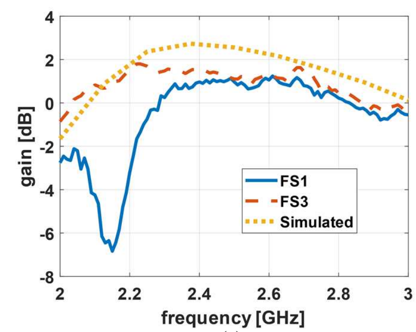
Fig. 6(a) and (b) show the radiation patterns of XOZ and YOZ planes of AUT under different feeding schemes. Compared to the FS1, the radiation patterns of FS2 are more consistent with the simulated radiation patterns. The maximum difference between the radiation pattern of FS1 and the simulated pattern in the YOZ plane even exceeds 6 dB.

As a result, the choice of coaxial cable outlet point can affect the accuracy of antenna passive test. Adopting feed scheme 2 can achieve accurate measurement of antenna performance.

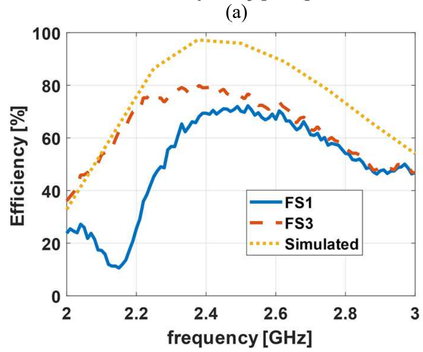
C. Optimization Experiment of FS1

The influence of the solder area between the coaxial cable and the ground plane on the AUT is also studied. The feed scheme 3 (FS3) is obtained through improvement of the feeding scheme 1, where all parts of the coaxial cable ranging from the feeding point to the outlet point are soldered to the ground plane, as shown in Figure 7. The improvement is in purpose of decreasing the interference introduced by the coaxial cable.

It can be seen from Fig. 8 that the operating frequency point of FS3 is closer to the simulation value than FS1. From Fig. 9, the efficiency and gain of FS3 are closer to the simulated results compared to FS1 in the 2 GHz to 3 GHz frequency range. From Table II, the gain of FS3 at the operating frequency point is 0.7 dB higher than that of FS1, and the efficiency is 10.9% higher. It can be seen from Fig. 10(a) and (b), in the XOZ and YOZ planes, the radiation pattern of FS3 is closer to the simulation than that of FS1, especially in the XOZ plane.

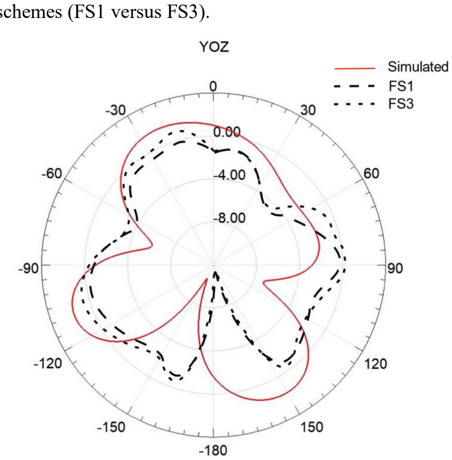


(a)

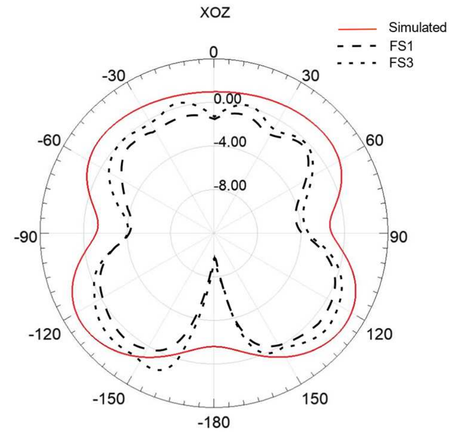


(b)

Fig. 9. Variation of antenna gain and efficiency with frequency for different feeding schemes (FS1 versus FS3).

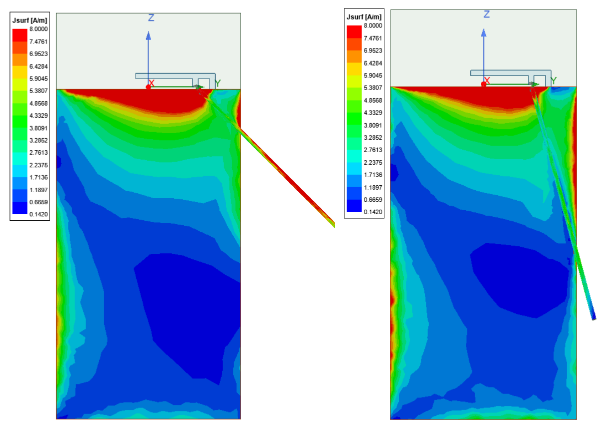


(a)



(b)

Fig. 10. Radiation patterns of different feeding schemes of AUT (FS1 versus FS3).



(a) (b)

Fig. 11. Simulated current distributions on ground plane and coaxial cable's outer surface with different FSs. (a) FS1. (b) FS2.

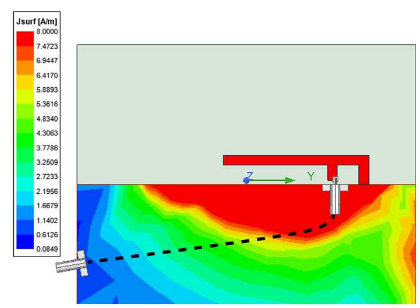


Fig. 12. Feeding Scheme 4

Thus, increasing the soldering area between the coaxial cable and the ground plane can reduce the influence of the common mode current interference to the passive measurement.

D. Currents Distributions of FS1 and FS2

The current distribution of FS1 and FS2 at 2.4G is simulated in HFSS software. From the comparison of Figure 11, it is found that the current on the outer surface of the coaxial cable in FS1 is significantly more than that in FS2.

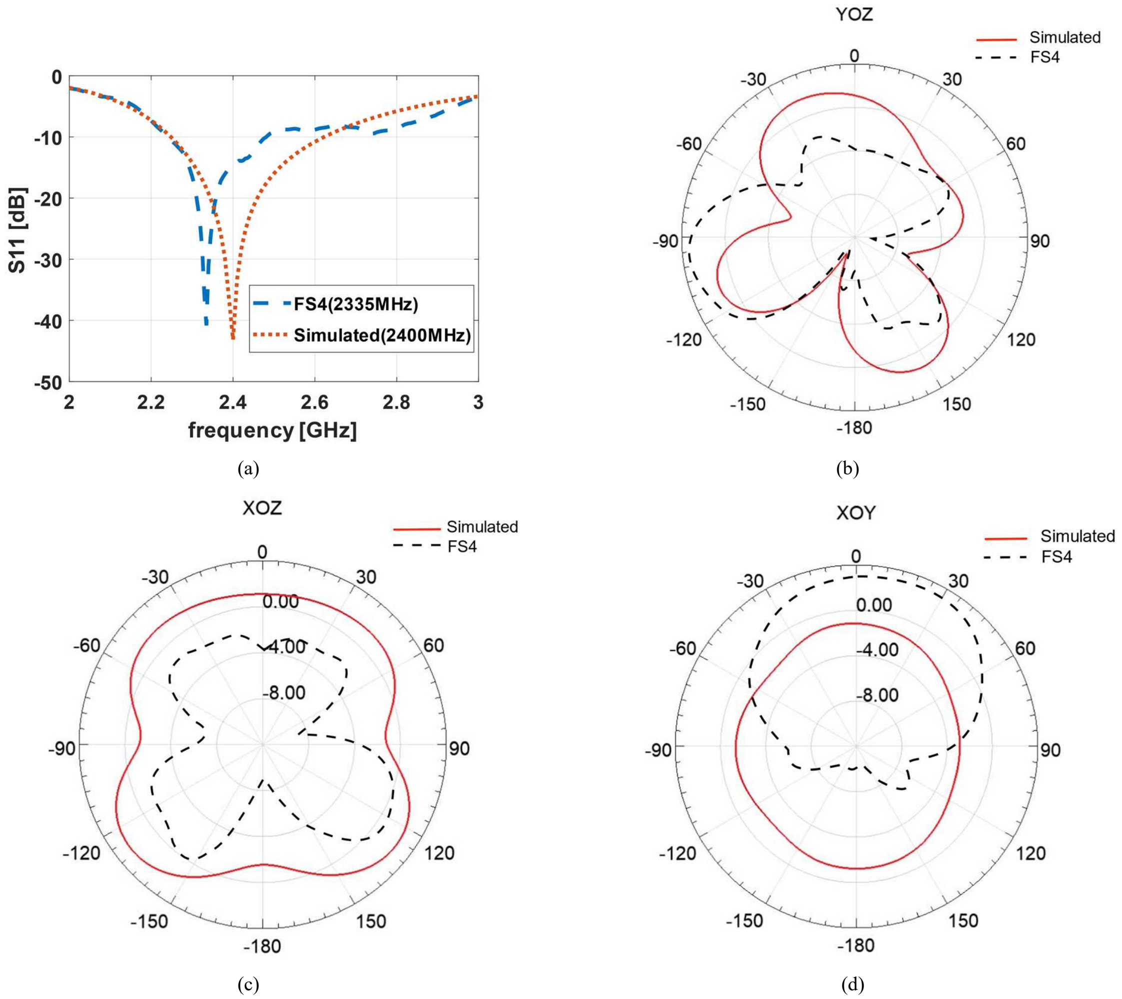


Fig. 13. Measured return losses and radiation patterns of AUT by feeding scheme 4.

In actual measurement, these currents flow into the outer surface of the coaxial cable in the anechoic chamber, effectively turning it into another radiator. This radiation can have a significant impact on the test results of the antenna under test, such as operating frequency, radiation pattern, gain, etc.

In addition, the weak current on the outer surface of the coaxial cable in FS2 makes the operating frequency and radiation patterns of FS2 almost the same as the ideal situation, as shown in Figure 4 and Fig. 6 (a) - (b).

E. Impact of Coaxial Cable Arrangement

In addition to the size of common mode current on the surface of the coaxial cable, the arrangement of the coaxial cable can also greatly affect the test results.

Feeding Scheme 4 is shown in Fig. 12. Change the coaxial cable arrangement to make it similar as FS1 close to antenna, and take the minimum current point on the other side of the ground plane as the outlet point.

As can be seen from Fig. 13 (a), the operating frequency of FS4 has shifted. More importantly, because the entire coaxial cable is almost parallel to the antenna polarization direction and very close to the antenna (less than one wavelength), the current on the cable is actually composed of two parts: common mode current and antenna coupled to the cable current. The coaxial cable and the measured antenna produce strong coupling, and the radiation generated by the current on the outer surface of the cable interferes with the radiation generated by the antenna, which deteriorates the measured antenna pattern, as shown in Fig. 13 (b)-(d), especially in YOZ plane (E plane) and XOY plane. The test results of antenna gain and efficiency are also affected. As shown in Table 2, the gain of FS4 is 3.17, higher than the simulated 2.69, and the efficiency is 66.2%.

Therefore, in the passive test of the antenna, the feeding cable should be as perpendicular as possible to the main polarization direction of the measured antenna, like FS2, to avoid strong coupling with the antenna, especially the part close to the antenna.

IV. Conclusion

In this paper, different test schemes are proposed to study the influence of common mode current on antenna radiation performance. Based on the simulation and measurement, the following three points can be obtained:

1) In passive testing of antennas, leading the coaxial cable from the point of minimum current can suppress the impact associated with the coaxial cable.

2) Increasing the soldering area between the coaxial cable and the ground plane can restrain the relevant impact of common mode current interference to the passive measurement.

3) The feed cable should be perpendicular to the main polarization direction of the antenna under test as much as possible, especially the part close to the antenna.

Consequently, this paper proposes such a testing method to minimize the common mode current on the signal cable and its interference with the tested mobile antenna. Firstly, obtain the current distribution on the ground plane of the system through simulation. Secondly, take the point with the minimum current as the feed cable's outlet point, while keeping the cable perpendicular to the main polarization direction of the antenna. Finally, add soldering points between the coaxial cable and the ground plane.

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