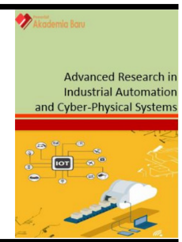
Penerbit Akademia Baru

Journal of Advanced Research in Industrial Automation and Cyber-Physical System

Journal homepage: www.akademiabaru.com/ard.html
ISSN: 2637-0263



RF Connector Insertion Loss Comparison between Electronic and Mechanical Calibration Kits from 300 KHz until 8.5 GHz

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ARTICLE INFO

Article history:
Received 7 August 2018
Received in revised form 13 August 2018
Accepted 17 August 2018
Available online 23 August 2018

Keywords:
Network analyzer, insertion loss, calibration kit, RF connector

ABSTRACT

Two calibration kits were commonly used to calibrate with Vector Network Analyzer (VNA) that were mechanical and automatic calibration kits. Mechanical calibration kit consists of several mechanical parts precisions in dimension accuracy and required high skills to perform the calibration. It also needs to be handled with extra care of the mechanical calibration kits because the parts and accessories are tiny. A simple mistake could break down the parts without notice. The precision in the dimension of the mechanical calibration kits will determine the accuracy in measurement. Automatic calibration kit used to be the simplest way to perform the calibration at the VNA. It does not require high skills workers to perform the task. The purpose of this work is to compare and correlate between mechanical and electronic calibration kits measured from 300 kHz until 8.5 GHz and analyze the differences between both calibration kits. The results suggest in this work and the method applied was found intolerance across the frequency range desired.

1. Introduction

Network Analyzer had been developed in the late 1960s together with the mechanical calibration kits. The development of the network analyzer had been introduced the scalar network analyzer (SNA) and vector network analyser (VNA). The SNA used to measure vector reflection coefficient with only the amplitude property across the entire frequency range as a previous study [1]. Initial stage only mechanical calibration kits were introduced together with the Network Analyzer. Late 90's, electronic calibration kits were introducing to enhance the calibration steps and process. Electronic calibration kits claim to be fast, easy and accurate compare to mechanical calibration kits as a previous study [2]. The benefits of the electronic calibration kits [3] are calibrated faster, reduce handling error and less temperature sensitivity coefficient compare to mechanical calibration kits.

RF connectors are found in a broad range of electronic equipment for extending the dynamic range of measuring equipment. Characterizing RF connector requires an accurate attenuation

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measurement equipment such as Network Analyzer. As previous study [4] the HP8510 was choosing to perform the calibration while this study is using the 8.5 GHz Network Analyzer. RF connector can be found in various dimensions and operating frequency range. The main issue is RF connector itself consuming very minor of signal loss that is technically identified as insertion loss between input and output.

Insertion loss is clarified as voltage drop when a signal passes thru the RF connector. Nevertheless, RF connector does not require annual calibration because it will be contributed an exorbitant of calibration cost. However, if a fragmented RF connector had been connected to the RF test system, it would be possible to break down the entire system. Another common solution that is keeping the safety stock for RF connectors. In actual, it is not practicable because it will significantly increase the entire operating cost and influence the return on revenue ratio. This study will show the difference between S12 and S21 techniques in an 8.5 GHz Network Analyzer characteristic by National Instruments electronic calibration kit and determine the insertion loss of the RF connector. At the end of the study will calculate the Linear Magnitude (Lin Mag), loss in dB and a degree from the “real and imaginary (.cti)” format measured from the Network Analyzer.

The objective of this paper is to perform calibration by using NI PXIe-5632 Network Analyzer calibration by using the mechanical calibration kit. Meanwhile, the device under test (DUT) is a 3.5 mm (female) to 3.5 mm (female) and 3.5 mm to Type N RF connector shown in Fig 1(a). It is used to interconnect from a 3.5 mm male with another 3.5 mm male or 3.5 mm to Type N connector. In this paper, these connectors had been chosen as divide under test to study the differences between the forward's insertion loss (S12) and reverse insertion loss (S21).

2. Methodology

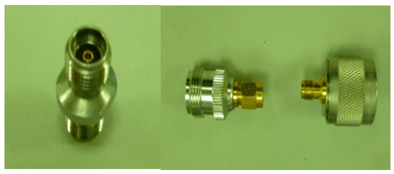
2.1 PXIe-5632 Vector Network Analyzer

The NI PXIe-5632 Vector Network Analyzer (VNA) is manufactured by National Instruments. It is an 8.5 GHz full two-port S-parameter Vector Network Analyzer shown as Fig 1(b). The NI PXIe-5632 includes the de-embedding feature that is most commonly used to remove the effect of the test fixtures between the network analyzer and device under test. The de-embedding of network analyzer refers to the process of removing network or test fixture data and introduce S-parameter measurement at the DUT as final measured data. Other words, it will be the characterization of the DUT in S-parameter.

Fig 1(c) refers to the National Instruments electronic calibration kit. The electronic calibration kits are commanded to several known standard that was predefined impedance states that the VNA measures. The measured value is compared with the known value stored in the EPROM of the VNA in order to compute the correction factors [5]. Fig 1(d) refers to an RF cable. It is an RF gore cable. Gore cable are proven for long lasting solution reliable signal transfer integrity. Gore cable full range of coaxial and RF assemblies withstand a broad spectrum of challenges in extensive environment operating ranges, vibration, and repeatability in measurement.

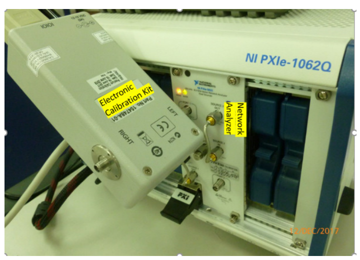
VNA is an instrument that able to perform measurement which involved with mathematics derives the systematic error model for the. This error model is an array of vector error coefficients that used, to begin with a fixed reference plane measure at zero phase shifts, zero reflection magnitude, lossless transmission magnitude and known impedance by referring to the mechanical calibration kits. The array of coefficients is calculated by measuring a set of known devices or calibration standards or calibration kits connected at a fixed measurement plane. It is also known as open, short, load, airline, transmission thru and isolation in an electronic calibration kit shown in Fig 1 (c).

Different calibration techniques are used to solve different error models such as reference at 50 ohms will be a reference to the electronic calibration kit's impedance load and airline. The definition of calibration standards and calibration types are set up differently for its appropriate calibration techniques. Solving the full 2 port of twelve-term error models using the short, open, load and thru (SOLT) calibration method [6] is an example of only one of the many measurement calibrations available [7]. The full two-port error terms include all six of the forward and reverse direction parameter for directivity, crosstalk, source mismatch, load mismatch and frequency response. It is reported in a total number of twelve error terms. This is the reason why a full 2 port calibration also refers to 12 error terms correction shown in Fig 2 [8].

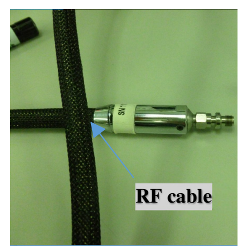


(a) RF Connectors

(c) National Instruments Electronic Calibration kits



(b) 8.5 GHz Network Analyzer With Electronic Calibration Kit



(d) RF Cable

Fig. 1. A full two ports set up calibration

2.2 Network Analyzer Measurement

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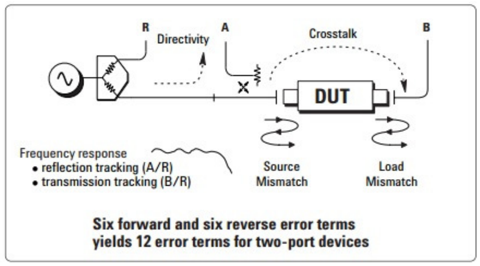

Fig. 2. Twelve Error Terms in a Network Analyzer

There are two types of calibration selected by the user depends on the device to be measured for example 1-port or 2-port device. The calibration standards available and the extent of accuracy enhancement desired to determine the maximum bandwidth and frequency available. A combination of calibrations can be used in the measurement of a device, such as adapter removal calibration for a different type of connector or devices.

The accuracy of subsequent device measurements depends on the accuracy and stability of the Vector Network Analyzer, the accuracy of the calibration standard model, and the calibration method used in conjunction with the error correction model as previous study [3]. A reflection standard known as "Offset Open" offers the advantage of broadband frequency coverage. Meanwhile "Offset short" cannot be used over more than an octave. The reflection coefficient is known as below equation [9]

$$\Gamma = \rho e^{-je} \quad (1)$$

The reflection coefficient measured of a perfect zero length open is 1 at 0 degrees for the entire frequency bandwidth. However, at microwave frequencies, the magnitude and phase of an offset open is effect by the radiation loss and capacitive fringing field respectively. In a coaxial transmission line, a shielding technique applied on the coaxial cable to reduce the radiation loss.

The magnitude (ρ) of a zero-length offset open is assigning to be 1 which means that zero radiation loss for entire frequencies when using the Network Analyzer standard type "Offset Open". Meanwhile, the fringing capacitance is not possible to be removed. However, the results of phase shift cable be modelled as a function of entire frequency C_0 through C_3 by using below equation [9]

$$C_0 \text{ through } C_3 = C_3\left((C_0 + C_1)f^1 + C_3 f^3\right) \quad (2)$$

The compensation VNA loss into DUT results generated to calculated offset measurement [10]

$$\text{Offset Measurement} = \left(1 - \left[\frac{O_{s21}^2 \cdot O_{s12}^2}{O_{s21} + O_{s12}} - \frac{A_{s21}^2 \cdot A_{s12}^2}{A_{s21} + A_{s12}}\right]\right) \quad (3)$$

2.3 Network Analyzer Calibration Environment Condition

The NI VNA 5632 required specific setup and environmental conditions. It is to ensure the quality of the results measured in optimum performance. Firstly, the ambient temperature and relative humidity are set to (23 ± 5) degree Celsius and (10 to 90) % RH noncondensing respectively [11]. The tight setting of the environmental conditions was reference to calibration laboratories accommodation especially for electronic calibration kits is sensitive to surrounding temperature deviation. Higher or lower surrounding environment will be resulting in inaccurate measurements.

Especially after the user calibration with a calibration kit, the ambient temperature deviation tolerance was set to less than 1 degree Celsius [12]. Secondly, the sufficient warm-up time at least 45 minutes after the chassis is powered in high fan mode and NI VNA 5632 is loaded with NI-VNA software and recognizes the Network Analyzer. It is to ensure the Network Analyzer and test instrumentation are at stable operating temperature. If any malfunctioning or synchronization issue with the instrumentation, an error message will be prompt up at the monitor. Abort the test and calibration if any error message displayed. Further investigation on the instrumentation is required on the error message code [13].

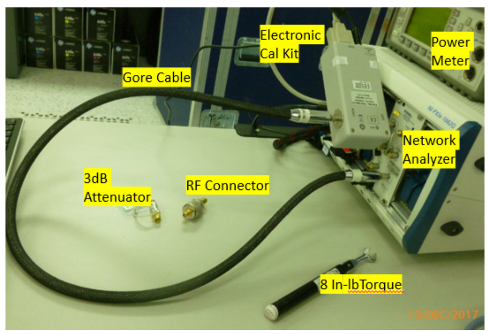

Fig. 3. Network Analyzer Calibration Environment Condition

3. Results

3.1 Analysis of S12, S21, and Average of S12 and S21 Comparison

This study will provide a possible solution for an analysis between the electronic and mechanical calibration kit. An unknown RF connector is shown in Fig. 3 named as RF Connector. As the previous study Agilent Technologies [8] explains why to use S-parameter to characterize the high-frequency networks [14]. The results of the RF connector by using S12 and S21 method on a 2.4mm RF connector as a previous study [15] available operate until 60GHz.

Figure 4 shows the results of the DUT measured in the Network Analyzer from 300 kHz until 8.5 GHz. It is clearly identified that insertion loss of RF connector is a non-linear graph. From the results, it can conclude that the insertion loss of Mcal S21 measured higher noise ratio comparing to the other 3 methods. Insertion loss S21 measured maximum peak voltage at Mcal S21 frequency 3.36 GHz with 1.007 units of linear magnitude. Insertion loss S21 measured minimum peak voltage at Ecal S21 frequency 300 kHz with 0.969 units of linear magnitude. The results for Mcal and Ecal were conclude as noisy signals. An averaging of insertion loss S12 and S21 combined as one graph to minimize the noise level or during the calibration, turn on the averaging in the VNA to improve the results become more linear.

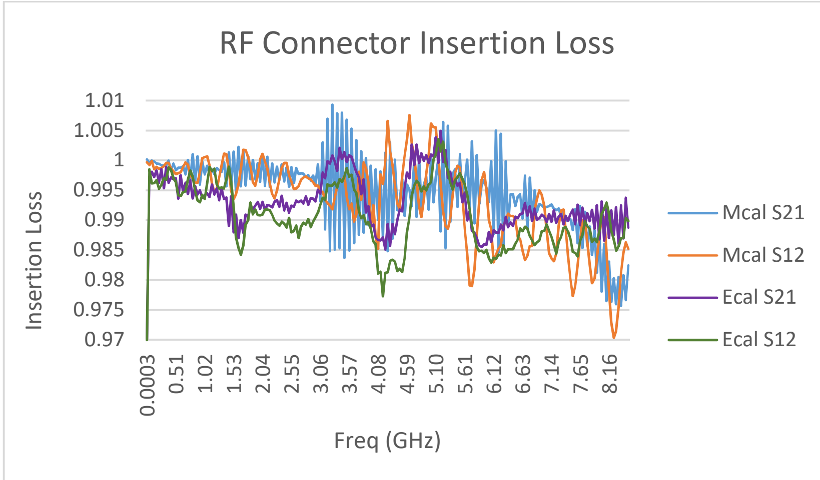

Fig. 4. Analysis of S12, S21 and Average of S12 and S21 comparison

3.2 Device Under Test Before and After Offset Measurement

The graph at Fig. 5 also clearly identified that both Insertion loss S12 and S21 signals strongly correlation with reference Linear Magnitude = 1 (at the middle of the graph). Fig. 5 shows that the average measurement of the DUT insertion loss compensates with the average measurement of the Network Analyzer "Offset" reading. Refer to the Fig.5, "Mcal Before offset" was identified as initial DUT measurement. "Mcal After offset" was taken after the averaging both DUT and Network Analyzer "Offset" measurement was taking into the count.

From the Fig.5, it was identified as Network Analyzer "Offset" measurement does not significantly change the character of the DUT initial measurement. However, the Network Analyzer "Offset" measurement was contributed to the DUT initial measurement, and it was measured closer to the reference Linear Magnitude =1 from 300 kHz until 4.2 GHz. From the results, it can conclude that the initial DUT measurement compensates with Network Analyzer "Offset" measurement will increase the precision and accuracy in term of making a measurement for an RF connector.

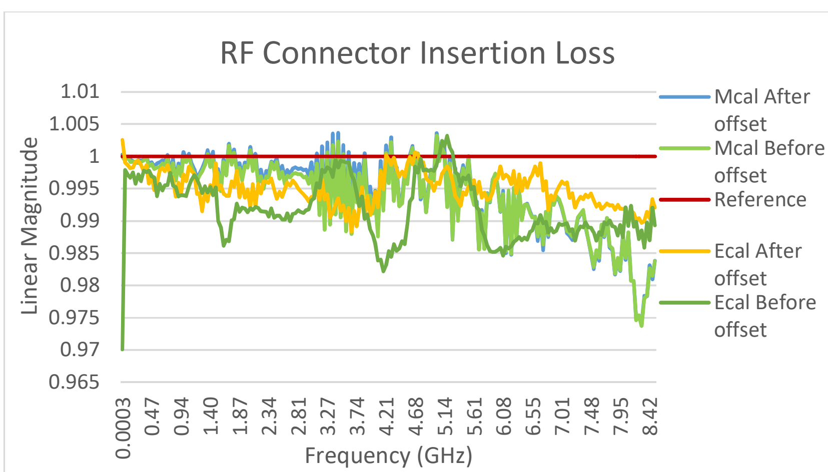

Fig. 5. Device Under Test Before and After Offset Measurement

With the “Offset measurement” formula applied with the results, both Ecal and Mcal after offset were found close to the reference. The measurement closer to the reference means that less error contributes to the calibration system. It will improve the accuracy and precision of the calibration system indirectly.

4. Conclusions

The experimental data of this study guide the operation of a Network Analyzer and calibration kits to perform the calibration according to the standards procedures. Calibration Kits are well establishing to evaluate the technique of ports calibration. The Ecal and Mcal techniques also successful measured in this study. It is a unique process to calibrate an RF connector measured from 300 kHz until 8.5 GHz. After the insertion loss of the RF connector had been determined, the loss of the RF connector will have compensated in the RF tester in production mode. In this study, the worst case of the insertion loss had been measured is approximate 0.973 in Linear Magnitude mode. It shows that the measurement was measured 0.027 off from the reference point. The error of 0.027 conclude as not significant towards the entire range of frequency. However, as a previous study [16] found that that are a few techniques to determine the in-tolerance or out-of-tolerance between S12 and S21 techniques correlation. From Fig 5, it can justify that the techniques applied in this paper were found in-tolerance.

Acknowledgment

This study was performed in a Radio Frequency Calibration Laboratory, National Instruments Malaysia.

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