Study on the Influence of Inserting Clearance on the Voltage Standing Wave Ratio in RF Connector

Xiang Li*1, Lijun Tong1, Libing Cai1, Qian Xie1, Jinling Xu1, Min Zhao1, Guangqin Shi1

1Aerospace Internet of Things Technology Company Limited/ Beijing Institute of Aerospace Micro-Electromechanical Technology, Fengying East Road, Haidian District, Beijing, China

*Corresponding author: LX310735@163.com

Abstract. RF (Radio Frequency) connector has been extensively applied in the field of communication for it is a key device of transmitting microwave signals. If the RF connector end is designed improperly in dimension, a clearance will be observed after inserting, resulting in an abnormal phenomenon in the voltage standing wave ratio (VSWR) of the RF connector. This paper studied the influence of the inserting clearance of RF connector on the voltage standing wave ratio through theoretical analysis and performance simulation. Moreover, the solution to the abnormal voltage standing wave ratio was also proposed. At last, the abnormal phenomenon of voltage standing wave ratio of the connector in the inserting process was handled by means of carrying out optimization design and test validation on the RF connector.

1. Introduction
RF connector with a pivotal role in the communication link is essential for transmitting microwave signals. The voltage standing wave ratio (VSWR) is an important indicator for characterizing the transmission performance of RF connector, which can directly measure the power reflectance of microwave device apart from showing the reflection coefficient in the signal transmission process. If an exception is encountered in the voltage standing wave ratio of RF connector within a certain test frequency band, there will be a strong reflection in the high-power signal. In that case, it might lead to large amounts of power loss in the connector and communication link, even destroying the entire system in an irreversible manner [1].

2. Abnormal voltage standing wave ratio situation
Through testing a cable-connected TNC RF connector (Figure 1), we found that there was a peak in the voltage standing wave ratio of the RF connector when the connecting nut was not completely tightened in the inserting process of a RF connector and a supporting socket. Evidently, if the RF connector fails to insert completely or loosens due to vibration in practical application, transmission power with strong reflection will be caused frequently.
Specific phenomena are presented as follows: A stable and continuous signal arises as soon as the TNC RF connector is inserted with the adapter socket (Figure 2). Then, the voltage standing wave turns into a curve increasing with the rising frequency when the connecting nut is tightened. Also, when the reference interfaces of the socket and plug are approaching to each other but not fitted completely in the process of inserting, a peak can be observed in the voltage standing wave ratio (Figure 3). And the peak will vanish or reoccur if we shake the cable or swing the shell. The frequency band of the peak is ranged from 1 to 3GHz, which is the common working frequency band for the TNC connector. But a peak cannot be found in the voltage standing wave ratio any more after the plug and socket are completely inserted, even if we shake the cable.

3. **Structural analysis of TNC RF connector**

3.1. *Introduction and inserting process of TNC RF connector*

The structure of the cable-connected TNC RF connector is displayed in Figure 4. A TNC connector is made up of a connecting nut, a internal circlip, a shell, a pin, an insulator, and a solder sleeve, etc. More precisely, the connecting nut is connected to the shell through the internal circlip; the pin and the welding sleeve are connected with the inner and outer cable conductors, respectively, via welding. At the same time, they are fixed tightly on the wall surface of the inner cavity of the shell using clamp nuts. The process of inserting a TNC connector is shown in Figure 5. Through tightening the connecting nut, the plug shell is fitted with the socket shell, while the pin is fitted with the socket.
3.2. Analysis of factors affecting the inserting process of TNC RF connector

As can be seen from the test results, the voltage standing wave ratio parameters of the high-power TNC RF connector that is completely inserted are well maintained without any abnormal phenomena. In that case, we can conclude that the design of internal microwave transmission path of the connector, the tightening of the standard surface end of the connector, the selection of RF cable, center conductor welding, and cable termination has no effect on the abnormal voltage standing wave ratio during inserting[2]. Since the peak of voltage standing wave ratio is found when the plug and the socket is completely fitted, we attributed the problem to the shell, a critical part of the inserting process. More precisely, important influencing factors leading to the problem might include the coordination between the end surface of the plug shell and the electrical reference surface of the socket, as well as the outer diameter of the front end of the shell. Standard interface dimensions of TNC RF coaxial connectors are demonstrated in Figure 6 and 7[3]. And two influencing factors are analyzed as below:

(i) Insulator bulges ranged from 0 to 0.127mm in size might be found on the electrical reference surface of the socket, affecting the contact between the end surface of the plug shell and the electrical reference surface of the socket. As a result, there might be a clearance between the plug and the socket, leading to peak arising [4].

(ii) The design size of the outer diameter of the front end of the plug shell is below the nominal size. The inner hole diameter of the socket shell is ranged from Φ8.10mm to Φ8.15mm in size, whereas the measured size is 8.12mm. Obviously, there is a clearance of about 0.06 between the plug and the socket shells, which might also a major cause of peak arising [4].

3.3. Validation of the simulated TNC RF connector inserting process

Upon analyzing the influencing factors of the inserting process, it can be also observed that there were clearances between the end face of the plug shell and the electrical reference surface of the socket as well as between the outer edge of the plug shell and the inner hole of the socket shell when the TNC RF connector was completely inserted with the supporting socket. Moreover, the front end of the plug shell was suspended at the plug-in section for the centering effect on the coordination of the center conductor. As can be seen from Figure 8, the complete disconnection of the TNC plug shell and the socket shell is an ideal model, and a good grip on the connecting nut of the connector can generate an
irregular air filling section, that is, clearances are witnessed at the side wall of the shell and the retracting groove of the connecting nut apart from the clearance $\delta$ at the front end of the plug shell as well as between the inner and outer circles along the surface.

![Figure 8. Profile of the TNC connector approaching to a complete inserting](image)

Based on the microwave transmission theory, the characteristic impedance $Z_0$ of the coaxial line should be calculated as \[ Z_0 = \frac{60}{\sqrt{\varepsilon_r}} \ln \frac{D}{d} \] (1)

where: $\varepsilon_r$ is the relative permittivity of the dielectric material; $D$ is the inner diameter of the outer conductor of the connector; and $d$ is the outer diameter of the inner conductor of the connector. The dielectric characteristic impedance $Z_0$ of the TNC connector is 50 $\Omega$. Besides, according to the impedance matching theory, the inner diameter $D$ of the outer conductor at the inserting section of the TNC connector is changed due to the presence of the irregular air-filled section shown in Figure 8. To be specific, the inner diameter $D$ of the outer conductor is enlarged irregularly, leading to an increase in the characteristic impedance $Z_0$. And a peak in the voltage standing wave ratio curve is a direct expression of the mismatched impedance of the transmission path.

The suspension of the plug shell is resulted from the clearance of the plug shell and the centering effect of the center conductor. Since the centering effect of the center conductor is inevitable according to the structural characteristics of the coaxial connector, the clearance of the plug shell is a major cause of peak arising in the standing wave ratio. To validate the centering effect of the center conductor, the plug shell is inserted into the socket by hands upon removing the connecting nut of the plug, as shown in Figure 9. The electromagnetic simulation model is shown in Figure 10.

![Figure 9. Profile of no connecting nut inserting](image)

The model simulation result is that the standing wave ratio approaches infinity at low frequency (Figure 11). The standing wave ratio drops rapidly with the rising frequency. But it becomes normal when the frequency exceeds 2 GHz. It is consistent with the measured results (Figure 12).
HFSS model shown in Figure 13 is established through simplifying the model of the clearance at the retracting groove of the connecting nut shown in Figure 8 in combination with the above two influencing factors. Then, the value of the air clearance can be calculated as per the design size and validated by simulation. The standing wave ratio curve obtained is shown in Figure 14. The voltage standing wave ratio curves under different air clearances are obtained through simulation with the air clearance $\delta$ as a variable. As can be seen from Figure 15, peaks can be found on the voltage standing wave ratio curves of different gaps.

According to the simulation results, (i) the suspension of the plug shell results in a peak on the voltage standing wave ratio curve ranging from 1 to 3 GHz. The frequency band is consistent with that of the peak occurring in the measurement (Figure 2). (ii) The voltage standing wave ratio out of the peak frequency band is not changed much in comparison to the simulation situation in complete inserting, which is also in good agreement with the test result. (iii) By changing the size of the air clearance $\delta$, the peak of the voltage standing wave ratio curve can be adjusted.
clearance $\delta$, we can find that the location and amplitude of the peak are changed. Specifically, the amplitude is extended with the increasing clearance, and the gap is declined with the declining amplitude. Apparently, the voltage standing wave ratio curve is highly sensitive to the air clearance $\delta$.

(iv) The actual peak value of the voltage standing wave ratio is roughly between 1.50 and 1.80, which is much lower than the simulated one (greater than 15), for shell suspension is extremely ideal. In reality, the shell is just contacted, rather than being “suspended” due to the coaxiality and roundness of the shell processing. The contact area and force of the plug and the socket shells are reduced under the centering effect, leading to a poor contact.

4. Structure improvement and validation of RF connector

4.1. Improved structure of RF connector

Hence, the suspension of the connector shell during inserting must be solved for coping with strong reflection of the TNC RF connector, which can be achieved in two ways. The first is to improve the contact of the end surface of the shell with the electrical reference surface of the socket through optimizing the end surface structure of the RF connector shell. The second is to reduce the fit clearance of the plug and socket shell through adjusting the outer diameter of the front end of the RF connector shell. By doing so, the abnormal occurrence of the voltage standing wave ratio can be eliminated during inserting, preventing strong power reflection from arising.

Specific structural improvement schemes are shown below: (i) A circle of steps is optimized at the end face of the plug shell as per the standard interface size due to the presence of insulator bulges on the electrical reference surface of the TNC socket. In this way, the front face of the connector shell can be contacted with the insulator bulge of the supporting socket to eliminate the air clearance between the front end of the connector and the socket. (ii) The outer diameter of the front end of the connector shell is adjusted to lower the fit clearance between the outer cylindrical surface of the connector and the socket shell, so that the peak in the standing wave ratio can be eliminated during inserting. Based on the simulation results in Figure 13, the probability of peak arising and the size of the peak value are closely associated with the clearance. Note that the clearance will disappear and no peak will emerge in the entire inserting process when the outer diameter is adjusted to a certain size.

4.2. Validation of improved structure

A standing wave ratio test was performed on the improved TNC RF connector. The varied standing wave ratio during inserting is shown in Figure 16. During inserting, the end face of the plug shell is not in contact with the socket insulator and the electrical reference surface. Also, the outer end face of the plug shell is tightened and well contacted with the inner hole end face of the socket shell. In this way, the normal voltage standing wave ratio can be observed in the full frequency range without any strong reflection phenomena.

![Figure 16. Optimized voltage standing wave ratio test pattern](image-url)
5. Conclusions

We studied the influence of the inserting clearance of the RF connector on its voltage standing wave ratio. As can be seen from the results, it can be found that the abnormal voltage standing wave ratio is primarily caused by the air clearance between the front face of the connector shell and the supporting socket as well as the clearance between the outer cylindrical surface of the connector shell and the supporting socket. The greater the clearance, the greater the amplitude of the voltage standing wave ratio will be. By improving the structural size of the connector shell in accordance with the above mechanism, no abnormal standing wave ratio phenomenon is found in the RF connector in case of incomplete inserting or loosening caused by vibration. This study is of great significance to improve the reliability of TNC RF connection, and safeguard the safety of the microwave link.

References

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