Investigation on RF Connector Degradation Using Time Domain Reflectometry

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***Abstract*—Radio Frequency (RF) connectors play an important part in electronic and communication systems. They are generally subjected to degradation in the contact interface during their service life, which affects signal integrity and communication quality of the systems. In the present work, the characteristics of RF connector degradation were theoretically analyzed and experimentally investigated using Time Domain Reflectometry (TDR). An accelerated test was designed to obtain the degraded connector samples. A series of experiments were conducted to measure the reflected voltages using a Network Analyzer for time domain analysis. Then, the reflection coefficients and load impedance were determined and the location of the degraded contact interface was identified. Based on classical electrical contact theory, transmission lines theory, and experimental results, an equivalent circuit model was developed and the degradation mechanism analyzed. The results showed that inductive characteristics increase with increase of the degradation. As the degradation increases beyond a certain level, the connector exhibits a more capacitive characteristic.**

Keywords—Time Domain Reflectometry (TDR), Radio Frequency (RF) connector, contact failure, degradation

I. Introduction

Electrical connectors are extensively used in communication systems to transmit signals between electrical equipment. As information transmission speed and frequency increases, higher requirements have been made for the reliability of electrical connectors. Electrical connectors tend to degrade in the process of storage and operation. Considerable previous work has been done on electrical contact properties and contact degradation mechanisms. For example, Flowers and his colleagues [1-2] studied contact interface characteristics and fretting corrosion, which provided insight into the basic fretting corrosion mechanism. Rodekohr, et al. [3] considered the effects of substrate characteristics on tin whisker degradation. Li, et al. [4] considered the effects of both environmental temperature and particle contamination on the life expectancy of electrical contacts. These works provide a good overview of the extensive work that has been done in the field of contact degradation and its basic impact on connector performance.

Connector degradation may cause discontinuities of impedance, which lead to voltage reflection. Considerable work has also been done to specifically address the effects of contact degradation on high frequency performance. For example, Timsit and his colleagues [5-7] studied the effect of skin effect on constriction resistance for frequencies ranging from direct-current (DC) to 1 GHz, established a model for constriction resistance, bulk resistance, contact capacitance and inductance and analyzed impedance characteristics at high frequency. Malucci [8-12] explored the contact mechanism for both clean and degraded interconnects at high frequency, and used the resistance and capacitance of a typical multipoint contact interface to estimate the influence of contact physics on high frequency signal integrity. Moreover, the capacitive interconnect effects of multipoint contacts was investigated based on the capacitive coupling and electronic tunneling for high frequency signal propagation. Rui Ji, et al. [13] developed an impedance model of a coaxial connector with a degraded contact interface based on transmission line theory on high frequency signal transmission.

Most of these studies were conducted to analyze electrical contact degradation properties in the frequency domain. Time Domain Reflectometry (TDR) technology is an effective method to analyze the signal transmission environment in the time domain, which is commonly used to determine the characteristic impedance of a transmission line or to quantify reflections caused by discontinuities along or at the termination of a transmission line. There have been a number of basic studies that analyzed transmission lines from one-port TDR measurements and extracted the propagation constant and characteristic impedance of transmission lines [14-15]. Therefore, TDR was adopted to investigate the influence of contact degradation of electrical connectors on high frequency signal transmission for the purposes of the current investigation.

In the present work, the characteristics of RF connector degradation are theoretically analyzed and experimentally investigated. First, an accelerated test is developed to obtain degraded connector samples at different degradation levels. Then, a series of measurements are carried out to estimate the voltage reflection characteristics resulting from the discontinuities of impedance in degraded RF connectors using a Network Analyzer for time domain analysis. Furthermore, the reflection coefficient and load impedance are evaluated. The position of the degraded interface is calculated for the electrical connectors using TDR theory. Finally, an equivalent circuit model for the contact interface is developed based on traditional electrical contact theory, transmission line theory, and experimental results. Simulation studies are performed on the equivalent circuit model. In addition, the voltage values are analyzed with different electrical parameters (R_2 , L_2 , and C_0).

II. EXPERIMENTAL CONFIGURATION

A. Samples obtained

SMA coaxial connectors, which are widely used in microwave equipment and radio frequency circuits of communication systems, were chosen as the samples considered in this study. As shown in Fig. 1, a pair of female to female and male to female SMA connectors is chosen to be investigated and tested. The samples are typical civilian industry products. For the SMA connector, its characteristic impedance is 50 Ω. It could be operated in the frequencies range from 0 to 12.4 GHz with soft electrical cables and 0 to 18 GHz with semi-rigid or semi-flexible electrical cables. Its central conductor is composed of a pin and receptacle whose base material is a copper alloy, and the cladding material is nickel and gold. The thickness of the gold plating is 0.1 μm.

The device under test (DUT) consists of a female to female connector, a male to female connector and a load with 50 Ω (Fig. 1 and Fig. 2) which would produce clear measurement results.

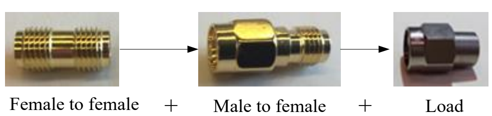

Fig. 1. Structure of a SMA pin and receptacle pair and the 50 Ω load

Fig. 2. Device under test (DUT)

In order to explore the effect of RF connector degradation on signal transmission, degraded connector samples were obtained by an accelerated test using nitric acid vapor. The pin of the SMA female-male was corroded by nitric acid with 65% concentration and the female of the SMA female-male was protected with a rubber casing and anticorrosion tape. Six sample pairs at different levels of degradation were obtained by using this method.

B. Time Domain Reflectometry

Time Domain Reflectometry (TDR) measures the reflections that result from a signal travelling through a transmission environment of some kind, for example a circuit board trace, a cable or a connector. The TDR instrument sends a pulse through the medium and compares the reflections from the unknown transmission environment to those produced by a standard impedance (50 Ω). A simplified TDR measurement block diagram is shown in Fig. 3.

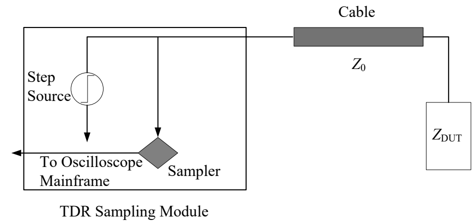

Fig. 3. Block diagram of the TDR circuit

The TDR display is the voltage waveform that returns when a fast step signal is propagated down a transmission line. The resulting waveform is the combination of the incident step signals and reflections generated when the step encounters impedance variations [16].

TDR measurements are described in terms of a reflection coefficient ρ . The coefficient ρ is the ratio of the reflected pulse amplitude to the incident pulse amplitude:

$$\rho = \frac{V_r}{V_i} \tag{1}$$

The load impedance Z_L can then be calculated with the value of ρ :

$$Z_L = Z_0 \times \frac{1+\rho}{1-\rho} \tag{2}$$

where V_r and V_i are the reflected and incident voltage, respectively. Z_0 is the characteristic impedance.

In addition, the position of impedance variations could be calculated by the transmission delay measured with TDR. The location of a reflection point is shown as follows:

$$L = \frac{V \times T}{2} = \frac{C \times T}{2\sqrt{\varepsilon_r}} \tag{3}$$

where V is the propagation velocity of the signal in the dielectric, T is the transmission delay value displayed in the instrument, C=3.0×10^8 m/s is the speed of light, and ε_r=2.05 is the dielectric constant.

C. Measurement setup of TDR

TDR measurements were conducted using an Agilent E5071C ENA Series Network Analyzer with TDR time domain analysis enhancing options. TDR permits the signal transmission environment to be analyzed in the time domain just as the signal integrity of data signals is analyzed in the time domain. It has a frequency range from 300 KHz to 20 GHz. A single-ended 1-port method of measurement was adopted to measure the voltage. The excitation is a low-pass step signal with voltage amplitude of 200 mV and rise time of 35 ps. The reference impedance is 50 Ω. The experimental setup is shown in Fig. 4.