ENTRO DE ENSEÑANZA TÉCNICA Y SUPERIOR

Colegio de Ingeniería
Dirección de Posgrado
Campus Mexicali

Proyecto de Ingeniería e Innovación

"An Improvement Proposal for Mismatch Condition Problem in Dragon Test System"

para obtener el grado de

Maestría en Ingeniería e Innovación

Presenta

Bernard Carpio Binuya

Director de proyecto: Dra. Dania Licea Verduzco

Co-director de proyecto: Dr. Luis C. Básaca Preciado

Asesor Industria: MBA Zelman Hernández Castro

Mexicali, Baja California. Junio de 2018

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Comité evaluador:

MC.Cristóbal Capiz Gómez

Dr. Miguel A. Salinas Yáñez

Dr. Miguel A. Ponce Camacho

Mexicali, Baja California. Junio de 2018

Acknowledgement and Dedication

I would like to acknowledge Skyworks for making my master's degree education possible, without its continuous improvement program, I may not be able to support my studies in this great university.

To my family, my inspiration who push me to the limit in search for fresh new knowledge, this is for you.

To my Guide in all of this work, I return all the recognition and all the dedication to our Almighty Creator.

Company Letter

SKYWORKS

SKYWORKS SOLUTIONS DE MEXICO S. DE R.L. DE C.V.
CALZADA GOMEZ MORIN 1690 COL. RIVERA
MEXICALI B.C
TEL. (686)564-2100

March 16, 2018

CETYS UNIVERSITY
College of Engineering
Post Graduate School
Mexicali Campus

Through this document, I would like to inform my accordance in the completion of the project:

"A design proposal to solve tester related mismatch condition problem in Dragon Test System"

This project will be developed by **Bernard Carpio Binuya** under the supervision of the Cetys academic assessor.

The project is accepted and considered relevant and it is aligned to company's mission, vision, and objectives. It would have the managerial support of the required resources for the completion of such project with the commitment of the employee to fulfill the objective mentioned in the details of the preliminary draft.

Respectfully Yours,

Zelman Hernandez Castro
Test Engineering Director

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Abbreviations

Overall Equipment Effectiveness (OEE)

Gross Margin (GM)

Device under test (DUT)

Automatic test equipment (ATE)

Radio Frequency (RF)

Dragon test system (DRG)

Printed circuit board (PCB)

Gigahertz (GHz)

Megahertz (MHz)

Alternating Current (AC)

Network Analyzer (NA)

Summary

Equipment availability in a Manufacturing company is one of the three factors to measure overall equipment effectiveness (OEE). It is the percentage of time that equipment is operating compared to the planned time of operation or available downtime losses (Munro, Ramu, & Zrymiak, 2015). The other factors that contribute to the OEE are *performance* and *quality* as shown in equation (a). All the factors in this project will be directed to availability.

$$\textbf{OEE} = \underline{\textbf{Availability}} \times \textbf{Performance} \times \textbf{Quality} \qquad \text{(a)}$$

Availability is the ability of the company to utilize resources in order to produce more products. It is also a metric that can be used to measure the performance and to effectively asses company's own growth. Skyworks is working continuous to improve the OEE that would directly impact the gross margin (GM). Gross margin is a company's total sales revenue minus its cost of goods sold, divided by total sales revenue, expressed as a percentage (Investopedia.com, n.d.). As mentioned, the more availability, the more goods to be produced thus increasing the sales.

The general objective of this project is to search and define the causes of the downtime and make recommendations to eliminate or minimize such factors. The project will be focused on identifying different factors that affect the productivity and measures its contribution to the total downtime.

This document presents the project investigation that consists of the definition and plan of the problem development. Some technical terms are well explained in the later part of the document based from credible sources. Case studies are also to explore in relation with this project.

1. Introduction

The Skyworks is one of the most well-known semiconductor companies in its business sector enabling the world of communications (Murphy, 2017). The company in Mexicali is the manufacturing section that has 2 major divisions – assembly and test as shown in Figure 1. The company assembles and tests microelectronics devices for wire and wireless business. This project would be focus in test production area when all the devices are being tested in conformity with the device's design and functionality.

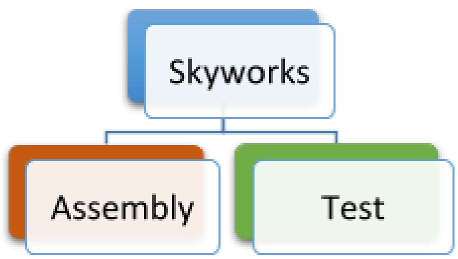


Figure 1. Skyworks Mexicali Main Divisions
Source: Own elaboration

1.1 Background

The test area is responsible in testing every product electrically to ensure the functionality as it is designed. The testing area is the last stage in the process before sending the product to customer.

In test area, there are 4 different test system types called automated test equipment (ATE) or simply "tester" as shown in Figure 2. The emphasis of this project is on Dragon test system (DRG) where majority of the time, the equipment availability is lower than expected. This test system is currently and widely used for testing different devices. In addition, this tester has the biggest number in quantity where it has more than 50% of the total testers available.

The downtime (unscheduled time losses in the machine) is significantly high compare to other tester types most of the time. The issues are mostly related to the availability of the testers, therefore, the focus will be limited to DRG test system.

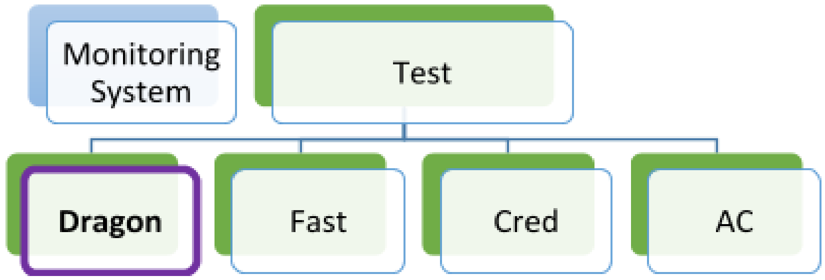


Figure 2. Test area subdivisions. DRG is the focus
Source: Own elaboration

In all the test system types, a central and online setup **monitoring system** is installed to help us identify current problem by specific day and time. The day to day problems are being compiled by shift and these data are being stored into a database that could be used for inquiry later on and further analysis by concerned group.

Data is collected from the online setup monitoring system in a period of 3 months from June to August 2017. The maintenance department that is responsible for the setup analyzed the data and generated a report. Based on this, there is an average of 150 setups being done per week. Each setup is expected to finish in 3 hours. However, majority of the time it lasts between 5-6 hours. That is double the amount of the standard setup time which directly affects availability.

A company that has high availability time produces more products therefore more profitable. In contrast, a company that has less availability time produces fewer products, therefore, less profitable. Key factors affecting the availability such as downtime must be minimized to be able to effectively use the resources to produce more products.

This setup issue has been one of the top problems since June 2017 and continuously being seen in production. As this issue is becoming more relevant and has major impact to production metrics, the management would like to take action to reduce its contribution OEE.

1.2 Justification

Currently, the corporate has a long term goal to achieve overall Gross Margin (GM) and all the country's divisions have been asked to contribute to this drive. Being the manufacturing division in the company where the OEE is a production everyday metric that is being monitored, that would have direct impact to the GM. In order to contribute towards the effort, the test engineering director is supporting this project improvement. At the end of the project, it expected to reduce the downtime (mismatch condition) which would increase the time available for testing product.

1.3 Problem Statement

To understand these factors, the complete test setup and its basic components are shown in Figure 3.

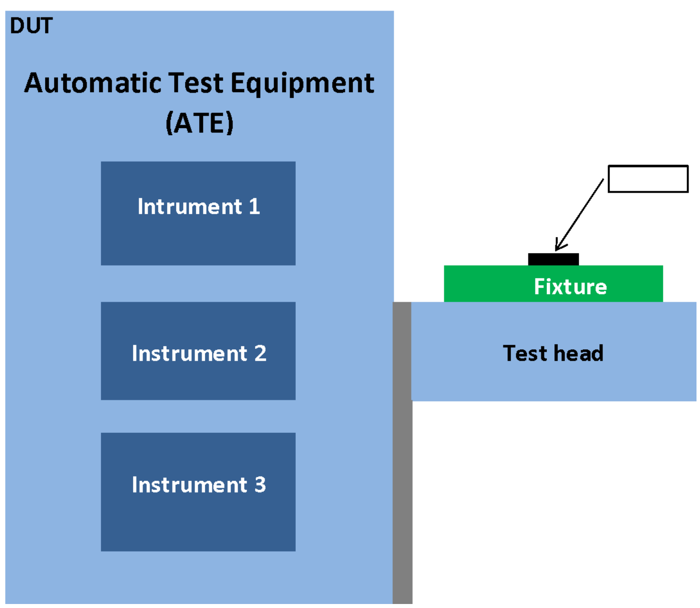


Figure 3. ATE test setup
Source: Own elaboration

ATE is a machine that is designed to perform tests on different devices referred to as a **device under test** (DUT). It is composed of different instrument necessary to produce signal needed in electrical testing and receive the DUT response that is translated to a readable measurement data. An ATE uses control systems and automated information technology to rapidly perform tests that measure and evaluate a DUT (Techopedia.com, n.d.). In case of DRG tester, there are 16 radio frequency (RF) ports used in sending and receiving signals.

A **fixture** is an interface between the ATE and DUT. It is composed printed circuit boards (PCB) that contain circuitry to correctly deliver the signal from the tester to the DUT. It is also composed of different components that are required in testing the DUT correctly. The fixture is normally place on top of the test head.

Based on the data analyzed by Maintenance department, a pareto chart was generated as shown in Figure 4. Pareto chart is a graphical tool used for ranking causes from most significant to least significant (Munro, Ramu, & Zrymiak, 2015). The x-axis represents the period where the data is taken and y-axis is the number of occurrence. There are 3 significant factors seen out of 5. These 3 significant factors have the highest occurrence and constantly present in 3 consecutive months. These are fixture issues, tester issues and mismatch condition.

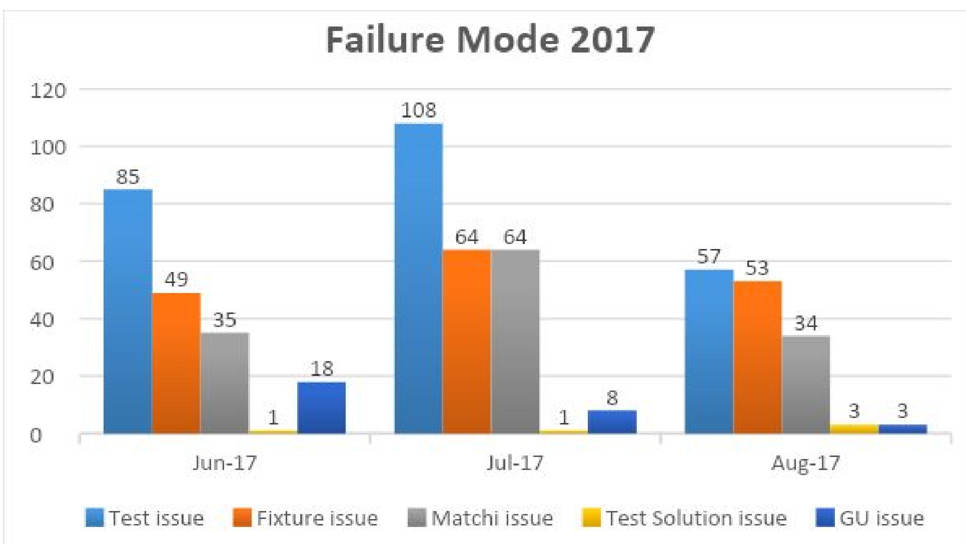


Figure 4. Pareto main downtime from Jun to Aug 2017
Source: Own elaboration

All the issues found on the components related fixture is called **fixture issue**. This includes but not limited to broken cable, wrong board used and wrong components used in PCB. At the same time, all issue found that is related to tester is called **tester issue**. This includes but not limited to damaged instruments inside the tester.

Mismatch condition is when the problem cannot be identified whether the tester or fixture is causing setup failure. Most of the time, this type of problem is being resolved by interchanging fixture or ATE. Some combination of such make the setup works and some are not.

Example is given in Table 1 to better understand the mismatch condition. In the first 2 rows, **Fixture 1** and **Fixture 2** are setup successfully on **Tester A**. Therefore, both fixtures are proven working. On the 3rd row, **Fixture 1** is setup on **Tester B** successfully as expected because it has been set up on previous tester without any problem. On the last row, when the **Fixture 2** that is proven working, is setup in **Tester B**, for an unknown reasons, it failed where it is expected to pass since it was successfully setup in previous tester. This condition is an example of the mismatch problem.

Table 1. Mismatch Condition
Source: Own elaboration

No.	Tester	Fixture	Works?
1	Tester A	Fixture1	Yes
2	Tester A	Fixture2	Yes
3	Tester B	Fixture1	Yes
4	Tester B	Fixture2	No

In addition, the tester calibration may cause mismatch condition. The tester calibration is a verification of the tester by measuring actual performance and compensating the losses comparing the establish standard to have more accurate measurement. It uses an input calibration files that consist of different input signal levels frequency list and different port combination. The calibration will use those signals and will measure the actual and would compare to the expected values. The difference will be the loss. The calibration will continue until it finished all the frequencies and all port combination. At the end of calibration, the tester will record all the losses in an output file that will be later use in production testing (Stern, 2016).

Physical condition of the connectors and contact between tester and fixture could cause mismatch condition also. There is a wide selection of RF connector and cables. The quality of these components should be the top priority in the selection. Due to regular interfacing of the fixture to the tester, the connectors might wear out and might produce metal particles. Since RF signals are transmitted in the cables and connectors, those particles may induce extrinsic signal that will alter the good signal. Therefore poor quality signal will be delivered to the DUT that will cause mismatch condition (Skinner, 2007)

Currently, there are groups now working with the fixture issue and tester issue but no group is currently assigned to work on the mismatch issue where it has 23% contribution to downtime as shown on Figure 5. Therefore, the project will be focused on the mismatch condition.

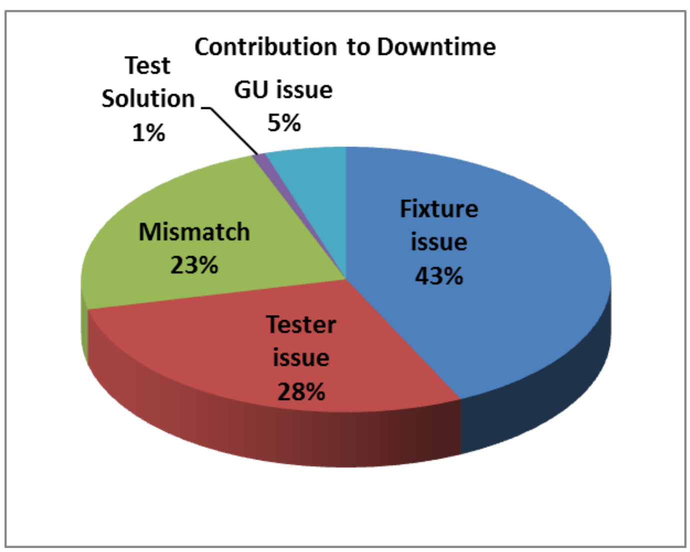


Figure 5. Contribution of Downtime
Source: Own elaboration

1.4 Investigation Question

This project is planned to seek and to answer the following question:

Why mismatch condition problem is present in Dragon Test system and what are the options to improve its causes?

1.5 Objectives

The general objective of this project is to give appropriate recommendations on how to improve the identified causes of the mismatch condition problem in Dragon test system.

1.5.1 Specific objectives

Based on above observations, more specific objectives are presented to further seek the most significant causes of the problem and propose specific recommendations to resolve the mismatch condition problem in Dragon test system.

1. Identify and corroborate the overall contribution of each factor and its elements that affect setup time (downtime).
2. Verify calibration settings are appropriately defined for testing.
3. Validate the application of the design rules and standard.
4. Verify the physical condition of the tester RF components.

1.6 Hypothesis

This project defines the following hypothesis to prove:

The Dragon test system is the principal cause of mismatch condition problem.

2. Theoretical Framework

The following are the terminologies used in this document as explained concisely.

The Gross Margin (GM) is a company's total sales revenue minus its cost of goods sold, divided by total sales revenue, expressed as a percentage. This metric is used by Skyworks to determine the financial health of the company. One factor that affects GM is the OEE (Investopedia.com, n.d.).

OEE has three main factors: availability, performance and quality. It is the standard for measuring manufacturing efficiency and effectiveness of process or equipment. The idea of the OEE is to assess when equipment is making good product and compare that duration with the total possible that the equipment could theoretically make good product. As manufacturing company, Skyworks is dedicated to increase the OEE in a short and long term period. (Munro, Ramu, & Zrymiak, 2015).

As mentioned, the main focus of the project is in Test Production area where more than 400 ATE is operated 24 hours a day. There are 4 types of ATE Skyworks is using but all of them has the same electrical characteristic. An ATE is a system of multiple instruments used to supply electrical energy to power up a device under test and measure its desired output performance based on the device functionality and design. It is a computer-operated machine that has the objective to quickly confirm whether a DUT works and to find defects (Techopedia.com, n.d.).

Device under test (DUT) is a device that is tested to determine performance and is being checked for defects to make sure the device is working the way it is designed.

For statistical analysis, the project involves the use of quality tools such as pareto chart to find the causes and identify the most significant factors. Pareto chart is a bar graph where the lengths if the bars represents frequency or cost in time or money that are arrange from longest bar on the left and shortest bar on the right. It used when analyzing data about the frequency of problems or causes in a process. It is used when there are many problems or causes and you want to focus on the most significant (Tague, 2005).

The next information is composed of difference case studies and references as a project resource.

This project is based on wireless technology that encompasses and uses radio frequency. The topic of radio frequency is entirely wide, hence a basic knowledge would be sufficient to understand the concept used on this project. The foundation of this information is based the application notes from one well know test equipment company that talks about the RF fundamental concepts. The information will start with what is Radio frequency. Radio frequency (RF) is basically defined as a form of electromagnetic wave, such as visible light, which make up a portion of the electromagnetic (EM) spectrum. The EM spectrum encompasses all forms of light, which ranges from audible frequencies such as the ubiquitous 60Hz, through the standard radio bands which include AM Radio, FM Radio, TV channels, and other RF bands. The spectrum continues through infrared, visible, and ultra-violet light, to higher forms of EM energy like X-rays, Gama-rays, and cosmic rays. RF is referred to low-frequency that human could hear from 20Hz to 20KHz to high frequency that produce infrared and visible light as shown in Figure 6. Radio frequency spectrum is highlighted in orange that are subdivided in different bands (Stoehr, 2012).

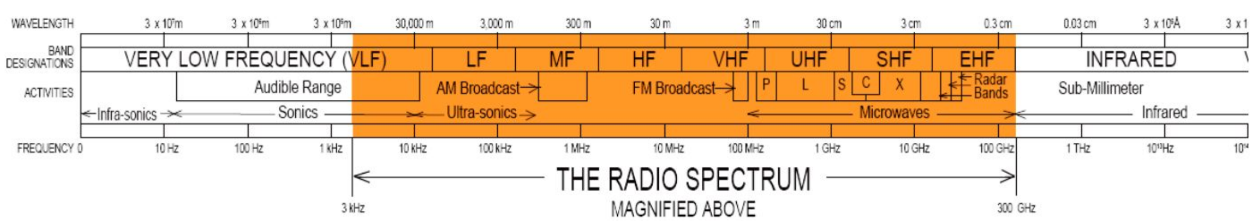


Figure 6 Radio Spectrum
Source: RFBasics by M. Stoehr

Most of the products that are being tested in Skyworks are within the 800MHz to 6.0 GHz. At this frequency ranges, the complexity to achieve a better test measurement results is highly expected since high frequency would be more vulnerable measurement errors. The characteristic of the ATE, fixture and DUT itself would become more complex as radio frequency gets high. It has been a challenge for many RF engineers how to get a good response from the measurement result in higher frequency ranges.

Part of the methodology is to verify the effectiveness of the system calibration of the Dragon test system. Measurement errors are divided into 2 categories. They are **random errors** that are non-repeatable measurement variations and are usually unpredictable and **systematic errors** are repeatable measurement variations in the test setup. Systematic errors include impedance mismatch, system frequency response and leakage signals in the test setup (Keysight Technologies, 2016). The project will do a research on the **system errors only**.

The reference used on the calibration method recommends that one way to correct these errors is by calibration. The test system calibration is a process to correct systematic errors. Compensation to achieve zero error could be done by typical calibration methods and kits. Calibration kit consists of set of physical devices called standards. Each of the standards has precise and accurate recorded values in a known frequency ranges. These standards are composed of short, open, loads and thru. Since the behaviors of all standards are known, the tester system error could be defined using them in a tester. The load behavior largely sets the directivity errors. Together, the short and open largely determine source match and reflection problem. The thru determines transmission tracking and load match Upon completion of calibration, the measurement result will be compared to the known values of each standard and the difference will be compensation values to correct the system error (Anritsu Company, 2012).

Based on the fundamental concept of high frequency testing on reference used, the impedance is another factor to be considered in testing RF devices. It is used to characterize electronics circuits and components. Impedance (Z) is generally defined as the total opposition a device or circuit offers to the flow of an alternating current (AC) at a given frequency. Impedance is a commonly used parameter and is especially useful for representing a series connection of resistance (R) and reactance (X), because it can be expressed simply as a sum. To find the impedance, we need to measure at least two values because impedance is a complex quantity. Many modern impedance measuring instruments measure the real and the imaginary parts of an impedance vector. It is only necessary to connect the unknown component, circuit, or material to the instrument. Measurement ranges and accuracy for a variety of impedance parameters are determined from those specified for impedance measurement. Automated measurement instruments allow you to make a measurement by merely connecting the unknown component, circuit, or material to the instrument. However, sometimes the instrument will display an unexpected result (too high or too low.) One possible cause of this problem is incorrect measurement technique, or the natural behavior of the unknown device (Keysight Technologies, 2016).

Part of the project is to measure and characterize RF components using Network Analyzer. An application notes available from a respected RF cable manufacturer is used as a reference. Warming up the instrument and doing calibration are the first steps to in acquiring an accurate measurement. The article explains how procedure is done. In addition, it explains different ways to verify the cables under test before going to electrical testing. Such tests are connector verification, electrical testing and stability testing. These tests are easily executed by most RF test engineers who might need a practical method to assess a cable's quality (Copper Mountain Technologies, 2017)

The project also requires to measure impedance of the RF components. There are two common parameters associated with the impedance which are inductance and capacitance. These parasitic components are present in proportion to the level of RF frequency. The higher the frequency, the higher the probability the components are susceptible to these unwanted parasitic signals that affect the impedance. Another example that affect impedance is when the wave traveling through the 75-Ω coaxial cable encounters a 50-Ω termination of another component. This condition is technically described impedance mismatch (National Instruments Corp., 2007).

Other measurement standard that is use to characterize RF components are Scattering parameter testing, or simply S-paramaters. In general, most of the RF components has 2 ports – input and output ports. The S-parameters technique is used for this type of components to measure 4 types of measurements which are explained briefly below.

S11 – reflected power at the input
S21 – gain or loss
S22 – reflected power at the output
S12 – isolation or reverse gain

These measurements could also be represented in graphical form using a Smith chart. The Smith chart as shown in Figure 7 is a graphical aid that can be very useful for characterizing transmission line. Although there are a number of other impedance charts that can be used for such problems, the Smith chart is probably the best known and most widely used. It was developed in 1939 by P. Smith at the Bell Telephone Laboratories. fact that it can be used to convert from reflection coefficients to normalized impedances. The normalized impedance at perfect match is found at the center of the Smith chart. (Pozar, 2012).

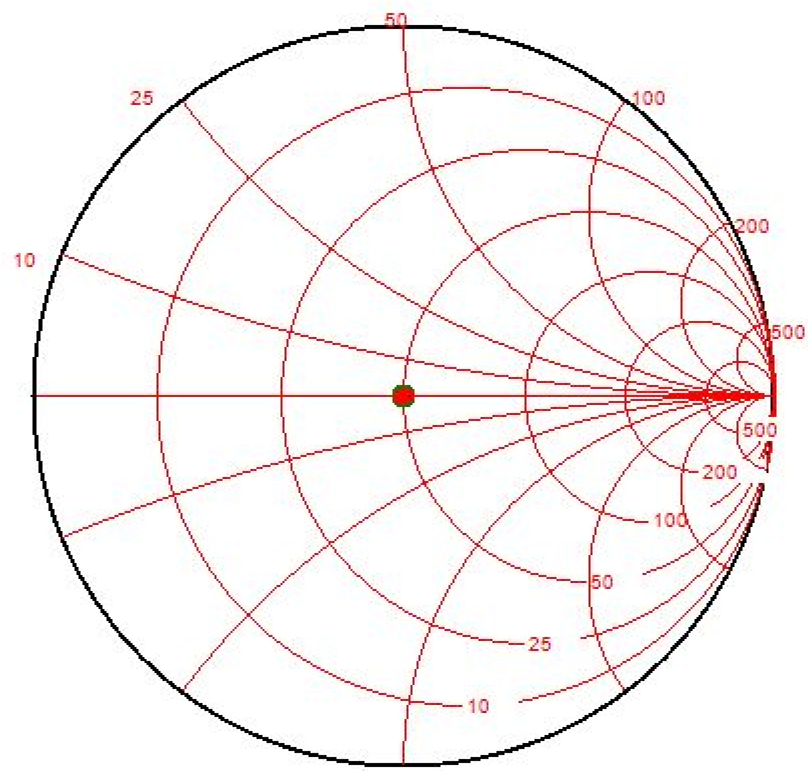


Figure 7. Smith Chart with Impedance of 50-ohms

Source: Fritz Dellsperger Smith Chart

In order to validate the electrical characteristics of the RF components analyzed in this project, the results are compared to the IEEE Standard for Precision Coaxial Connectors (DC to 110 GHz) shown in Table 2. Below is the electrical specification of the SMA type connector (IEEE , 2007).

Table 2. 3.5 mm / SMA Connector Electrical Specifications
Source: IEEE Std 287™-2007

Description	Symbol	GPC/GPC specification	LPC/GPC specification	Definition paragraph	Test method paragraph
Impedance	Z_0	50 Ω	50 Ω	2.1.3	4.2.1
Delta impedance	ΔZ_0	0.4%	0.2%	2.1.3	4.2.1
Minimum upper rated operating frequency	f_{op}	33 GHz	33 GHz	2.2.7	n/a
Cutoff frequency (air line)	f_{c11}	38.8 GHz	38.8 GHz	2.2.7	n/a
Return loss magnitude	$\lvert S_{11}\rvert$	32 dB	36 dB	2.2.1 2.2.8.1	3.2
Repeatability of return loss	$\lvert\Delta S_{11}\rvert$	55 dB @ 26.5 GHz	60 dB @ 26.5 GHz	2.2.4	3.3
Insertion loss magnitude	$\lvert S_{21}\rvert$	0.30 dB @ 33 GHz	0.30 dB @ 33 GHz	2.2.2 2.2.8.2	3.4
Repeatability of insertion loss (mag)	$\Delta\lvert S_{21}\rvert$	0.008 dB @ 33 GHz	0.008 dB @ 33 GHz	2.2.4	3.4.4
Repeatability of insertion loss (arg)	$\Delta \arg S_{21}$	±0.1° @ 33 GHz	±0.1° @ 33 GHz	2.2.4	3.4.4
Accuracy	Δl_e	±0.0075 cm	±0.0075 cm	2.2.6 2.2.8.4	3.4.3
Shielding effectiveness	a_s	100 dB	100 dB	2.2.5 2.2.8.3	3.5
Description	**Symbol**	**Inner conductor**	**Outer conductor**	**Definition paragraph**	**Test method paragraph**
Contact resistance	R_{dc}	0.75 mΩ	0.13 mΩ	2.2.3 2.2.8.5	3.6
Repeatability of contact resistance	ΔR_{dc}	0.15 mΩ	0.02 mΩ	2.2.4	3.6

On another reference, it is recommended that selection, the physical/mechanical condition and the torque used to tighten the coupling of RF components such as connectors and cables are crucial in getting a reliable signal. The type of cables that is widely used is coaxial cable. A coaxial cable comprises of an inner conductor contact and an outer conductor contact which is separated by a dielectric between them. Both ends are terminated with connectors that are used to couple to another system or components. The most important characteristic of RF cables is the frequency where it operates giving the best result possible. Beyond its operating frequency, the measurement performance would degrade and unexpected measurement variation would start to appear. Due to this, it is recommended to consider this characteristic and compatibility to the proposed application in the selection (Rohde & Schwarz, 2015).

The physical condition and mechanical interfaces of the cables and connectors are subject to damage with continued used. Dirt and metallic particles maybe present on the connector and would only be visible under a microscope. Bent or worn out inner conductor is also possible to happen. Taking care and regular maintenance of the coaxial cables such as cleaning is essential for the following reasons.

- Minimum RF insertion loss and mismatch
- Good stable measurement repeatability
- Minimizing damage to expensive test equipment connectors
- Maximizing the life of the connector

New and well-maintained cables could be connected to another system or components with an appropriate torque to tighten for interface. A special tool called torque wrench should be used to apply the necessary force for tightening to ensure tolerances are not exceeded, which could cause early damage to mating connectors. (Rohde & Schwarz, 2015).

3. Methodology

The methodology is divided in 4 main phases: data collection, calibration review, design rules application, and tester-fixture interface. These phases will be focused to achieve the specific goals.

These main activities are spread out get more details that is used for data analysis. Each activity is directed to achieve the specific goals.

1. Data Collection

The first phase in the investigation is to collect data to verify the problem does continuously exist. This will be an explorative qualitative investigation, using the descriptive statistics to describe the results. The data will be collected in the period of 3 months, similar to the data presented in Figure 4. The fresh data will be compared to the previous to demonstrate the recurrent existence of the problem. The full data will be analyzed and a pareto chart will be provided to know the most significant factors that is causing downtime. The data could be analyzed by different criteria to better define the possible root causes.

2. Calibration

The second phase is to verify and analyze the tester calibration files. Tester calibration is done on two parts – source and measure path. Calibration is very important to make sure that signal going out and in to the tester are on the right level. This guarantee the levels going to the DUT is at the correct magnitude. In addition, it assures precise measurement of the signal coming from the DUT by compensating the path losses inside the tester.

When the signal is not correct, the behavior of the DUT will change is a different state where the result of the measurement would not be accurate leading to failures and quality issues. These activities will make sure the calibration is being done correctly and correction data is accurate and well within the specification.

3. Design Rules Application

The third phase would be design rules validation. This phase is to characterize RF components using a special equipment to measure its electrical characteristics. Each component in the testing system such as fixture and tester has their own impedance characteristic. For RF components, a 50-ohm impedance is the standard where the it is a good compromise between lowest loss and highest power handling. Non-RF devices could use different impedance that will be more suitable for its application (Breed, 2007).

Tester compatibility to 50 ohms impedance will be measured to make sure the fixture and the tester will have a perfect match. Perfect match impedance is a condition where all the RF power is delivered from source to the load (Pozar, 2012). Each of these components should have 50 ohms. If one of the components does not have a 50 ohms impedance, power would be lost and the result of the measurement would be different to what is expected. Even high level of difference would be acquired if two or more components do not have 50 ohms impedance. This might happen when the design of the test fixture and tester does not follow standard design rules.

4. Tester connectors condition

The last phase is the verification of the connection between the fixture and tester. This phase is to verify the physical damaged or worn-out connectors as well as loose connection between RF components. These are the basic problems that cause impedance mismatch. This phase also includes activities to ensure the connection is adequately tightened to a standard torque of 8-lb (Fairview Microwave). This is to make sure of perfect impedance is acquired.

3.1 Work Plan and Required Resources

The summary of the activities is listed in the Figure 8 including the post activities such as documentation of all experiment evidences and reports for the final presentation.

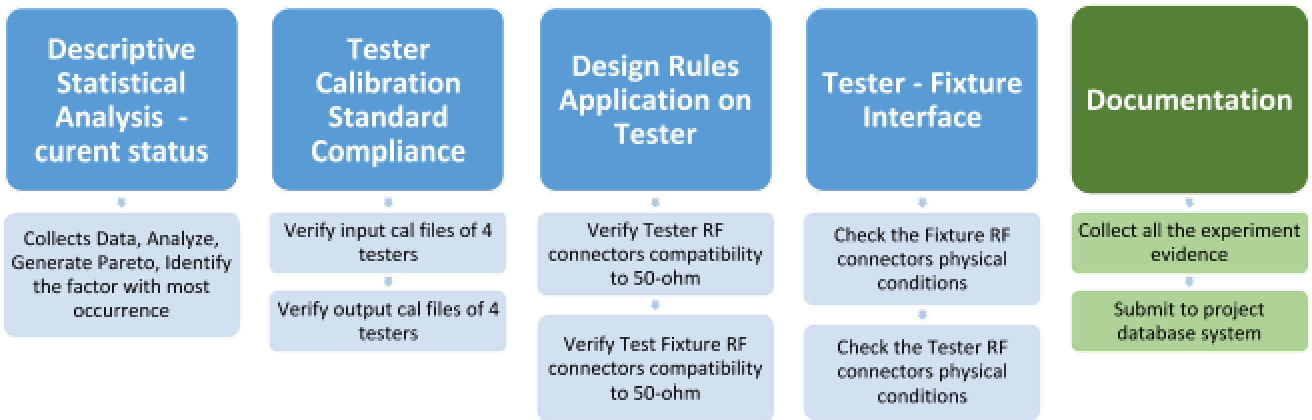


Figure 8. Project Work Plan
Source: Own elaboration

The responsible and required resources by activity are summarized in Table 3. These activities will start on March 20, 2018 and expected to finish on June 1 2018. Starting phase 2, partial tester time (4 hours per day) will be needed to start the calibration verification. Phase 3 and phase 4 will need full tester time (8 hours per day). It is expected to use 2 full tester time per week during the phase 3. The documentation will follow for the preparation for the final presentation scheduled on June 9, 2018.

The whole team will be composed team member (TM) from test hardware, test maintenance and test engineering.

Table 3. Summary of Activities and Resources

Source: Own elaboration

Phase	Task Name	Period (Days)	Responsible	Resources
1	Descriptive Statistical Analysis	9	TM - Hardware	n/a
2	Tester Calibration Standard Compliance	7	TM - Hardware	Partial Tester time
3	Design Rules Application	30	TM - Hardware, TM-Maintenance, TM –Test Engineering	Network Analyzer
4	Tester - Fixture Interface	5	TM - Hardware, TM-Maintenance	Partial Tester time
5	Documentation	5	TM - Hardware, TM-Maintenance, TM –Test Engineering	n/a

* TM – Team member

To organize the activities, a Gantt chart is generated in Figure 9. This tool will make the tracking of the activities more efficient. Upon the confirmation of this project, the activities will resume in accordance to the work plan.

The expected start of project is March 20, 2018. Different activities per phase will be done in accordance to the planned dates as seen on the start and finish date. The total duration the activities are also observed on the period column. The Gantt chart on the last column would be used to track each activities and its progress. The project completion date including the documentation is expected on June 1, 2018.

	Task Name	Duration	Start	Finish	Resource Names
✓	**Project**	**56 days**	**Tue 3/20/18**	**Sat 6/9/18**	
✓	Start	0 days	Tue 3/20/18	Tue 3/20/18	
✓	**Descriptive Statistical Analysis - Current status**	**9 days**	**Tue 3/20/18**	**Tue 4/3/18**	
✓	Collect Data from Jan- Mar 2018	3 days	Tue 3/20/18	Thu 3/22/18	Hardware TM
✓	Analyze data	3 days	Fri 3/23/18	Tue 3/27/18	Hardware TM
✓	**Genate Pareto**	**3 days**	**Fri 3/23/18**	**Tue 3/27/18**	**Hardware TM**
✓	Pareto by Product	3 days	Fri 3/23/18	Tue 3/27/18	
✓	Pareto by Shift	3 days	Fri 3/23/18	Tue 3/27/18	
✓	Pareto by Tester	2 days	Fri 3/23/18	Mon 3/26/18	
✓	Identify PN with most occurrence	3 days	Wed 3/28/18	Tue 4/3/18	Hardware TM
✓	Identify tester with most occurrence	3 days	Tue 3/27/18	Mon 4/2/18	
✓	**Tester Calibration Standard Compliance**	**7 days**	**Wed 4/4/18**	**Thu 4/12/18**	
✓	**Verify input cal files of 3 testers**	**4 days**	**Wed 4/4/18**	**Mon 4/9/18**	**Maint TM**
✓	Collect Data from tester	3 days	Wed 4/4/18	Fri 4/6/18	
✓	Convert Data to readable format (csv)	1 day	Mon 4/9/18	Mon 4/9/18	
✓	**Verify output cal files of 3 testers**	**4 days**	**Wed 4/4/18**	**Mon 4/9/18**	**Maint TM**
✓	Collect Data from tester	1 day	Wed 4/4/18	Wed 4/4/18	
✓	Convert Data to readable format (csv)	1 day	Mon 4/9/18	Mon 4/9/18	
✓	Analyze Cal Input and Ouput file	3 days	Tue 4/10/18	Thu 4/12/18	
✓	**Design Rules Application**	**30 days**	**Fri 4/13/18**	**Fri 5/25/18**	
✓	Verify Tester RF connectors compatibility to 50-ohm	15 days	Fri 4/13/18	Fri 5/4/18	Maint TM
✓	Verify Fixture RF connectors compatibility to 50-ohm	15 days	Mon 5/7/18	Fri 5/25/18	Hardware TM
✓	**Tester - Fixture Interface**	**5 days**	**Mon 5/7/18**	**Fri 5/11/18**	
✓	Check the Fixture RF connectors physical conditions	5 days	Mon 5/7/18	Fri 5/11/18	Hardware TM
✓	Check the Tester RF connectors physical conditions	5 days	Mon 5/7/18	Fri 5/11/18	Maint TM
✓	**Documentation**	**5 days**	**Mon 5/28/18**	**Fri 6/1/18**	
✓	Collect all the experiment evidence	5 days	Mon 5/28/18	Fri 6/1/18	
✓	Submit to project database system	5 days	Mon 5/28/18	Fri 6/1/18	
✓	End	0 days	Fri 6/1/18	Fri 6/1/18	
✓	Presentation	0 days	Sat 6/9/18	Sat 6/9/18	

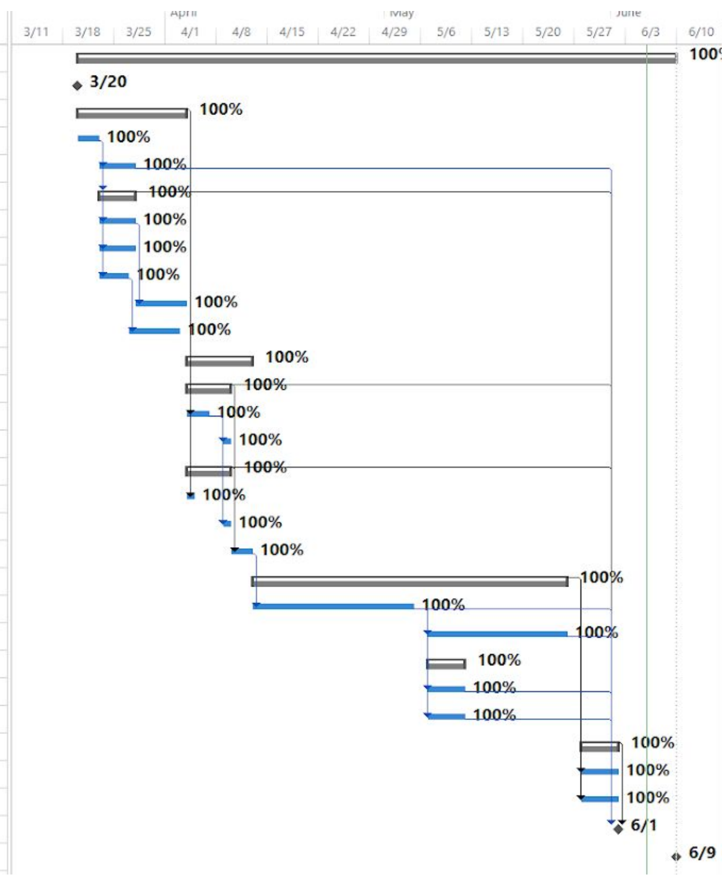


Figure SEQ Figure * ARABIC 9. Work plan

4. Results

According to the work plan described in the methodology section, the result is divided into 4 phases - data collection, calibration review, design rules application, and tester-fixture interface. These activities were done to accomplish the goals defined on this project to give appropriate recommendation on how to improve the mismatch condition problem. The results are given following the work plan.

1. Data Collection

The first phase is done to corroborate the continuous existence of the problem as observed previously from Figure 4. This activity is intended to identify the possible sources of the mismatch condition in Dragon test area.

Data is taken from all DRG testers from January to March 2018 that showed different types of failures in general.

There are 3 data analysis done by reviewing and evaluating three different categories - by tester, by product and by period (monthly). As a compliment, the data is also analyzed by work schedule (shift).

On general analysis, the data presented here is the failure mode grouped by month starting from Jan to Mar 2018. Figure 10 shows that the match issue is continuously present during the first quarter of 2018 as shown on the green bar. It is observed that there are increase in the number of occurrence compared from the previous year (June to August 207 from Figure 4). There are from 133 events on 2017 compared to 253 event in 2018. This increase represents 90%, almost doubled from the previous.

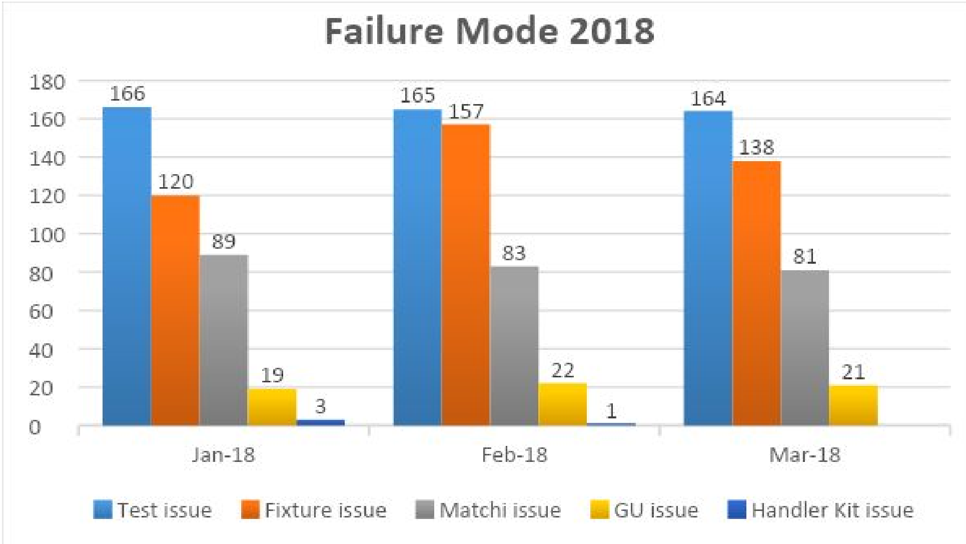


Figure 10. Pareto main downtime from Jan to Mar 2018
Source: Own elaboration

To verify how much is the contribution of each factor, a pie graph is shown to Figure 11. It is observed that there is 20% problem related to mismatch condition very close to the 2017 data of 23%.

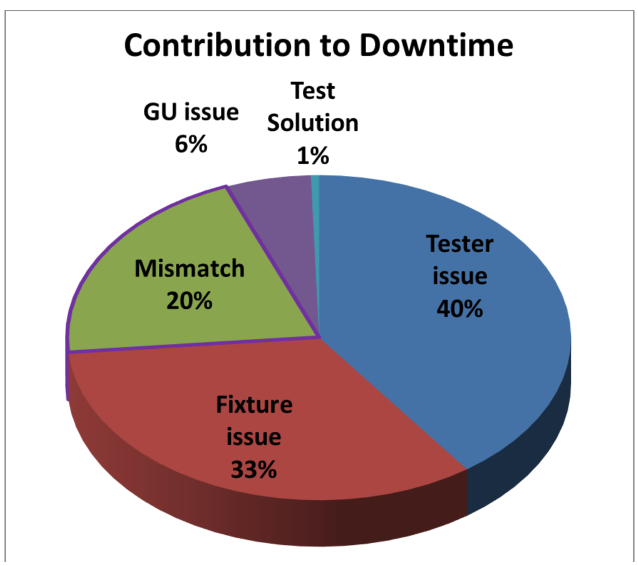


Figure 11. Contribution to Downtime, Jan to Mar 2018
Source: Own elaboration

The following analysis is focus on the mismatch issue which is the 3rd main failure mode in the DRG test area. The data was analyzed from 3 perspectives: by product, by tester and by working shift.

On the 1st analysis by product, only the mismatch issue is analyzed. It is done by grouping it by product or part number. Figure 12 shows the mismatch issue number of events grouped by month. It is observed that the product 13762 and 77916-21 are consistently on the top for 3 consecutive months. Therefore, these products are further analyzed by the other member of the group where is assigned to the fixture.

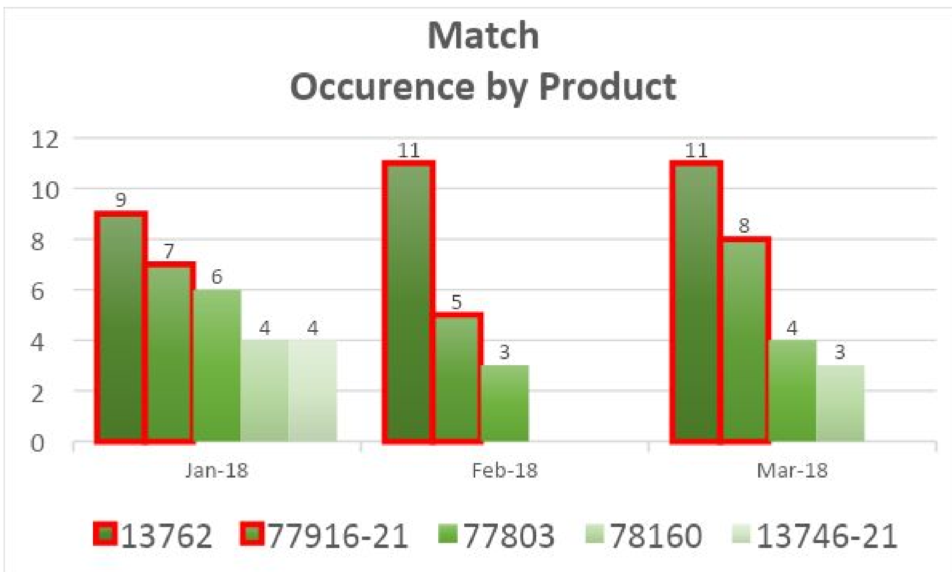


Figure 12. Match Failure mode pareto by product
Source: Own elaboration

On the 2nd analysis by tester in 3 months, the number of occurrence (vertical axis) of mismatch issue is shown on Figure 13. Reviewing this pareto diagram, it is observed that 50% of the testers under this the evaluation has an occurrence of just only one, however, the rest of the testers have occurrence of 2 or more. Interestingly, there are 4 testers that have 5 occurrences marked in red box. These testers are then analyzed and will be discussed in the next section of this project.

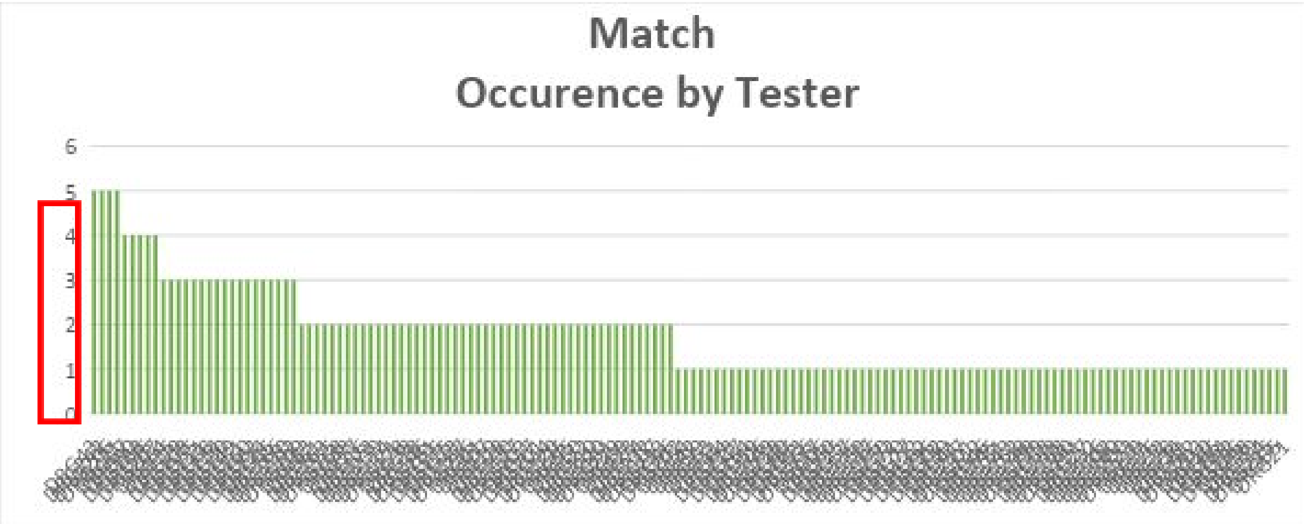


Figure 13. Match Failure mode pareto by tester – all
Source: Own elaboration

On the 3rd analysis by working shift in 3 months, the most occurrence of mismatch issue happened on one working shift which is shift C that represents 33% of the total shown in Figure 14. This data may provide information to the production and maintenance group to better understand the reason and improve the process of doing a test setup.

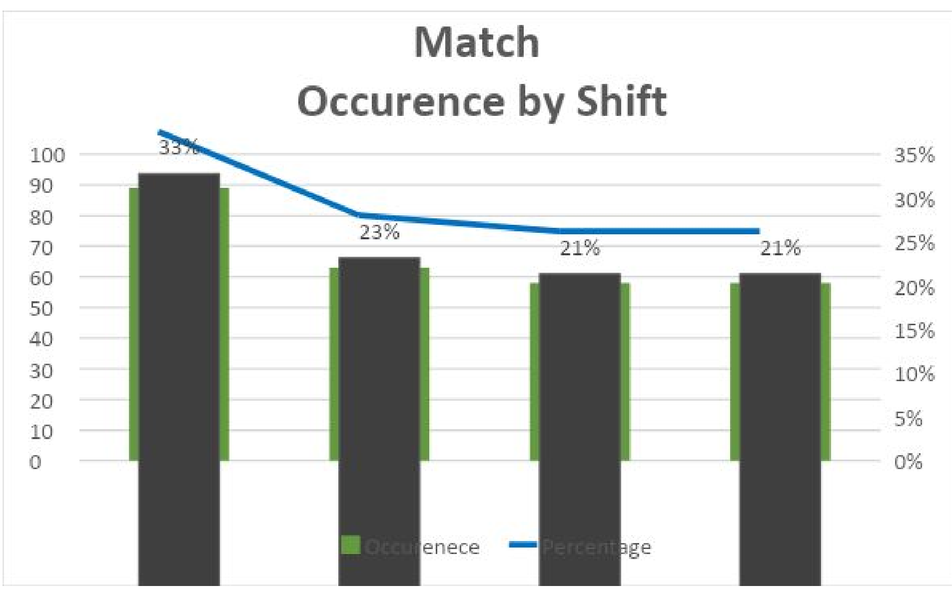


Figure 14. Match Failure mode pareto by work shift
Source: Own elaboration

2. Calibration

The 2nd phase is done to verify calibration settings are appropriately defined for testing. This activity is intended to ensure that the calibration is done in accordance with the standard discussed in the Theoretical framework.

The input and output calibration files from various testers are compiled and analyzed. The input calibration file contains the specific series of frequencies that will be use to run the calibration. The series of frequencies should have enough frequency points to cover all the required frequencies by testing the DUT. Figure 15 shows the frequency points on the input file of various testers. The input file has 4 calibration types which are composed of RF Setup source, RF Setup measure, RF Setup noise and RF Setup vector. These types are being used in different testing methods as defined in the product test specification. The x axis is the frequency and the y-axis is the series. It is observed that all of the analyzed testers have the same frequency series from 10MHz to 6.0GHz in different types of calibration. It is being observed in the all the chart where testers' frequency overlap each other and formed single line.

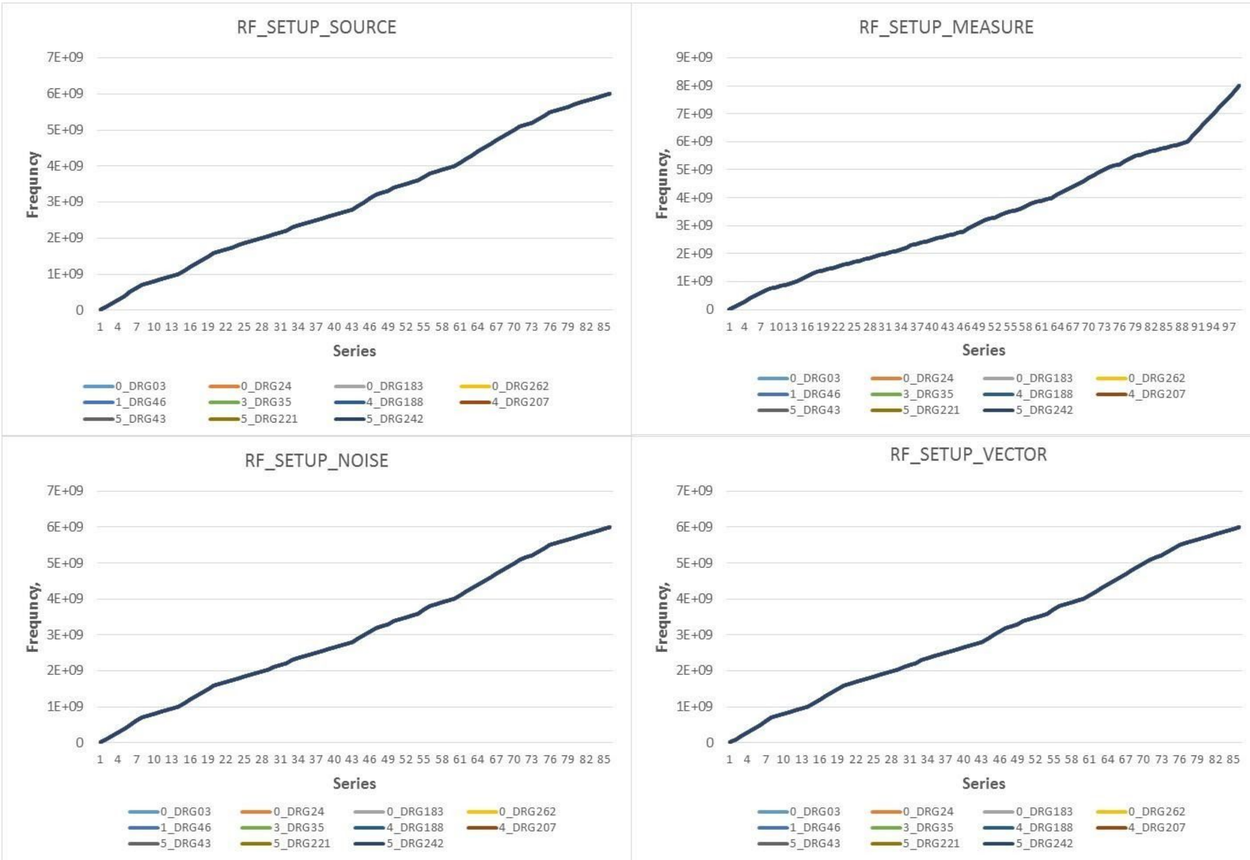


Figure 15. Input Calibration files of DRG testers
Source: Own elaboration

Based on the analysis done from Figure 7, the 10 testers that have the most number of mismatch issue events are shown on Figure 16. From these 10 testers, 2 out of 4 testers are selected and further analyzed. The testers are DRG43 and DRG242.

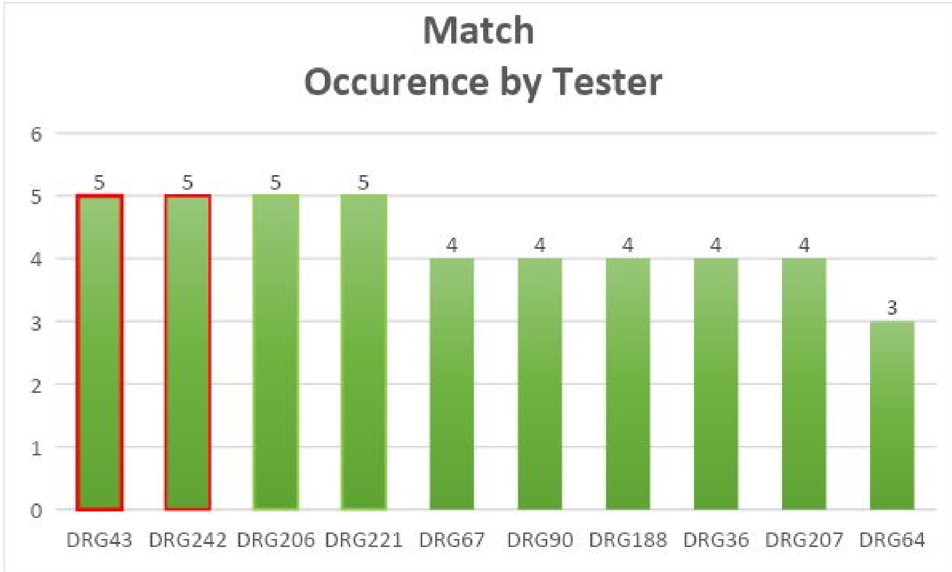


Figure 16. Match Failure mode pareto by tester – Top 10
Source: Own elaboration

The next files that were reviewed are the output calibration files. These files are the results of the tester calibration which contains the losses of the port and paths inside the tester. These losses are being measured from the signal generator up to the tester ports. The signal from the signal generator travels through a series of switches and multiplexers that have multiple connection. The same signal will enter the RF cable before it will reach the tester port which is the interface to the test fixture. To ensure the correct level is present in the test port, the calibration is done to calculate the losses of the signal the travel from the signal generator to the tester ports.

There are 18 different types of calibration at the output in general. Each calibration type is being used with different test specification. The 2 most common calibration types are selected because they are being used in most of the product being tested. They are the **Scalar Source path** and **Scalar Measure path** calibration. All the calibration that will be shown from this project is using the RF port 1 only. There will be more experiment to explore and study the other RF ports behavior.

From the analysis shown on Figure 16, 2 of the 4 testers with 5 events of mismatch are compared to 2 testers with no mismatch event. For simplicity, let's call them bad and good tester respectively. The Figure 17 shows the Scalar Source path losses of the scalar source calibration. The losses are displayed on the y-axis while the frequency is on the x-axis. This graph shows that the 2 bad testers has a different loss compare to the good testers. The average difference is ~6.0dBm.

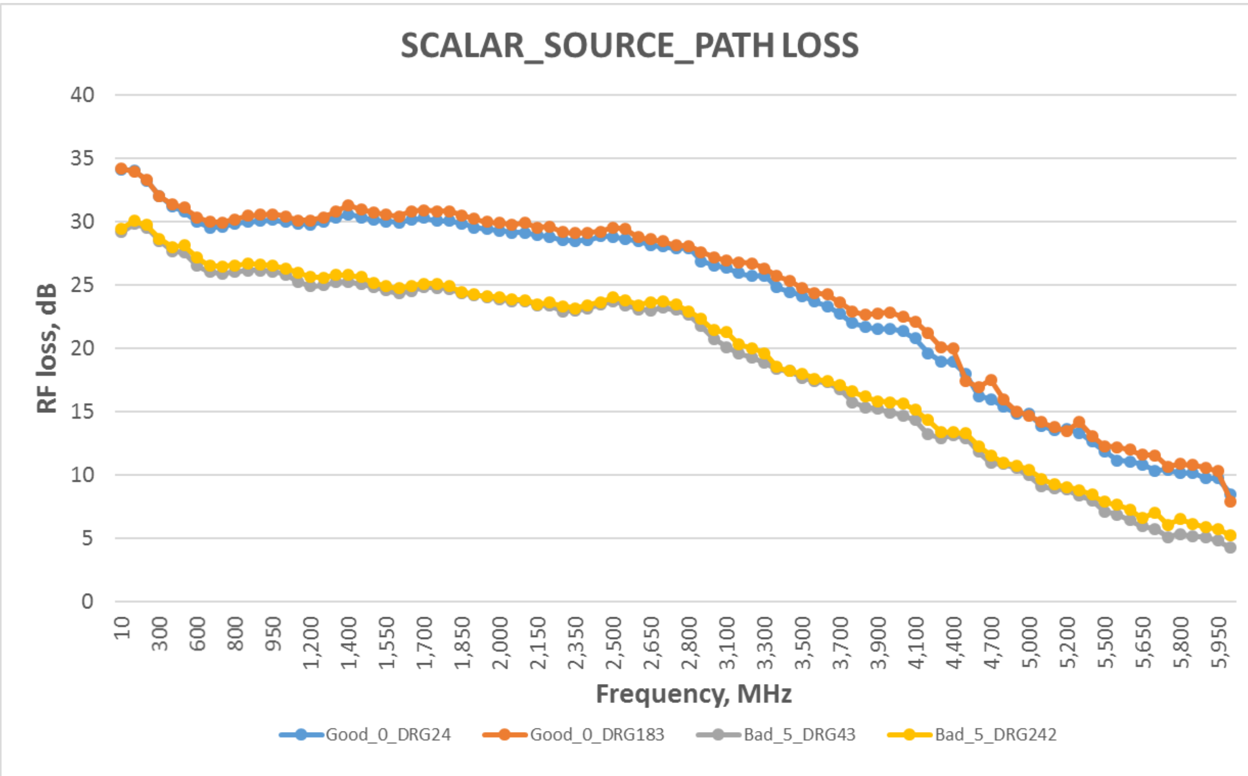


Figure 17. Output Calibration of DRG Testers (Scalar Source Path Loss)
Source: Own elaboration

On the next calibration, Figure 18 shows RF Scalar Measure path loss on the x-axis by the frequency from 10MHz to 6.0GHz. Based on the analysis and from the graph, there no evidence of significant difference between the good and bad testers.

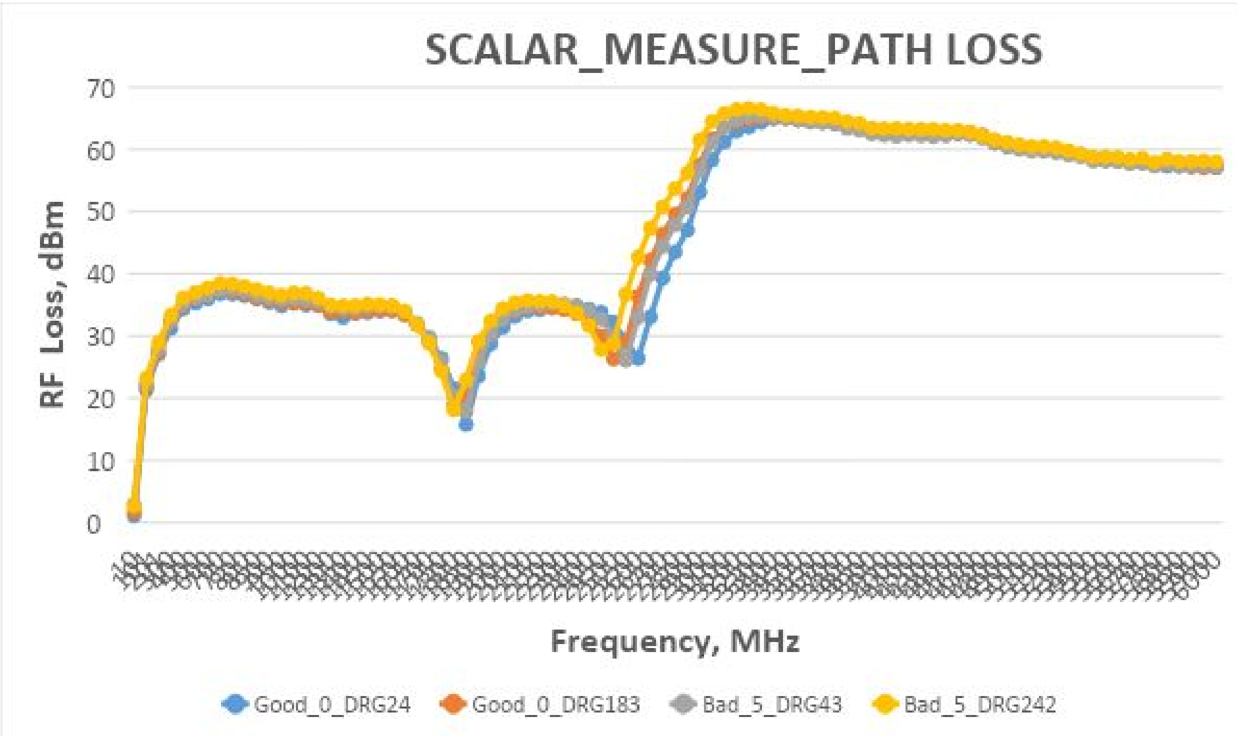


Figure 18. Output Calibration of DRG Testers-Scalar Measure Path Loss

Source: Own elaboration

3. Design Rules Application

The 3rd phase is done to verify the application of the design rules and standard. This activity is set to validate the RF design standard between tester and the fixture. As discussed in the theoretical framework and by design standard, RF components such as cable and connectors should have a characteristics impedance of 50 ohms in order have the lossless transmission.

Two sets of tester cable and fixture connectors have been characterized. These components are the main connections between the tester and fixture. The interface between these components should be at 50 ohms impedance to have the optimum performance with less power loss during the device testing. The behavior of the system that has an impedance of 50 ohms is shown on Figure 19. All the RF components must have this characteristic to achieve high performance. The S parameter S11 of the 50 ohms load is plotted on the left by the corresponding frequency on the x-axis. Similarly, the trace is presented in a graphical form using a Smith chart (right). As a result, the points of the load is concentrated the center of the Smith chart which is expected when measuring a 50-ohm load. For the S11, the lower the measurement is, the better. For the next experiment and analysis, focus will be on the S11 only. Further studies could be elaborated on the other S-parameter result.

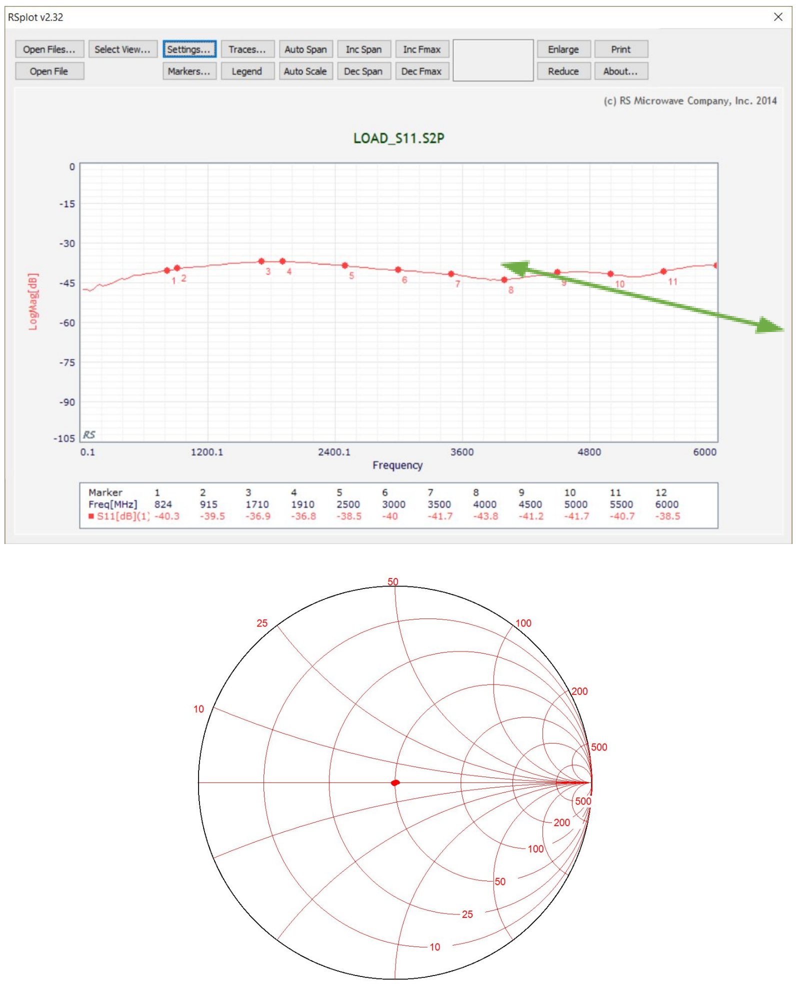
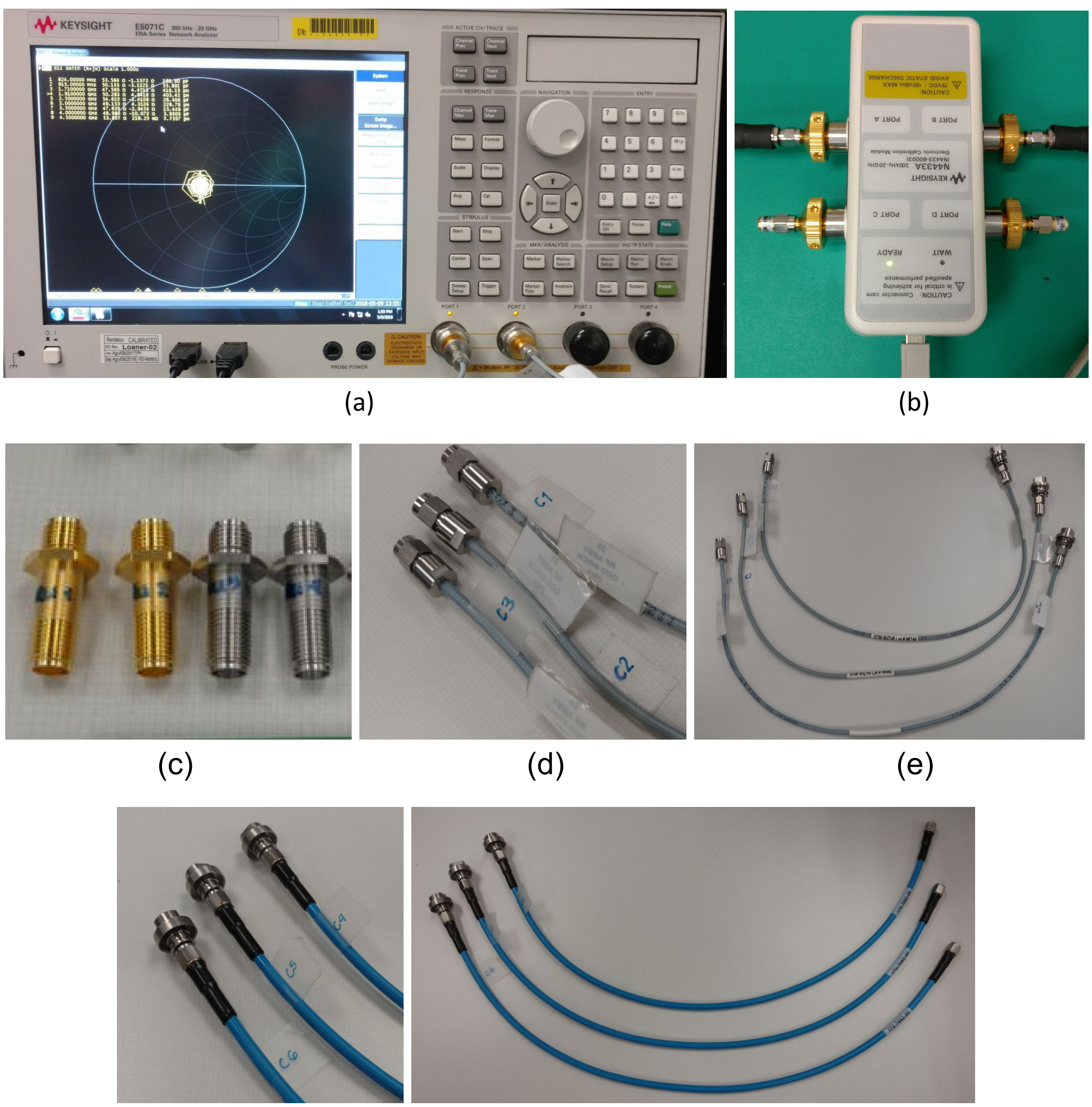


Figure 19. S11 plot (left) and Smith chart trace (right) of 50ohms Standard - Ideal
Source: Own elaboration

To validate the design rules and standards, the next components were characterized.

1. Two sets of new and old types of RF cables – are tested using a Network Analyzer (NA) with model Keysight E5071C to verify the impedance and their performance.
2. Two types of thru connectors that are being used in the fixture were measured to validate using the same network analyzer.

To ensure the correct measurement using the network analyzer, a kit is used for calibrating the instrument. The network analyzer (a), calibration kit (b), RF thru connector (c) and RF cables (d,e,f,g) are shown on Figure 20.



(a) (b)

(c) (d) (e)

(f) (g)

Figure 20. Network Analyzer (a), Calibration kit (b), RF thru connector (c), old RF cables (d,e) and new RF cables (f,g) used in Characterization
Source: Own elaboration

In the 1st test, 2 set of different types of RF cables use in the tester are characterized – 2 old type and 2 new type of cables. Figure 21 shows the measurement behavior by frequency found on the x-axis. S11 measurements are displayed on the y-axis. The lower these values are, the better. This means that the reflected power from the input port in less, therefore, most of the incoming signal could be delivered with minimum loss. The first 4 frequencies shown on the legend are the most commonly used frequency in majority of the product in Skyworks being tested. The program from RS Microwave Company is used to analyzed the data from the Network Analyzer. The next are the observations from this evaluation.

1. 824MHz, new cables have better S11 measurement than old by ~4dB.
2. 915MHz, new cables have better S11 measurement than old by ~10dB.
3. 1710MHz, old cables are slightly better S11 measurement than new by ~2dB.
4. 1910MHz, old cables are slightly better S11 measurement than new by ~2dB.

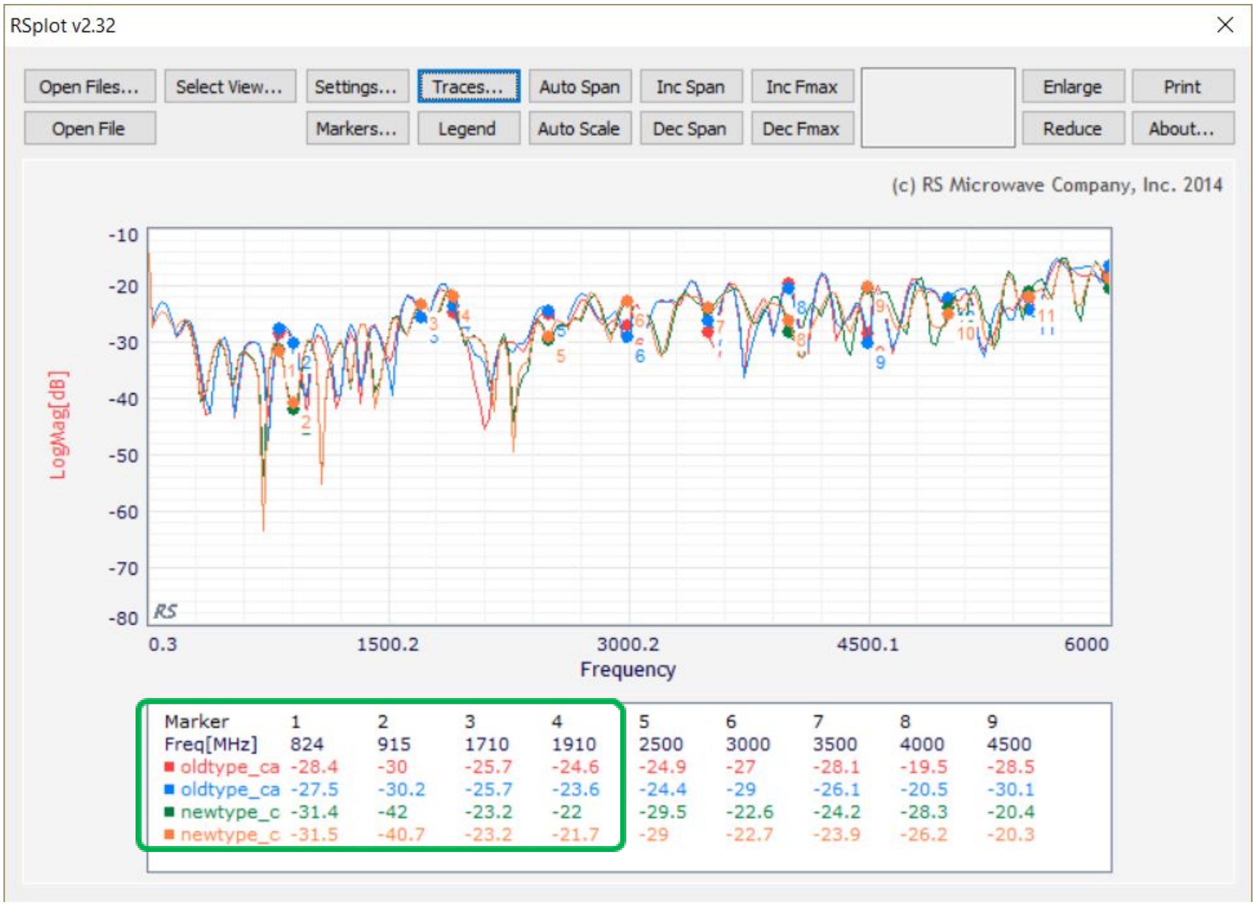
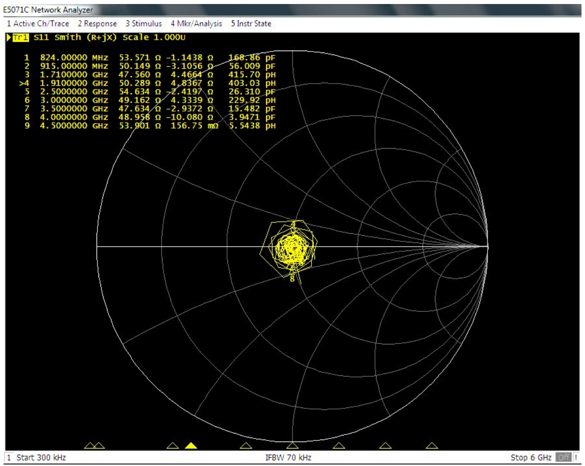
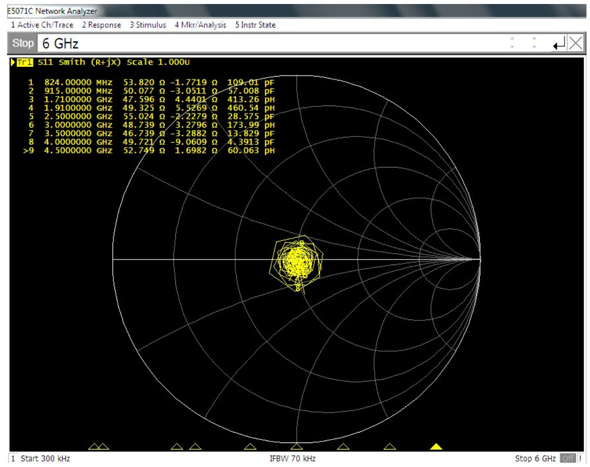


Figure 21. S11 Input Return Loss of RF Cables
Source: Own elaboration

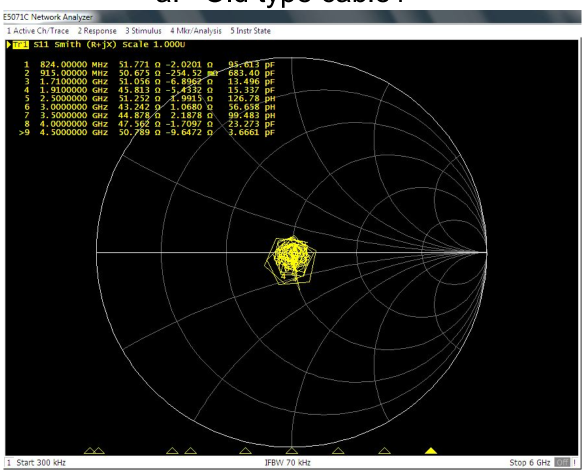
From the same set of data used to analyze the S11, Figure 22 shows the graphical representation using a Smith chart. This chart has many functionalities but on this project, the impedance will be the only measurement of interest. As discussed on the theoretical framework, the impedance could be measured by using the NA. The lines on the center of each chart are the impedances and its parasitic elements called reactance. The ideal impedance would be pure 50 ohms without any reactance, therefore a single dot will be visible at the center of the Smith chart as shown earlier on Figure 7. From the characterization of the cables displayed in the Smith chart, it is observed that most of the line are close to the center. There are points that are slightly away from the center but not significant.



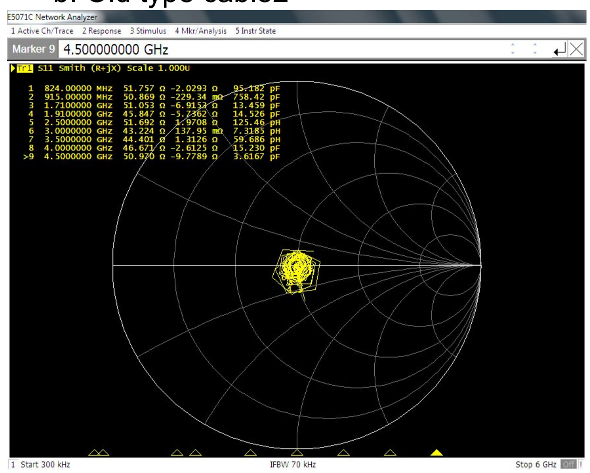
a. Old type cable1



b. Old type cable2



c. New type cable1

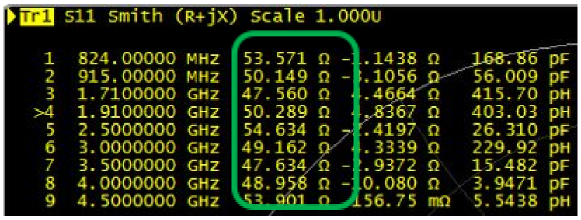


d. New type cable2

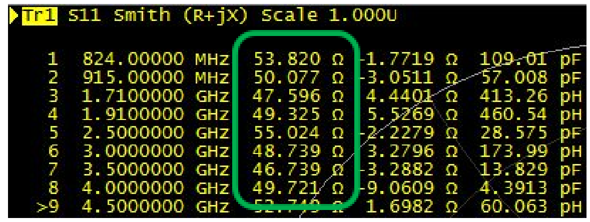
Figure 22. Impedance of RF Cables on Smith Chart
Source: Own elaboration

To appreciate the smith chart result, the impedance values are listed on the 3rd column of the Table 4. The current type of cable impedances are well within the tolerance compared to the datasheet available from manufacturer's website shown on Figure 23. This is an example to verify the component's electrical characteristics based on their manufacturer's design.

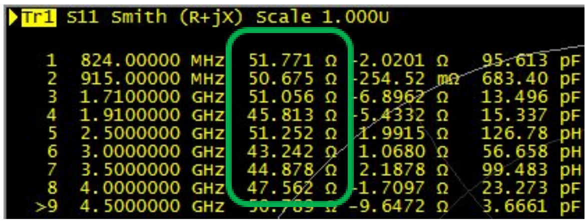
Table 4. Impedance Measurement of the new and old cable
Source: Own elaboration



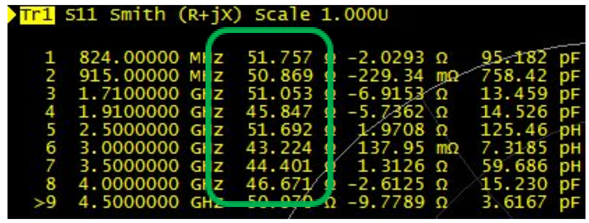
a. Old type cable1



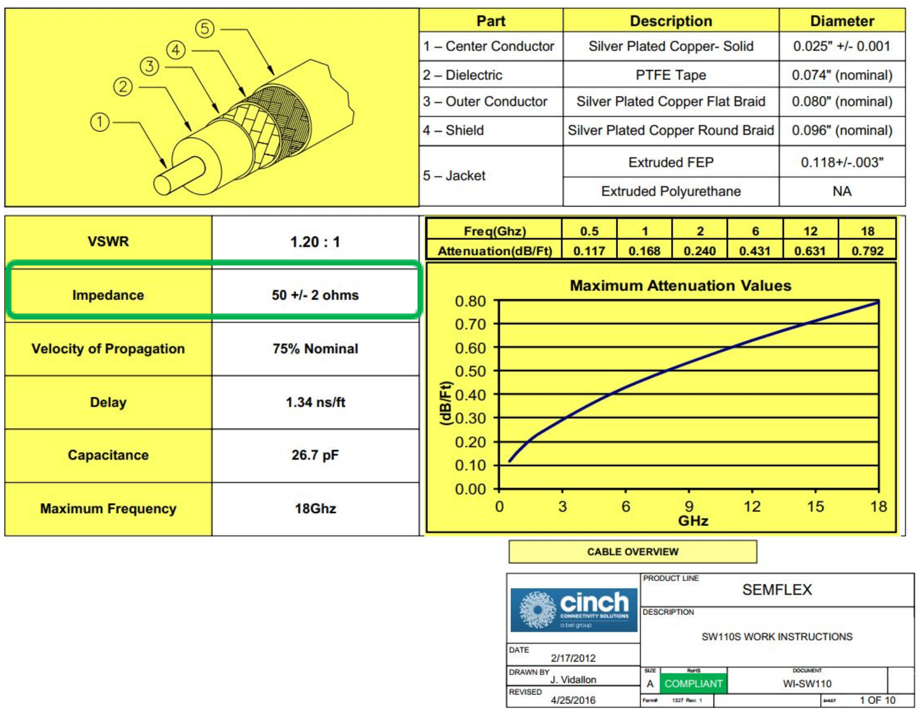
b. Old type cable



c. New type cable1



d. New type cable2



Part	Description	Diameter
1 – Center Conductor	Silver Plated Copper- Solid	0.025" +/- 0.001
2 – Dielectric	PTFE Tape	0.074" (nominal)
3 – Outer Conductor	Silver Plated Copper Flat Braid	0.080" (nominal)
4 – Shield	Silver Plated Copper Round Braid	0.096" (nominal)
5 – Jacket	Extruded FEP	0.118+/-.003"
	Extruded Polyurethane	NA

VSWR	1.20 : 1
Impedance	50 +/- 2 ohms
Velocity of Propagation	75% Nominal
Delay	1.34 ns/ft
Capacitance	26.7 pF
Maximum Frequency	18Ghz

Freq(Ghz)	0.5	1	2	6	12	18
Attenuation(dB/Ft)	0.117	0.168	0.240	0.431	0.631	0.792

Figure 23. RF Cables Datasheet (old cable)
Source: Semflex

In the 2nd test, 2 original and 2 alternate RF connectors from the fixture are characterized. The same cable characterization methodology is used for the connector using the network analyzer. S11 measurements are displayed in on Figure 24 showing the same frequency points used in the cable.

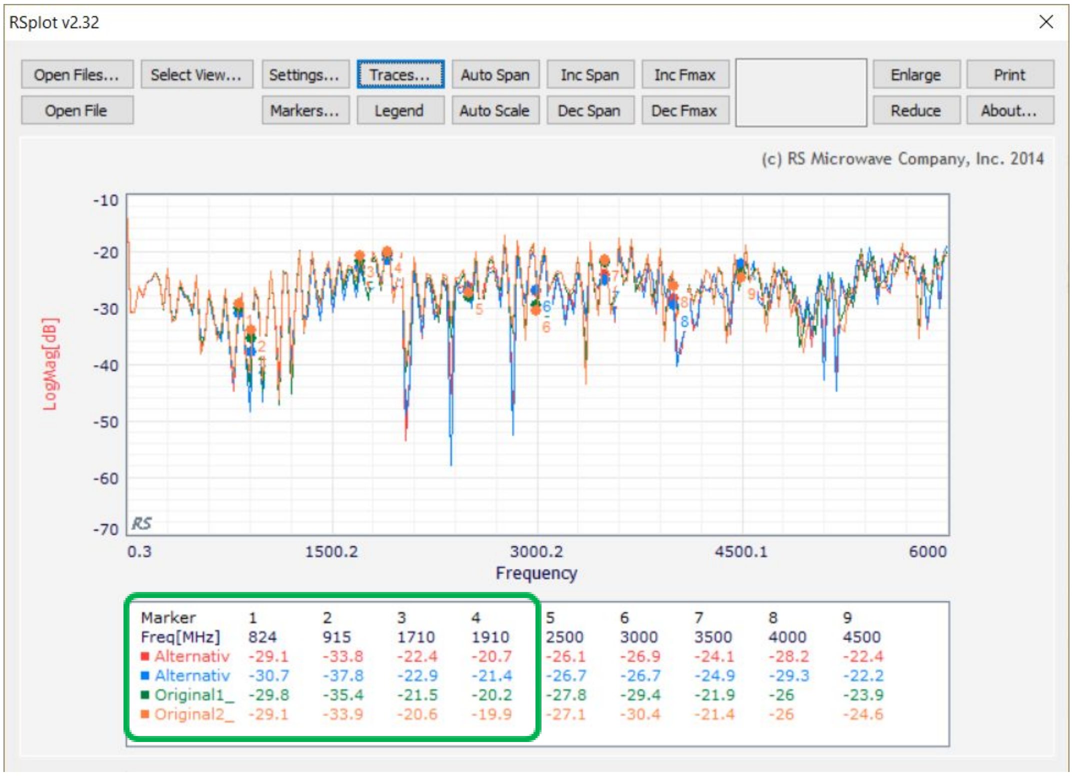
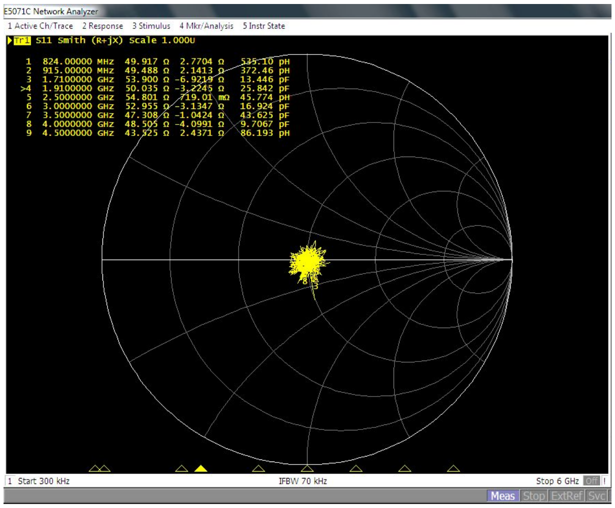


Figure 24. S11 Input Return Loss of RF Connector
Source: Own elaboration

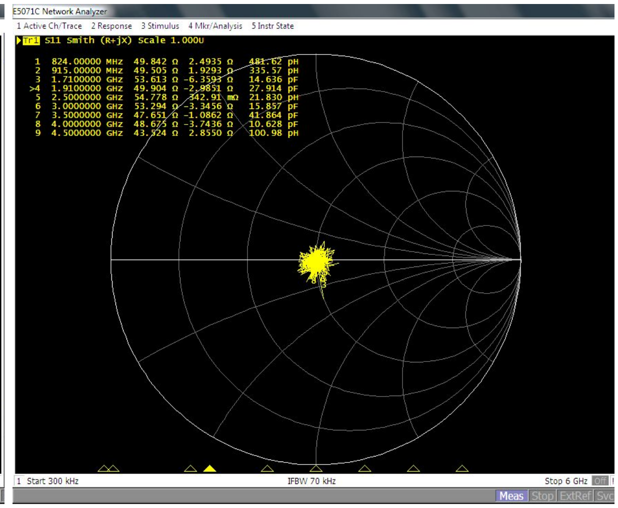
Below are the observations from the Figure 24.

1. 824MHz, alternate and original connector have minimum difference in S11.
2. 915MHz, alternate and original connector have minimum difference in S11.
3. 1710MHz, alternate and original connector have minimum difference in S11.
4. 1910MHz, alternate and original connector have minimum difference in S11.

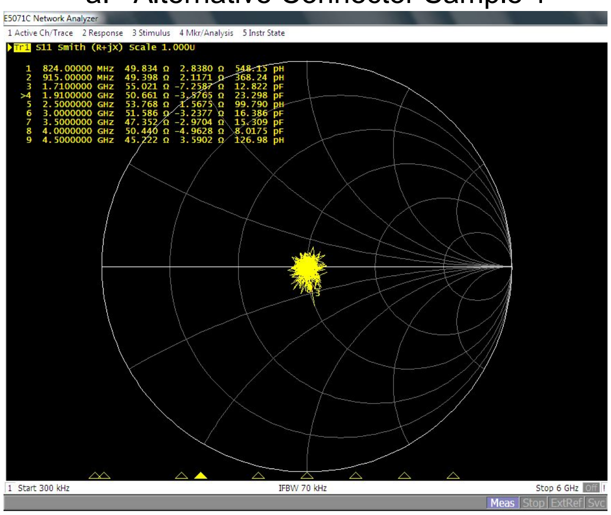
The same data collected in Figure 24 are presented in a graphical form using Smith chart again. It is observed from Figure 25, the lines in all the connectors are close to the center of the Smith chart, therefore the impedances are close to 50 ohms.



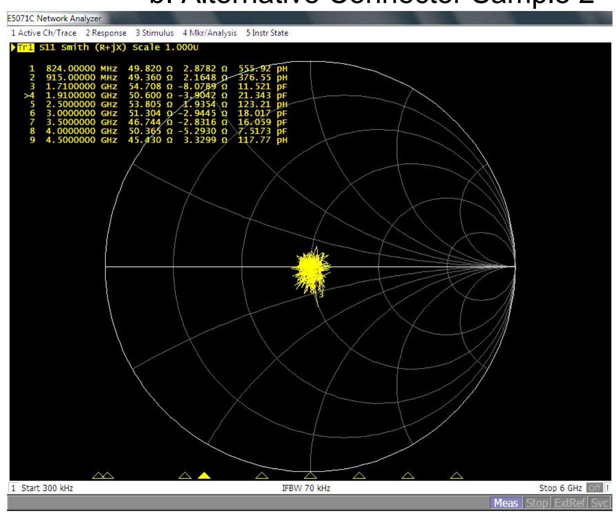
a. Alternative Connector Sample 1



b. Alternative Connector Sample 2



c. Original Connector 1

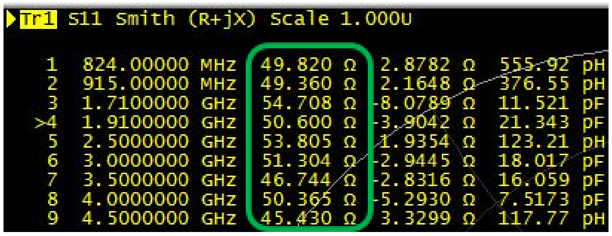


d. Original Connector 2

Figure 25. Impedance of RF Connectors on Smith Chart
Source: Own elaboration

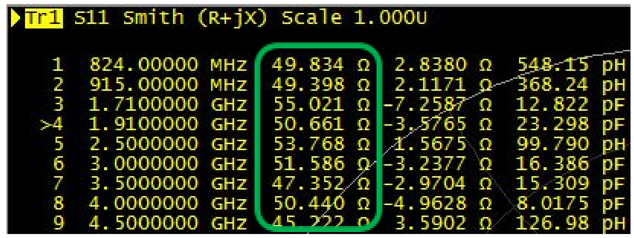
The impedance of the connectors being analyzed is shown on the 3rd column encircled in green on Table 5. The datasheet of the thru connector is not available since DRG manufacturer did not provide any detail on the part number.

Table 5. Impedance Measurement of RF connector
Source: Own elaboration



Tr1 S11 Smith (R+jX) Scale 1.000U

1	824.00000 MHz	49.820 Ω	2.8782 Ω	555.92 pH
2	915.00000 MHz	49.360 Ω	2.1648 Ω	376.55 pH
3	1.7100000 GHz	54.708 Ω	-8.0789 Ω	11.521 pF
>4	1.9100000 GHz	50.600 Ω	-3.9042 Ω	21.343 pF
5	2.5000000 GHz	53.805 Ω	1.9354 Ω	123.21 pH
6	3.0000000 GHz	51.304 Ω	-2.9445 Ω	18.017 pF
7	3.5000000 GHz	46.744 Ω	-2.8316 Ω	16.059 pF
8	4.0000000 GHz	50.365 Ω	-5.2930 Ω	7.5173 pF
9	4.5000000 GHz	45.430 Ω	3.3299 Ω	117.77 pH

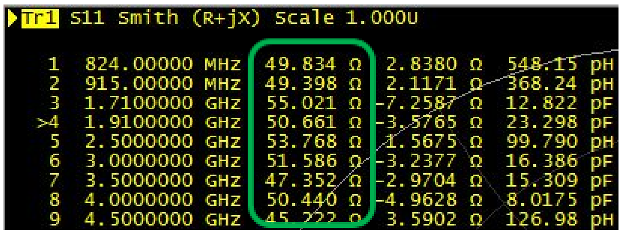


Tr1 S11 Smith (R+jX) Scale 1.000U

1	824.00000 MHz	49.834 Ω	2.8380 Ω	548.15 pH
2	915.00000 MHz	49.398 Ω	2.1171 Ω	368.24 pH
3	1.7100000 GHz	55.021 Ω	-7.2587 Ω	12.822 pF
>4	1.9100000 GHz	50.661 Ω	-3.5765 Ω	23.298 pF
5	2.5000000 GHz	53.768 Ω	1.5675 Ω	99.790 pH
6	3.0000000 GHz	51.586 Ω	-3.2377 Ω	16.386 pF
7	3.5000000 GHz	47.352 Ω	-2.9704 Ω	15.309 pF
8	4.0000000 GHz	50.440 Ω	-4.9628 Ω	8.0175 pF
9	4.5000000 GHz	45.222 Ω	3.5902 Ω	126.98 pH

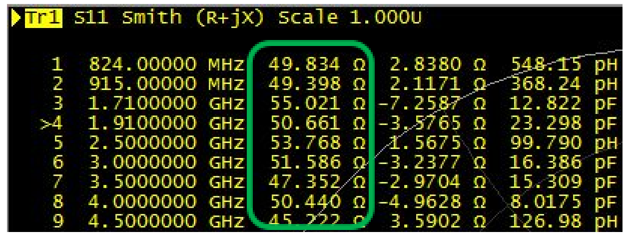
a. Alternative Connector Sample 1

b. Alternative Connector Sample 2



Tr1 S11 Smith (R+jX) Scale 1.000U

1	824.00000 MHz	49.834 Ω	2.8380 Ω	548.15 pH
2	915.00000 MHz	49.398 Ω	2.1171 Ω	368.24 pH
3	1.7100000 GHz	55.021 Ω	-7.2587 Ω	12.822 pF
>4	1.9100000 GHz	50.661 Ω	-3.5765 Ω	23.298 pF
5	2.5000000 GHz	53.768 Ω	1.5675 Ω	99.790 pH
6	3.0000000 GHz	51.586 Ω	-3.2377 Ω	16.386 pF
7	3.5000000 GHz	47.352 Ω	-2.9704 Ω	15.309 pF
8	4.0000000 GHz	50.440 Ω	-4.9628 Ω	8.0175 pF
9	4.5000000 GHz	45.222 Ω	3.5902 Ω	126.98 pH



Tr1 S11 Smith (R+jX) Scale 1.000U

1	824.00000 MHz	49.834 Ω	2.8380 Ω	548.15 pH
2	915.00000 MHz	49.398 Ω	2.1171 Ω	368.24 pH
3	1.7100000 GHz	55.021 Ω	-7.2587 Ω	12.822 pF
>4	1.9100000 GHz	50.661 Ω	-3.5765 Ω	23.298 pF
5	2.5000000 GHz	53.768 Ω	1.5675 Ω	99.790 pH
6	3.0000000 GHz	51.586 Ω	-3.2377 Ω	16.386 pF
7	3.5000000 GHz	47.352 Ω	-2.9704 Ω	15.309 pF
8	4.0000000 GHz	50.440 Ω	-4.9628 Ω	8.0175 pF
9	4.5000000 GHz	45.222 Ω	3.5902 Ω	126.98 pH

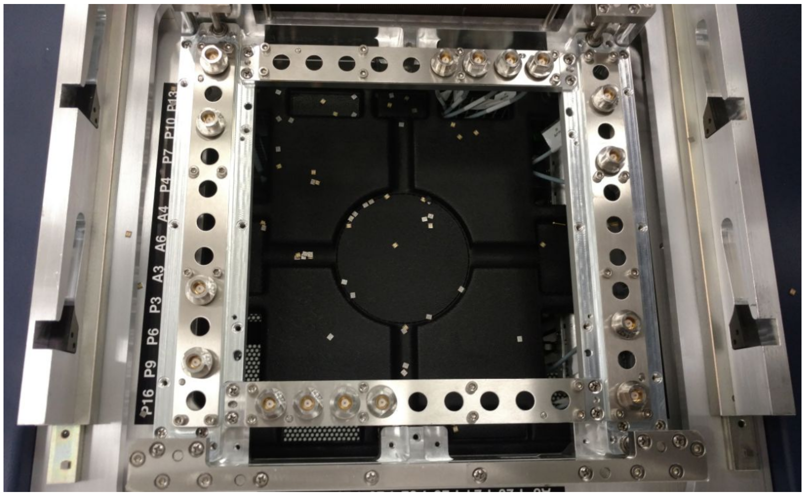
c. Original Connector 1

d. Original Connector 2

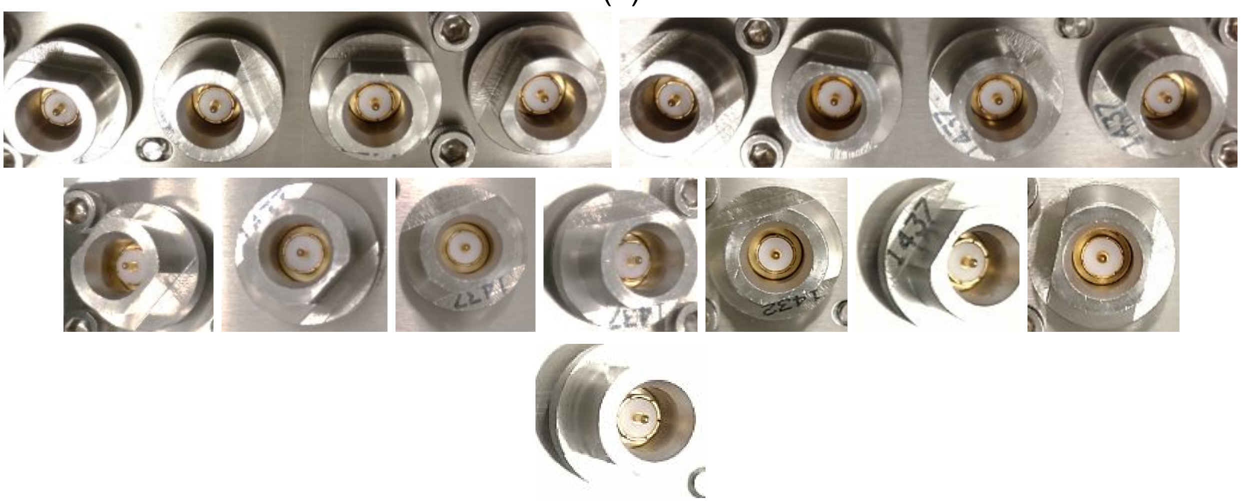
4. Tester connectors condition

The 4th phase is done to verify the condition of the connectors of the tester. Two verification steps are done on this activity - visual inspection and tightness of the connection between cable and connector (by torque). This activity was expected to demonstrate the performance of connectors and identify its physical deterioration and damage. This activity will determine the usefulness of the such components and decide to replace or do a regular maintenance.

Based on the result in phase 1, DRG242 is selected and its RF ports have been verified. This tester is one of the top most that have mismatch occurrence. The physical condition of the RF ports has been inspected for any worn-out pins and for any metallic dirt around the connector by maintenance expert that work regularly with the tester. Figure 26 (a) shows the tester port assembly and its 16 individual ports (b). From the inspection performed with Maintenance people, there are no signs of wear and tear, neither metallic dirt compared to brand new cable. The torque of the connectors has been inspected as well and no evidence of loose cable is found.



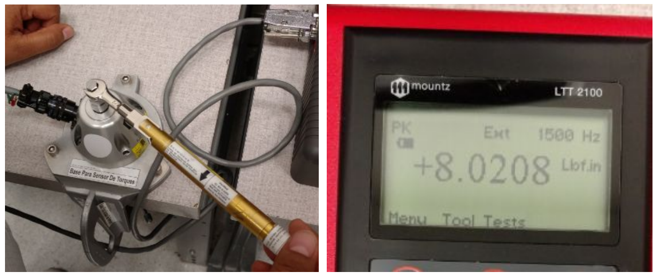
(a)



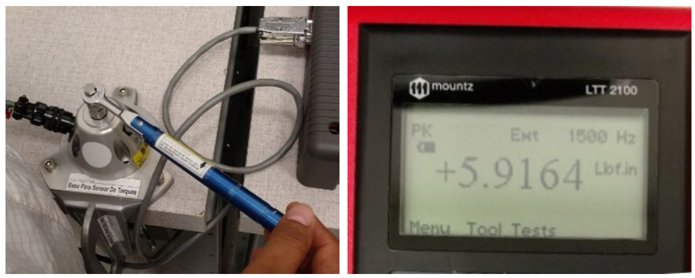
(b)

Figure 26. RF port in DRG 242 (top) and its 16 individual ports
(1-8 middle, 9-16 bottom)
Source: Own elaboration

To validate the effect of the torque necessary for tightening the connector, an independent experiment from the tester is performed. Two calibrated torque wrenches are used. Torque wrench 1 (a) is calibrated at 8.0 lb-in. of torque and torque wrench 2 (b) is calibrated at 6.0 lb-in. as shown in Figure 27. These wrenches were used to tightened a 50-ohm broadband load and both forces are measured in the Network analyzer.



(a)



(b)

Figure 27. RF torque wrench calibration, torque wrench with 8 lb-in (top) and torque wrench with 6 lb-in (bottom)
Source: Own elaboration

The S11 measurements of both torques are compared. The same frequency points are used. Additionally, a loose torque connection (less than 1.0 lb-in) is also analyzed to verify how important the use of a calibrated torque wrench. As observed on Figure 28, the S11 measurements between the 8.0 (blue trace) and 6.0 (red trace) lb-in torque has no significant difference. However, the loose torque (green) has a substantial effect of the S11 of 5dB maximum.

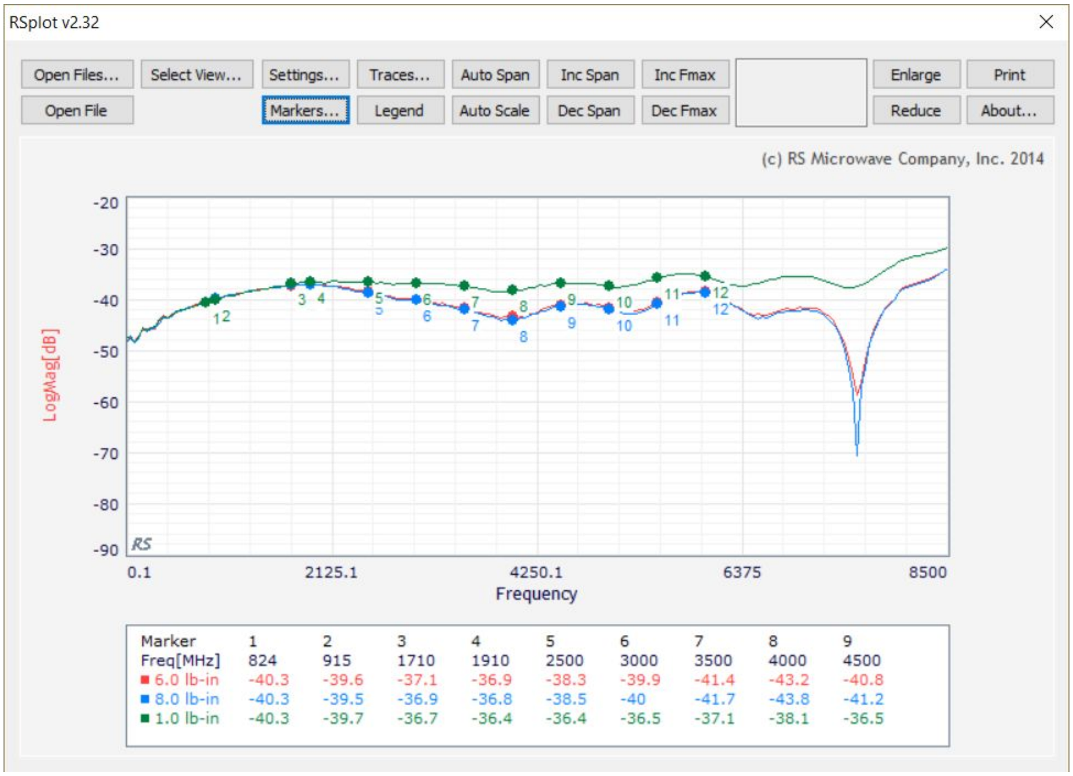
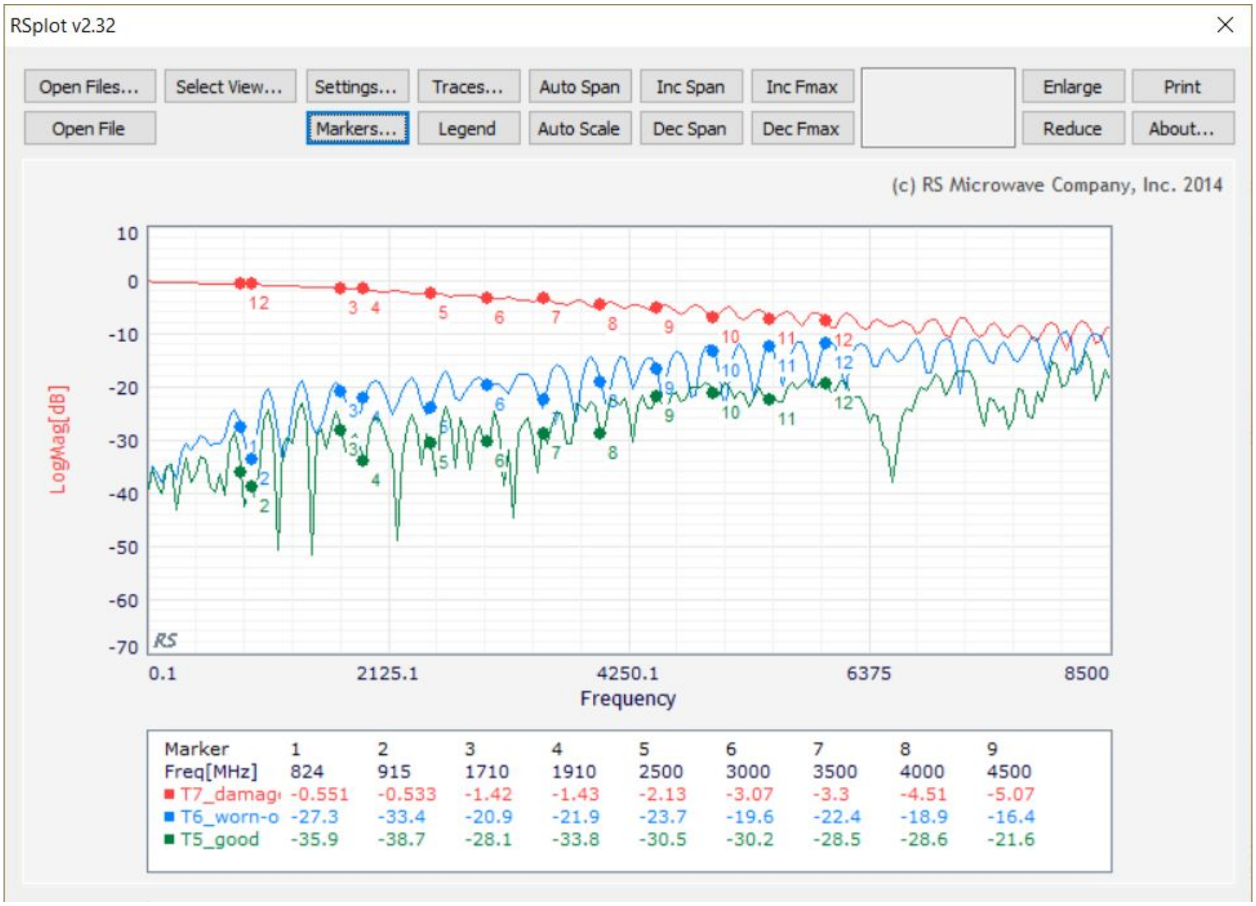
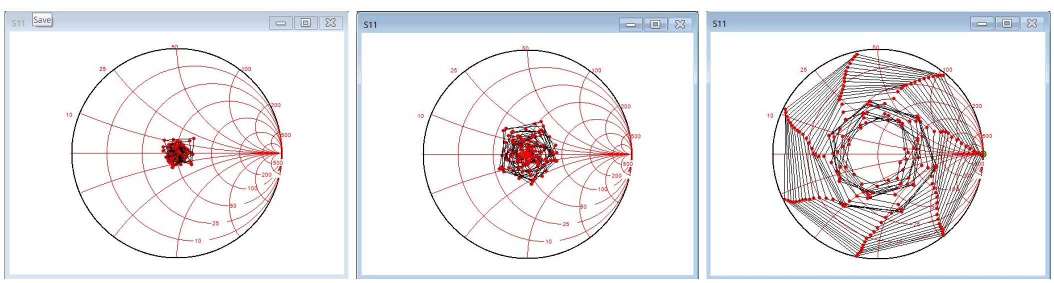


Figure 28. S11 Measurement of 50-ohm load using 8.0, 6.0 lb-in and loose torque (<1.0lb-in)
Source: Own elaboration

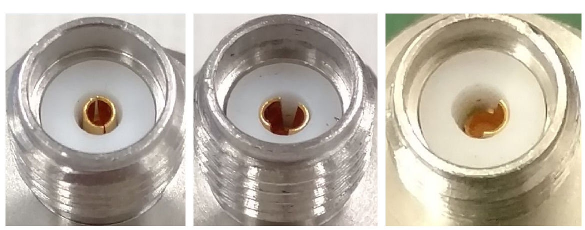
Simulating the effect of the damaged connector is analyzed next. The degree of damage of 2 thru connectors are measured in NA. Connector T6 has a gap between its core part where the concentration of the RF signal passes. Connector T7 has a considerably bad damage where the core is broken into half, thus less contact with the mating connector will be evident. As expected, these damage connectors exhibit a worse performance compared to the good connector as shown on the Figure 29. The S11 of connector T7 (red trace) has 20-25 dB delta from the good connector (green trace) while S11 of connector T6 (blue trace) has 6-8 dB delta across the frequency points. The Smith chart traces compliment the S11 measurement from the NA. The worse the degree of the damage of the connectors, the farther the points tends to go out from the center the chart.



(a)



(b)



(c)

Figure 29. S11 Measurement (top) and Smith chart traces (middle) of good (bottom left), T6-worn-out (bottom center) and T7-damaged (bottom right), RF connector.

Source: Own elaboration

5. Conclusions and Recommendations

The Test area in Skyworks have observed arising issues in Production that

This project is intended to respond to why mismatch condition problem in Dragon Test System is present. To resolve this problem, the general objective is defined **to give appropriate recommendations on how to improve the identified causes of the mismatch condition problem in Dragon test system.**

The methodology used is to achieve the main objective was divided in 4 phases. These activities are completed in exploring the possible causes by analyzing different components of the tester.

On the 1st phase, this is done to corroborate the existence of the mismatch issue in Test Dragon area. An explorative qualitative investigation is conducted and based on the result, it is proven that the problem not only still exists, but also the number of the mismatch issues in a period of 3 months has increased. The increment is from 133 events in 2017 to 253 event in 2018. This represents 90% almost doubled from the previous. This corroborate that the problem still persists in DRG test area. The following data is analyzed by product, by tester and by schedule (shift) and sustained the given objective to identify the possible causes of the mismatch issue.

1. From the data analysis by product, there are 2 products that showed significant number of incidence, they are 13762 and 77916-21.
2. From the data analysis by testers, there are 4 testers the presents the most number of mismatch issues which is 5.
3. Interestingly, the data analysis by shift revealed that 33% of the time, the mismatch issue occurred in Shift A which is in the night.

Based on these observations, the existence of the mismatch problem continues to persist thus concluding the objective to corroborate its current presence. For further studies, it is recommended to investigate the 2 products stated further and do deeper analysis on why the majority of the event happened in Shift C.

On the 2nd phase, this is done to verify the calibration settings are appropriate defined. The activities is intended to ensure calibration is done with a common input file and output file should not divert nor have a significant difference among testers.

For the input files, the frequency list being used in the calibration in all the testers analyzed in this project is found to be exactly the same, thus the frequency points being calibrated are the same on majority of the testers. Therefore, the testers should cover of the required frequencies by the all of the products being tested. There are couple of recommendations aroused.

1. Verify the frequency list of the calibration input files regularly to ensure all new products' frequencies are covered
2. Validate the calibration input files on each of the testers to confirm all testers are using a common frequency list.

For the output files, the **scalar measure path loss** did not show any significant different among the testers. However, the **source scalar path loss** of the testers with high event of mismatch issues compared to the tester without issue has a difference of ~6dB. This raised a doubt that the other calibration categories might be in the same situation. Therefore, the recommendations are the following:

1. Examine and verify all the calibration categories of the output files.
2. Compare all the calibration output files from all testers to create a statistical study to add appropriate tolerances.

The input and output files are verified successfully and based on the result, there are more analysis to be done as stated in the recommendations for more elaborated analysis.

On the 3rd phase, the work is done to verify the application of the design rules and standard on the tester components such as cables and connectors. The validataion is done by measuring the components using Network Analyzer.

By design rules, it is expected that these components have 50-ohms characteristics impedance in able to have a good performance in delivering the lossless power to the DUT. At the same time, to be able to measure the DUT output with minimum loss and reflection.

Based on the network analyzer results, all the RF components complied with the objective to the design rules and standard. The S11 difference found on the 915MHz shows that the new cable is better than the current type. Therefore, it is strongly recommended to use the new type of cables as they would better tester performance.

On the 4^{th} phase, the activities are done to verify the physical condition of the connectors found on the tester head assembly (refer to Figure 20) and the tightness of the connector. Damaged, dirty connectors and loose connection are very prone to performance issue as they affect the impedance directly.

The result from this verification therefore confirmed that no physical and partial damage is observed in the verification of the connectors. In addition, the torque of each connector are properly tightened to 8 lb-in.

Given the result from simulated experiment of loose connection and partial and full damaged connectors, it is recommended to do following.

1. Perform a periodical visual inspection of the RF port of the tester
2. Make sure all the RF connection are tightened to a torque of 8 lb-in not only on the tester but also on the fixture side.

Given the overall results and observations from this project, there are possible causes identified in the mismatch condition problem in Dragon Test System that could be improved. However, there is no sufficient evidence to affirm that the Dragon test system is the principal cause of mismatch condition problem. The recommended activities are given and are highly expected to finished to acquire more information that could give more evident element to prove that the tester is the main cause.

The experiments and activities in accordance to the specific objectives have been completed. Based from the results, the possible causes are identified and proper recommendations to improve the mismatch condition are given. Therefore, the main objective of this project is achieved.

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