Modeling and Analysis of Electrical Connectors in Salt Spray Environment

Lin Guan[1,*], Yuanlong Li[2], Chendi Feng[1], Qingya Li[1], Yuqi Zhou[1] and Jinchun Gao[1]
[1]School of Electronic Engineering,
[2]Automation School, Beijing University of Posts and Telecommunications, Beijing 100876, China
[*]Corresponding author

Abstract—As a basic component, electrical connectors play a major role in the transmission and control of electric signals. In this paper, SubMiniature version A (SMA) coaxial connectors, which are widely used in the microwave equipment and radio frequency circuits, were taken as the research objects to investigate the degradation of electrical connectors in salt spray environment. The simulation model was built to analyze the failure mechanism. An accelerated test was conducted to study its electrical contact properties and obtain the degradation data. The experimental and simulation results showed consistent trends. Accordingly, the degradation of the high-frequency performance for the electrical connector in the salt spray environment is mainly due to the formation of corrosion film on the contact surface.

Keywords—electrical connectors; modeling; salt spray test

I. INTRODUCTION

There are many electronic components in the communication systems. The performance of each component will affect the properties of the entire system. Electrical connector is an electronic element that interconnects the transmission media of a system, whose main function is to realize the transmission and control of electric signals. It is easily affected by the external environment, resulting in functional degradation or even totally failure [1]. Therefore, it is important to study its performance trends under various stresses.

Contact resistance is an important indicator to characterize the performance of the connector. The increase of contact resistance will directly affect the reliability of the signal transmitted by the electrical connector. When the contact resistance rises to a certain extent, it can cause failure. There are many factors that affect the contact resistance of electrical connector. Kong [2] found that the contact resistance of electrical connector would jump after plugging and unplugging and concluded that plugging would speed up the degradation of the electrical connector. Luo [3] established a simulation model and found that the maximum equivalent stress value was affected by both temperature softening and thermal stress enhancement, resulting in increased contact resistance and degradation of connector performance. In addition, the reliability of the electrical connector under vibration stress was researched by Pan [4], and expressed which in a statistical model. Moreover, the influence of dust, plating material selection and other factors on contact resistance had also been studied.

High-frequency parameter, such as return loss, is also the critical test items in ensuring the normal use of the connector [5]. With the development of high-speed interconnections, the clock frequency is constantly being improved. The limited propagation speed and fluctuation phenomenon of the electromagnetic field began to appear. At this time, the circuit theory applied at low frequencies had become insufficient. In order to systematically evaluate the performance, the high-frequency parameters of electrical connector must be taken into account.

In the coastal areas, the change of performance of electrical connector is significantly different from that in other regions, which is mainly determined by the variation of the salt spray concentration.

In this paper, an accelerated test was designed to measure the contact resistance and high frequency parameters, and a simulation model was built to systematically analyze the degradation mechanism of electrical connectors under the salt spray environment.

II. EXPERIMENTAL SETUP

The failure mode of the electrical connector is mainly contact failure, manifested as the increase of the contact resistance [6]. As the exposure to salt spray increases, the contact surface of electrical connector will be gradually corroded. The accelerated test controls other variables and only changes the time that the connectors are exposed to salt spray.

A. Samples and Experimental Instruments

A national standard salt spray test chamber (Figure I) was used for testing. 24 SMA-KFK-1 connectors were placed in the test, and the droplets accumulated on the top of the chamber were to be prevented from falling on the sample.

B. Experimental Procedures

In this paper, the concentration of salt spray is used as the accelerated stress, and the performance degradation of electrical connector is studied by using a constant stress for accelerated test.

According to GB/T 2423.17 and GJB360A standards [7, 8], we choose one of the most widely used accelerated corrosion test method - neutral salt spray test (NSS test). The NSS test requires that the temperature be within (35±2) °C, the humidity should be greater than 95%, the fogging amount should be 1~2mL/80cm*h, and the nozzle pressure should be 78.5~137.3kPa. In a neutral salt spray test chamber, salt water

containing (5 ± 0.5) % sodium chloride and having a pH of 6.5 to 7.2 was sprayed through spraying devices to allow the salt mist to settle on the samples to be measured. After 24h of spraying, the solution collected by each collector should be 1 to 2 mL/h for 80 cm^2. In this environment, 24 samples were randomly selected and placed in a test chamber for testing. The placement of test sample is as shown in Figure II.

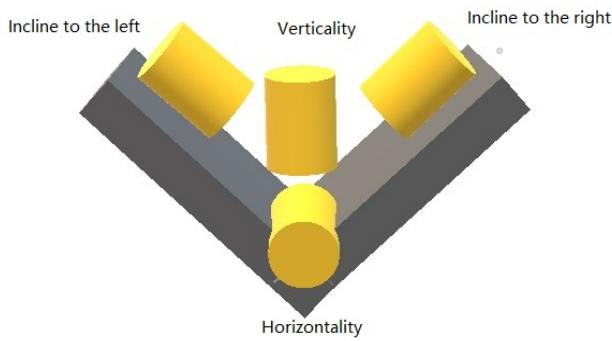FIGURE I. THE SIMULATION MODEL OF SMA-KFK1 CONNECTOR

FIGURE II. THE PLACEMENT OF SAMPLES

As shown in Figure II, there are four cases:

a) Horizontally: The cross section of the connector is parallel to the vertical direction of the salt solution tank.

b) Vertically: The cross section of the connector is vertical to the vertical direction of the salt solution tank.

c) Incline to the left: The cross section of the connector is placed at an angle to the vertical direction of the salt solution tank.

d) Incline to the right: The cross section of the connector is placed at an angle to the vertical direction of the salt solution tank.

During the test, the contact resistance of the connector was measured with a micro-ohmmeter and the high-frequency S-parameter was measured with a vector network analyzer. Each parameter change was measured every 48 hours and a total of 6 groups of data were obtained.

III. MODELING AND DEGRADATION MECHANISM ANALYSIS

The simulation uses the CST three-dimensional electromagnetic field simulation software based on FDTD (finite-different time-domain), which is suitable for simulating broadband spectrum results. The simulation sample is a SMA-KFK-1 connector, consisting of contact body, insulator and housing. The material of the contact body and the housing is copper, and the material of the insulator is polytetrafluoroethylene (PTFE). The simulation frequency is ranging from 0 to 10 GHz.

A. Simulation Model

The SMA-KFK1 coaxial RF connector was cut open and measured. Modeling and simulation are based on related technical manuals. The simulation diagram is shown in Figure III.
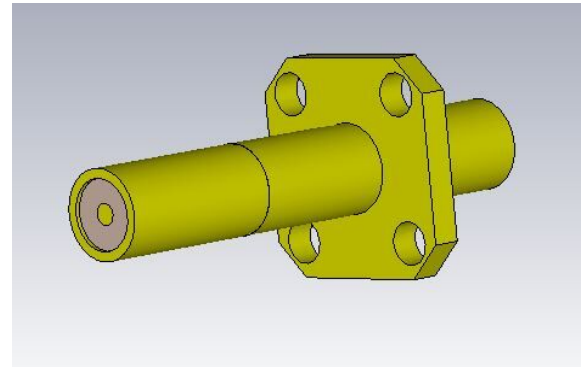

FIGURE III. THE SIMULATION MODEL OF SMA-KFK-1 CONNECTOR

In Figure III, the yellow parts are the housing and contact body, and the white part is the insulator.

B. Degradation Analysis

Connector failure depends on whether the corrosion is within the allowable ranges following the degradation mechanism. The changes in the contact area of the connector will change its contact resistances. The chloride ions in the salt spray penetrate the fine protective coating of the metal surface and react with the internal metal to produce corrosion. The formation of corrosion products expands the volume of the metal part, increases the internal stress of the metal, and reduces the contact area between the metals. Therefore, the contact resistance will increase, and the parameter environment of the metal operation will change, affecting the entire device.

In this simulation model, the influence of salt spray corrosion was simulated by adding a corrosion film, and the thickness of the corrosion film was modified to simulate the different effects of multiple experiments. The dielectric constant of the corrosion film was set to 12, and the electrical conductivity was set to 0.3 s/m, with the frequencies range from 0 to 10 GHz.

The simulation results show the relationship between S_{11} and frequency is shown in Figure IV (a)-(c). Figure IV shows the S_{11} with different thickness of the corrosion film of electrical connectors.
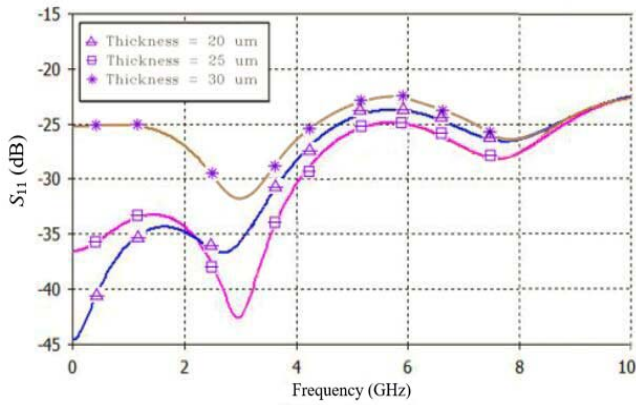
FIGURE IV. S_{11} PARAMETERS WITH DIFFERENT CORROSION FILMS

The Figure IV presents that with the thickening of the corrosion film, the low frequency (below 3 GHz) S_{11} parameter increases. Around 3 GHz, S_{11} will have a huge trough. The frequency of this trough slightly increases with the thickening of the corrosion film. In the range of 3-8 GHz, S_{11} shows an upward trend, and the peaks appearing around 6 GHz. However, the thick corrosion film has a higher peak. In general, the thicker the corrosion film, the larger the value of S_{11} parameter as a whole.
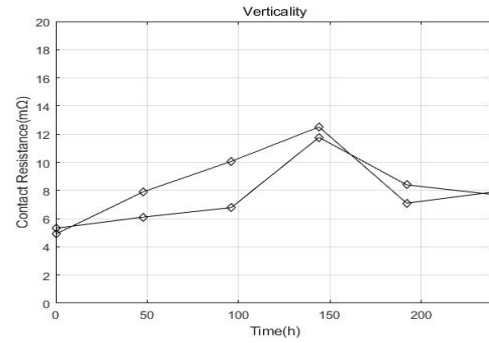
IV.   RESULTS AND DISCUSSION

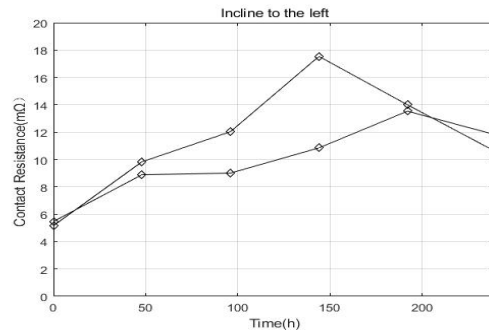### A.   *Results and Discussion of Contact Resistance*

Two sets of representative samples were selected for each placement, and the change in contact resistance over time is shown in Figure V (a)-(d). It is found that the contact resistance reaches its maximum after 144 hours of salt spray corrosion when the sample is placed horizontally, vertically, and tilted to the left. When the sample is tilted to the right side, the trend of the contact resistance is basically the same as the first three methods, but the peak appearance time is slightly different.
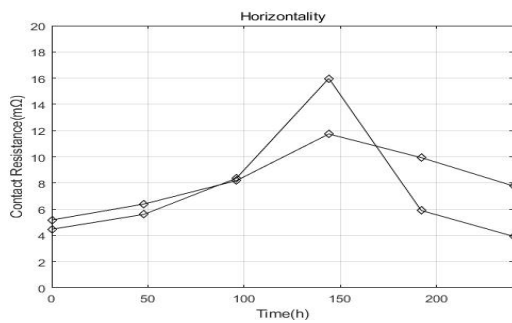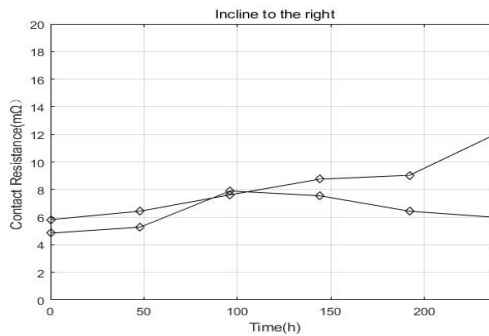

(A) PLACED HORIZONTALLY

(B) PLACED VERTICALLY

(C) PLACED INCLINING TO THE LEFT

(D) PLACED INCLINING TO THE RIGHT

FIGURE V. CONTACT RESISTANCE IN DIFFERENT PLACING MODES

B.   *Results and Discussion of High-frequency Parameter*

The S_{11} parameters of the eight samples were further analyzed. As the frequency gets higher, the trend of S_{11} under the four placement modes is shown in Figure VI (a)-(d).

It can be found that as the corrosion time changes from 96 hours to 240 hours, S_{11} becomes larger in the low frequency band (under 3 GHz, especially under 1.5 GHz). Figure VI (a)-(b) presents that in the range of 3-10 GHz, S_{11} rises in volatility. However, the S_{11} parameters of the samples that have been subject to longer periods of corrosion remain roughly above one another. In general, with the increase of time, the overall trend of S_{11} parameters appears to gradually increase.

(A) PLACED HORIZONTALLY

(B) PLACED VERTICALLY

(C) PLACED INCLINING TO THE LEFT
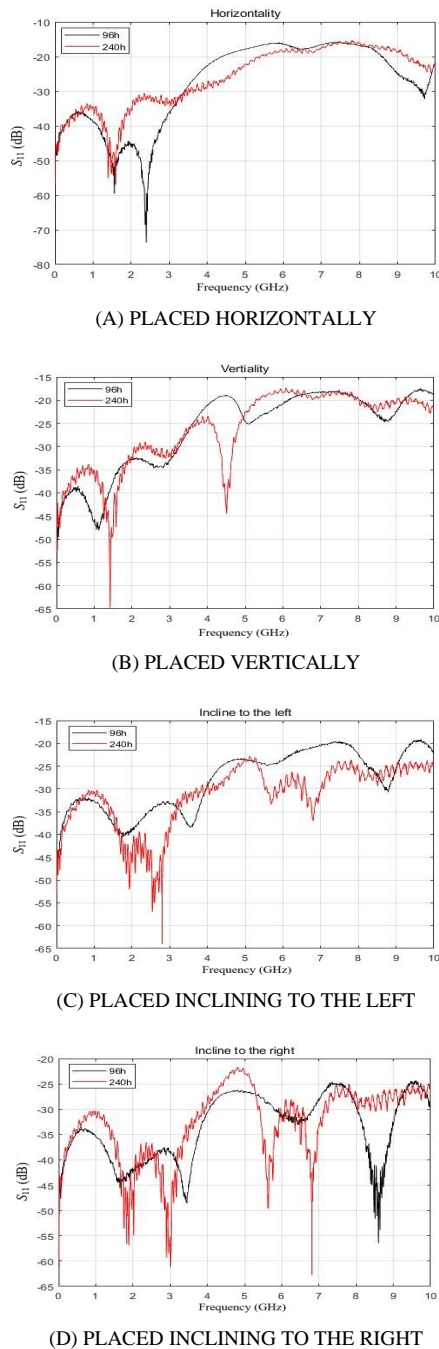

(D) PLACED INCLINING TO THE RIGHT
FIGURE VI. S_{11} PARAMETERS IN DIFFERENT PLACING MODES

By comparing the experimental results with the simulation results, it was found that the S_{11} trends of the experimental samples with the corrosion time can be roughly described by the S_{11} trend of the simulation model with the thickness of the corrosion film.

V. CONCLUSION

In this paper, the contact resistance and s-parameter of electrical connector (SMA-KFK) are analyzed under the environmental stresses of salt spray corrosion. A CST simulation mod-

el was established. The corrosion film was added to the simulation model and related parameters were set to simulate the connector under salt spray corrosion. Accordingly, the degradation mechanism of the SMA connector was analyzed. Then, by conducting the accelerated tests, the data of contact resistance and s-parameter under different corrosion time were obtained. It was found that the contact resistance of the connector generally increases with the increase of the corrosion time. The S_{11} parameter also presents an overall trend of growth over time, which strongly proves that under the single environmental stress of salt spray corrosion, the overall performance of the connector degrades with the increase of corrosion time. Finally, by comparing the experimental results with the simulation results, it is found that they are consistent. Therefore, it can be considered that in the salt spray environment, the corrosion film on the contact surface of the connector directly leads to the degradation of its high frequency performance.

REFERENCES

[1] W.Ren, P.Wang and L.Cui, "Status of Test Methods for Contact Materials Fretting Wear Characteristics[J]." Transactions of China Electrotechnical Society,2012(4):25-29.

[2] X.Kong, "Study on the effect of plug on the storage life of contact parts of electrical connector[D]". Zhejiang Sci-Tech University,2016. (In Chinese)

[3] Y.Luo, J.Yang, X.Liu and X.Li. "Numerical analysis and experimental verification on stress field of electrical connector contact[J]. "Chinese Journal of Engineering Design, 2016.

[4] J.Pan. "Modeling and Analysis of Space Electric Connector's Vibration Reliability[D]".Zhejiang University,2002.

[5] F.Tian, "A Return Loss Test Method for RF Coaxial Connectors." Electronics World,2013.

[6] H.Wang, T.Xu and W.Zhou, "Lifetime Prediction Method for Missile Electrical Connector Synthesizing Degradation Data and Lifetime Data".Journal of Shanghai Jiaotong University(Science),2014, 48(5): 702-706.

[7] GB/T2423.17-2008 Environmental testing for electric and electronic products-Part2: Test methods- Test Ka: Salt mist.

[8] GJB360A-1996 Test methods for electronic and electrical components.

[9] Z.Zhou,"Simulation Optimization Of Twist Contact Insertion Characteristics and Prediction of The Insertion Life[D]."University of Electronic Science and Technology of China, 2016.

[10] H.Wang, T.Xu and J.Zhao,"Residual life prediction method fusing accelerated degradation and field degradation data.[J]".Chinese Journal of Aeronautics, 2014, 35(12): 3350-3357.DOI: 10.7527/S1000-6893.2014.0010.

[11] B.Sun, T.Ye and Y.Fang . "A Novel Model of Failure Rate Prediction for Circular Electrical Connectors[J]." Journal of Shanghai Jiaotong University(Science), 2015, 20(04): 472-476.

[12] H.Wang, T.Xu and Q.Mi, "Lifetime prediction based on Gamma processes from accelerated degradation data[J]." Chinese Journal of Aeronautics, 2015, 28(01): 172-17.