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An Analysis for 2.4mm-2.4mm RF Connector Insertion Loss Measure From 45MHz Until 50GHz by Using Electronic Calibration Module and Mechanical Calibration kits in a Network Analyzer

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Abstract. This paper is a study regarding the Radio Frequency (RF) connector characteristic (insertion loss) in applications at 50 Ω Impedance from 45MHz until 50GHz by using the Network Analyzer and two type of calibration kits that are Electronic Cal (E-Cal) Module and Mechanical Calibration (M-Cal) Kits. RF connector will always assume as idle (lossless) in a calibration system. It can exist in varying types in dimension and length (delay line). The purpose of this study is to determine the significant and impact of the RF connector loss against its frequency range. The objective is to gain more knowledge about the RF connector characteristic, network analyzer and the two type of calibrations kits setting and usage. One port and full two ports calibration techniques are used to determine the loss of RF connector. This study will analyze the differences between both techniques (one port and full two-port calibration) and calibration kits (E-Cal and M-Cal kits) in the RF connector insertion loss.

1 Introduction

Radio frequency (RF) connectors are found in a broad range of electronic equipment for extending the dynamic range of measuring equipment. Characterizing RF or microwave circuits and devices requires an accurate attenuation measurement. RF connector can be found in any dimension and frequency range. The problem is the RF connector it does not come to the reading of dB against the frequency range. The objective of this work is to create a new process to characterize RF connector using a network analyzer [1]. It is to determine the insertion loss and port match of the RF connector. This also covers the calibrations kit usage on the network analyzer. At the end of the project will implement an excel spreadsheet to be filled in all the parameters and information. The spreadsheet will guide how to determine the spec, system buy-off and calculating EN Ratio.

2 Background

RF connector is designed and manufactured a wide variety to meet the needs of nearly every application. The major specifications are the characteristic impedance, frequency range, and quality. Each connector has its unique parameters as well as its cautions and techniques for making reliable measurements [2]. Table 1.1 below reflects a variety of connectors typically used around in the field.

Table 1. RF Connector Usable Frequency Range

Connector type	Range in GHz
APC-7	Up to 18
Type-N	Up to 18
3.5mm	Up to 33
2.4mm	Up to 50

Precision Slotless Connector (PSC) is of higher quality than the Precision Variety (Slotted) and can make a better repeatable measurement [3]. A PSC is also defined as a metrology grade connector. It is expensive, reliable, repeatable and precision in dimension. The RF signals are much more stable in frequency and power than ocean waves. The results of the reflections are also more stable. In fact, they are stuck in a particular location on the RF path and are thus called Voltage Standing Wave Ratio (VSWR).

3 Method

3.1 Network Analyzer Set Up Process and Procedure

The N5230C is a Network Analyzer that can measure S-parameter up to 50GHz. It is suitable to replace the older version of Network Analyzer model 8510C. It is recommended that a user is familiar with the calibration techniques and terminologies to get the maximum understanding from the service manual or application note. The type of measurement calibration selected by the user depends on the device to be measured. For example one port or full two-port device. The calibration standards are available. The extent of accuracy enhancement desired is refered to the standards. Devices such as an adapter removal calibration for a different type of connectors use a combination of calibratons in measuring them. The accuracy and stability of a test equipment determine the accuracy of subsequent device measurements. The accuracy of the calibration standard in the network analyzer and the calibration method either one port or full two-port calibration was used in conjunction with the error correction model by using an automated E-Cal Kit [4]. It is important to carry out the calibration process according to the manufacturer recommended requirements. The network analyzer set up as below for S-parameter one port and full two-port calibration.

i. Preset the network analyzer
ii. Start frequency:45MHz
iii. Stop frequency:50GHz
iv. Averaging factor:1
v. IF bandwidth: 100 Hz
vi. Number of points: 201
vii. Data: S11

Then go to the network analyzer toolbar and select “Cal”

i. Do not preset the network analyzer anymore
ii. Select “Cal Wizard”
iii. “Smart Cal” (guided calibration) and one port / full 2 port calibration
iv. DUT port 1 is APC2.4 female
v. DUT port 2 is APC2.4 female (only for full two-port calibration)
vi. Select the cal kit, for this case, is “85056A 2.4mm calibration kits / E-Cal kit”
vii. Follow the pop-up message and make the calibration by connecting the M-Cal / E-Cal kit to the corresponding port.
viii. After finishing the calibration and save it to the directory name “cal 1”

After complete calibration, the network analyzer is ready to measure DUT. The new network analyzer calibration is more users friendly, and it is easy to perform the calibration. It only requires 20 minutes or less to complete the calibration as shown in Figure 1.

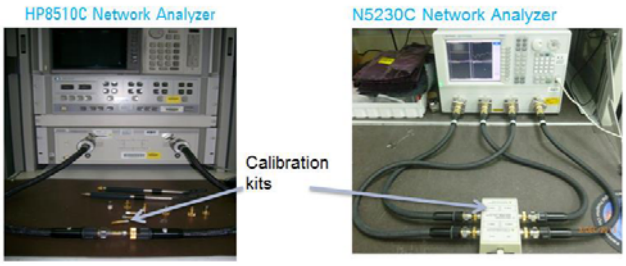

Figure 1. An Example of the VNA HP8510C and PNA N5230C with the connection.

3.2 S-parameter Single One Port (S1p) Calibration

After the setting in 3.1 completed, choose the right connector for port one network analyzer. This technique only consists of one port calibration only as shown in Figure 2 whereby the port 1 of the NA connected to the calibration kits. It takes 10 minutes to complete the calibration. It does not require any specific skills to do the S11 one port calibration by using the calibration kits.

Figure 2. One Port Calibration using E-Cal (left) and M-Cal (right)

3.3 S-parameter Full Two Port (F2p) Calibration

This technique consists of both ports one and two at the network analyzer for calibration as shown in Figure 3. The time consumed for full two ports are 20 minutes to complete the calibration by using the E-Cal or M-Cal [5] module. It requires high skills to do the full two-port calibration.

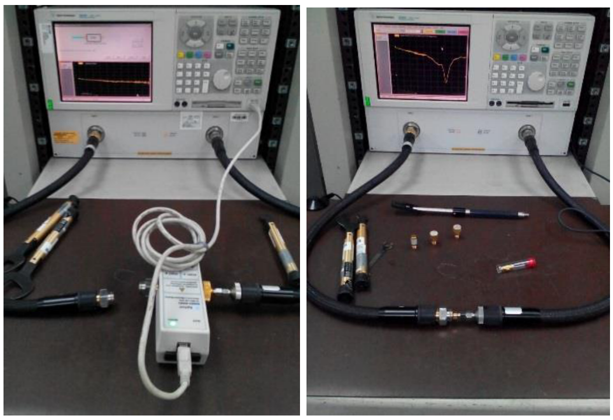

Figure 3. Full Two Port Calibration using E-Cal (left) and M-Cal (right)

3.4 Calculate Error Normalize Ratio (EN Ratio)

In the final results, the pass and fail condition will determine by the Error Normalize Formula (EN ratio). The EN ratio is performance statistic stands for Error Normalized. It is derived by dividing the difference between a DUT measured value and the reference assigned values by the square root of the sum of the square of the DUT’s uncertainty and reference uncertainty that are pre-determine in the network analyzer calibration system. Equation 1 defines the EN ratio [6].

$$EN\ ratio\ = \left(\frac{ILC - REF}{\sqrt{U_{ILC}^2 - U_{REF}^2}} \right) \quad (1)$$

Where:
ILC is the Device under Test measure value
REF is the reference assigned value
U^2_{ILC} is the DUT measurement uncertainty squared
U^2_{REF} is the reference assigned measurement uncertainty squared.

4 Results And Discussion

4.1 S-parameter Single One Port (S1p) Calibration

In the overall results for Linear Magnitude, it can reflect in statistical theory. It is any statistical relationship between two sets of random variables or two sets of data. Correlation refers to any of a broad range of statistical relationships involving dependence. A high correlation applies to both data and they are are well related. A less relationship, however, will reflect the opposite direction, or it is not well related. Refer to the Figure 4, the Linear Magnitude for S1p are high correlation from 45MHz until 17GHz. After 17GHz, the results show that E-Cal S1p and M-Cal S1p have its trend that is less correlation. Beyond 17GHz, both results cannot determine which technique show the more accurate and precise measurement. More sets of measurement need to be taken to further study the results.

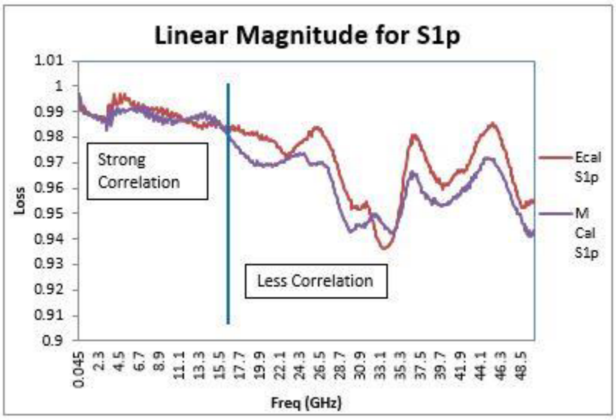

Figure 4. Linear Magnitude for One Port Calibration

Figure 5 show the loss in dB for the S1p technique. E-Cal S1p measured the RF connector having the maximum loss -0.564dB at 33GHz while M-Cal S1p measured the maximum loss -0.501dB at 29.7GHz, -0.539dB at 34.5GHz and -0.524dB at 49.3GHz. M-Cal S1p measure more peak loss compare to E-Cal S1p only found one peak loss in dB.

The maximum loss different for both techniques are 0.025dB. It is considered very close to each other. However both M-Cal S1p and E-Cal S1p measure noise and harmonic from 45MHz until 22GHz frequency range. Both sets of data also show that 22GHz until 50GHz having a clean and less harmonic measurement. The harmonics occur along the frequency is due to the averaging that is needed to be set higher instead of the averaging is set to 1 in this project.

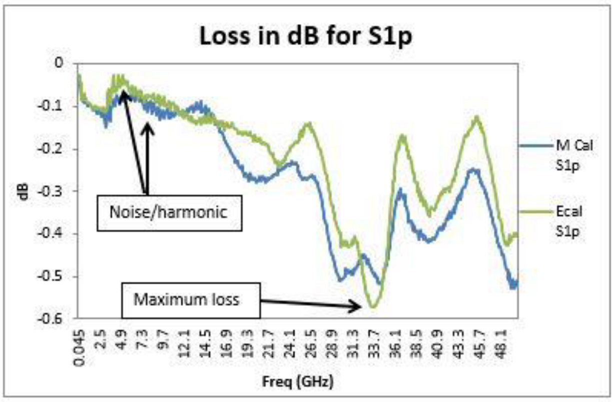

Figure 5. Loss in dB for One Port Calibration

4.2 EN ratio for Single One Port (S1p) Calibration

In this experiment, EN ratio was chosen to use to determine the pass and fail condition. EN ratio calculated more than 1 is a fail. If the EN ratio less than one is a pass. Table 2 show the RF connector results comparing the M-Cal S1p and E-Cal S1p. Both measurements was found passed for all the frequency range.

Table 2. EN Ratio for Single One Port Calibration

EN ratio S11 one port cal								
	M Cal S1p		E Cal S1p					
Freq GHz	Linear Mag	Uncertainty	Linear Mag	Uncertainty	Delta	RSS	EN Ratio	Status
0. 045	0.9969	0.0220	0.9968	0.0220	0.0001	0.0311	0.0028	PASS
1	0.9895	0.0220	0.9900	0.0220	0.0005	0.0311	0.0161	PASS
5	0.9911	0.0220	0.9950	0.0220	0.0039	0.0311	0.1254	PASS
10	0.9872	0.0220	0.9886	0.0220	0.0014	0.0311	0.0462	PASS
15	0.9878	0.0220	0.9867	0.0220	0.0011	0.0311	0.0345	PASS
20	0.9692	0.0480	0.9794	0.0480	0.0102	0.0679	0.1503	PASS
25	0.9727	0.0480	0.9790	0.0480	0.0063	0.0679	0.0926	PASS
30	0.9432	0.0860	0.9516	0.0860	0.0084	0.1216	0.0691	PASS
35	0.9463	0.0860	0.9472	0.0860	0.0009	0.1216	0.0072	PASS
40	0.9536	0.0860	0.9596	0.0860	0.0060	0.1216	0.0495	PASS
45	0.9720	0.0860	0.9847	0.0860	0.0127	0.1216	0.1045	PASS
50	0.9431	0.0860	0.9545	0.0860	0.0114	0.1216	0.0935	PASS

Refer to the Table 2 above, it can conclude that the RF connector was measured under very consistent and stable condition. The amount of change was too small. The maximum EN ratio was measured 0.1503 at 20GHz. It shows that at 20GHz, both data were found less correlation at this point.

4.3 S-parameter Full Two Port (F2p) Calibration

Adapter delay is specially only measured in a full two-port calibration system. It's measure the time delay between port one and port two of the network analyzer. The adaptor delay is significant because the network analyzer will automatically offset the delay time before measuring the DUT. Hence, the measurement makes more accurate and precision. Equation 2 defines the adapter delay time [7].

$$\text{Adapter Delay} = \pm \left(\frac{1}{4\,X\,f} \right) \text{Second} \quad (2)$$

The adaptor delay only exists in the Programmable Network Analyzer series while the older generation of

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network analyzer requires another technique call Adaptor Removal method to measure the non-insertable device such as 2.4 mm female to 2.4mm female adapter. By using the equation 2 to manual calculate the 50GHz adaptor delay is approximate 0.005nsec as shown in Table 3. It is the best adapter delay value for a 2.4mm RF connector by using the formula to calculate.

Table 3. An Adaptor delay manually calculated at 50GHz

Frequency	50000000000	Hertz
Constant Value	1	-
Constant Value	4	-
Adaptor delay	5E-12	Seconds
Approx	0.005	nsec

Figure 6 show the E-Cal kit and Figure 7 show the M-Cal kit adapter delay measured in the network analyzer.

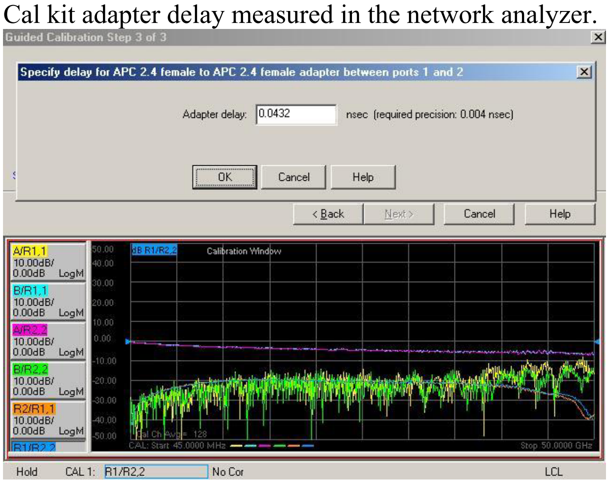

Figure 6. E-Cal Kit Adapter Delay in Network Analyzer

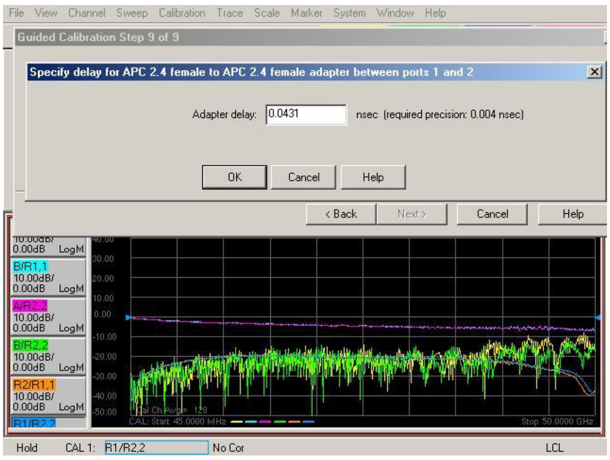

Figure 7. M-Cal Kit Adapter Delay in Network Analyzer

Refer to the Figure 8, the Linear Magnitude for F2p are high correlation from 45MHz until 50GHz. However at 28GHz and 32GHz, the E-Cal F2p has run off from M-Cal F2p trend before it comes to a spike at 36GHz. It shows E-Cal F2p at 28GHz measure less compensates, and 32GHz had been over compensated. It is because the E-Cal Module unable to identify the accurate reading for its open, short and load value at 28GHz and 32GHz. It does not perform well at that two frequency points.

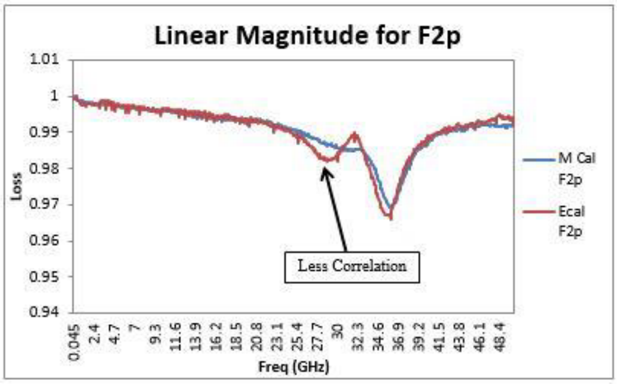

Figure 8. Linear Magnitude for Full Two Ports Calibration

Figure 9 show the loss in dB for the F2p technique. M-Cal F2p measured the RF connector having the maximum loss -0.274dB at 35.1GHz while E-Cal F2p measured the maximum loss -0.302dB at 36GHz. The maximum loss different for both techniques is 0.028dB. It is considered very close to each other. However, the M-Cal F2p measure more clean and linear than E-Cal F2p. E-Cal F2p shows noise and harmonic along the entire frequency range. Averaging causes the harmonics to occur along the frequency range. It needs to be set higher instead of value 1. Thus, M-Cal F2p produces a more accurate result than E-Cal F2p.

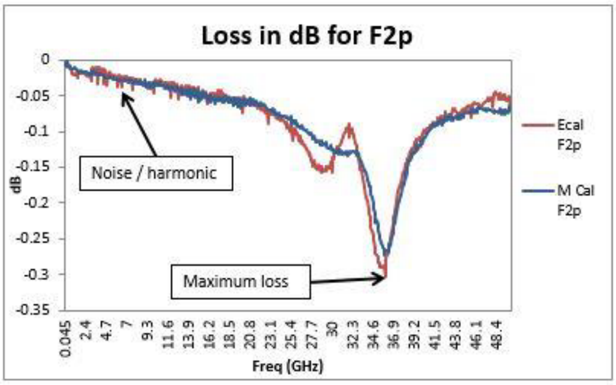

Figure 9. Loss in dB for Full Two Ports Calibration

4.4 EN Ratio for Full Two Port (F2p) Calibration

Refer to the Table 4, shows the RF connector results comparing the M Cal F2p and Ecal F2p. Both measurements were found passed for all the frequency range. Each of the measurements measured was very close. It can be concluded that the RF connector was measured under a very consistent and stable condition. The maximum EN ratio was measured 0.0501 at 15GHz. It shows that at 15GHz, both data M-Cal and E-Cal were found less correlation.

Table 4. EN Ratio for Full Two Port Calibration

EN ratio full two port cal								
	M Cal F2p		E Cal F2p					
Freq GHz	Linear Mag	Uncertainty	Linear Mag	Uncertainty	Delta	RSS	EN Ratio	Status
0. 045	0.9991	0.0220	0.9996	0.0220	0.0005	0.0311	0.0167	PASS
1	0.9986	0.0220	0.9978	0.0220	0.0008	0.0311	0.0263	PASS
5	0.9973	0.0220	0.9977	0.0220	0.0004	0.0311	0.0122	PASS
10	0.9957	0.0220	0.9947	0.0220	0.0010	0.0311	0.0309	PASS
15	0.9941	0.0220	0.9957	0.0220	0.0016	0.0311	0.0501	PASS
20	0.9935	0.0480	0.9916	0.0480	0.0019	0.0679	0.0280	PASS
25	0.9909	0.0480	0.9891	0.0480	0.0018	0.0679	0.0263	PASS
30	0.9858	0.0860	0.9821	0.0860	0.0037	0.1216	0.0302	PASS
35	0.9742	0.0860	0.9690	0.0860	0.0052	0.1216	0.0428	PASS
40	0.9866	0.0860	0.9862	0.0860	0.0004	0.1216	0.0030	PASS
45	0.9916	0.0860	0.9925	0.0860	0.0009	0.1216	0.0075	PASS
50	0.9923	0.0860	0.9922	0.0860	0.0001	0.1216	0.0006	PASS

5 Conclusion

Conclude that this project guides the operation of a network analyzer and calibration kits to perform the calibration job according to the standards and procedures. Network analyzer will not limit to measure the RF connector. An EN ratio had been calculated between the Mechanical Cal Kits and Electronic Cal Kits are well establishing to evaluate the technique of ports calibration. The S1p and F2p techniques also successful documented in this project. It is a unique process to calibrate an RF connector measured from 45MHz until 50GHz. The results also showed that the F2p very correlate along the wide bandwidth, but the S1p only correlate well in low frequency until 17GHz. Beyond the frequency of 17GHz, both techniques for S1p will start to lose the strong correlation.

Table 5. Overall Results for M-Cal and E-Cal Kits

Overall Results				
	Mechanical Cal Kit		Electronic Cal Kits	
	M Cal S1p	M Cal F2p	Ecal F2p	Ecal S1p
Time	5 minutes	30 minutes	20 minutes	10 minutes
Speed	Very fast	Slow	Medium	Very fast
Accuracy	Low	High	Medium	Low
Precision	Low	High	Medium	Low
Skills	Low	High	Low	Low
Investment	Expensive	Expensive	Expensive	Expensive

Table 5 is the overall conclusion of this study. It compares the technique of S1p and F2p against the time, speed, precision, skills and investment budget. Each technique has its advantages and disadvantages. If the method need apply in a mass production, M-Cal S1p is the most applicable. It is very fast but not accurate and not precise. It does not involve any high skills worker to perform the calibration job. Each RF connector only consumes 5 minutes per calibration compare to M-Cal F2p is the longest calibration time. It is 6 times longer than M-Cal S1p, but M-Cal F2p shows more accurate and precision measurement. M-Cal F2p technique suitable for high accuracy and particular workstation to measure the RF connector insertion loss and port match. It is also required high accurate, precision and skills workers to carry the calibration task. Electronic cal kit would be more users friendly. It does not require too much connection compare to Mechanical cal kit. It is all in one module to perform the entire calibration task. It is less connections and allowed the worker to multitasking while waiting for the Electronic cal kit module performing the calibration with the network analyzer. It is a great tool for low volume but wide variety production because no monitoring process is required along the calibration.

References

1. Keysight Technologies, Keysight Technologies Network Analyzer Selection Guide, USA: 5989-7603EN, August 19, 2015.
2. HUBER+SUHNER, RF Connector Guide - Understanding connector technology, Switzerland, 4th edition, 2007.
3. Keysight Technologies, Keysight 11904S 2.4 mm/2.92 mm Adapter Set, USA: 11904-90009, Edition 5, August 2014.
4. Keysight Technologies, Keysight Electronic Calibration Modules, USA: N4693-90001, Edition 2, July 29, 2015.
5. Keysight Technologies, Keysight Technologies 85056A 2.4 mm Precision Calibration Kit, USA: 85056-90020, October 2014.
6. Asia Pacific Laboratory Accreditation Cooperation, Calibration Interlaboratory Comparisons APLAC PT 001 APLAC PT 001, North Melbourne VIC 3051 ,Australia: NATA, 03/08.
7. Agilent Technologies No.16000-95024, Agilent E5070B/E5071B ENA Series RF Network Analyzers Adapter Characterization First Edition, Japan: Agilent Technologies Japan, Ltd., September 2002.