THRU REFLECT LINE CALIBRATION KIT FOR RADIO FREQUENCY POWER AMPLIFIER CHARACTERISATION

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by

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LIST OF ABBREVIATIONS

ADS	Advanced design system
RF	Radio Frequency
PA	Power Amplifier
TRL	Thru-Reflect-Line
SOLT	Short-Open-Load-Thru
PCB	Printed Board Circuit
DUT	Device Under Test
VNA	Vector Network Analyzer
2G	Second generation mobile telephone system
4G	Fourth generation of broadband cellular technology
IC	Integrated Circuit
GHz	Giga Hertz
LO	Local Oscillator
DC	Direct Current
PAE	Power Added Efficiency
MMIC	Monolithic microwave integrated Circuit
WLAN	Wireless local-area network
GPS	Global Positioning System
CMOS	Complementary metal-oxide-semiconductor
SIW	Substrate integrated waveguide
SMT	Surface Mount Technology

KIT PENENTUKURAN TERUS PANTUL BALIK GARIS UNTUK PENCIRIAN PENGUAT KUASA FREKUENSI RADIO

ABSTRAK

Perkembangan luar biasa dalam komunikasi mudah alih tanpa wayar dan pengukuran gelombang mikro meningkatkan permintaan untuk ketepatan dan ciri-ciri prestasi peranti tanpa wayar dalam pelbagai frekuensi. Oleh kerana fakta ini, teknik penentukuran termaju dengan ciri-ciri yang lebih baik di reka untuk mengalih ralat yang disebabkan oleh pengukuran. Tesis ini tertumpu pada pembangunan kit penentukuran mengikut piawaian iaitu terus, pantul balik, dan garis (TRL) yang memenuhi keperluan pencirian penguat kuasa dan beroperasi dalam pelbagai frekuensi bermula dari 2.5 GHz hingga 2.57 GHz bagi mengekalkan kelelurusan yang ditetapkan. Reka bentuk kit penentukuran TRL di reka dengan menggunakan perisian reka bentuk termaju (ADS). Rekaan pertama merangkumi dua lapisan papan litar bercetak yang difabrikasi diatas 'Duroid RO4003' dengan ketelepan dielektrik 3.38 dan ketebalan 0.813 mm. Sementara itu, reka bentuk papan berbilang lapis kedua di reka pada papan gelombang 'Laminate Hitachi MCL E-679' dengan ketelapan dielektrik sebanyak 4.4 dan ketebalan 1.2 mm. Pengesahan reka bentuk dan teknik yang dicadangkan dicapai melalui pengukuran perkakasan. Teknik ini telah dibandingkan dengan teknik konvensional iaitu penentukuran pendek, terbuka, terus dan garis (SOLT) berdasarkan gandaan, S_{21}. Bagi teknik penentukuran SOLT, gandaan penguat kuasa bagi reka bentuk papan dua lapis adalah 24.598 dB dan 24.15 dB, manakala bagi reka bentuk papan berbilang lapis ialah 26.5 dB dan 25.981 dB. Kedua-keduanya telah diukur pada frekeuensi 2.505 GHz dan 2.565 GHz masing-masing. Sebaliknya, dengan kit penentukuran TRL yang dicadangkan, gandaan penguat kuasa untuk reka bentuk papan dua lapis adalah 24.823 dB dan 24.406 dB manakala bagi reka bentuk papan berbilang lapis ialah 27.92dB dan 27.408dB pada 2.505 GHz dan 2.565 GHz. Akibatnya kira-kira 10% peningkatan didapati jika dibandingkan dengan gandaan yang diperolehi dengan teknik penentukuran konvensional. Hasil pengukuran menunjukkan bahawa penentukuran TRL lebih tepat daripada kaedah penentukuran SOLT dimana terdapat peningkatan yang ketara dalam prestasi penguat kuasa. Di samping itu, pelaksanaan teknik ini telah terbukti cekap kerana gandaan dapat ditingkatkan dengan mengurangkan ralat sistematik.

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ABSTRACT

Tremendous development in wireless mobile communication and microwave measurement increase the demand for accuracy and performance characterizations of wireless device over various frequency. Due to this fact, advance calibration technique with better features are developed to remove measurement errors. This thesis focuses on development of Through-Reflect-Line (TRL) calibration standard kit that meets the requirement for power amplifier characterization operating in the range of frequency from 2.5 GHz to 2.57 GHz in order to meet stringent linearity requirement. The design of the TRL calibration kit were performed using Advanced Design System (ADS). The first double layer design was fabricated on Duroid RO4003C with a dielectric permittivity of 3.38 and thickness of 0.813 mm. Meanwhile, the second multilayer design was fabricated on Hitachi MCL E-679 laminated microwave board with dielectric permittivity of 4.4 and the thickness of 1.2 mm. Verification of the proposed design and technique were accomplished through hardware measurement. This technique has been compared with the conventional Short-Open-Load-Through (SOLT) calibration technique in terms of the gain, S21. As for the conventional technique, the PA gain for double layer designs are 24.598 dB and 24.15 dB, while for multilayer design are 26.5 dB and 25.981 dB. Both were measured at 2.505 GHz and 2.565 GHz, respectively. On the other hand, with the proposed TRL calibration kit, the gain of the Power Amplifier for double layer design are 24.823 dB and 24.406 dB while for multilayer design are 27.92dB and 27.408dB at 2.505 GHz and 2.565 GHz. As a result, an improvement of approximately 10% from the conventional calibration

technique was achieved. The measurement result indicates that the TRL calibration is more accurate than the SOLT calibration method which significantly improve the performance of the PA. Besides, the implementation of this technique has been proved be efficient as the gain is enhanced by reducing the systematic errors.

CHAPTER ONE

INTRODUCTION

1.1 Background

In recent years, advances in Microwave and Radio Frequency (RF) wireless communication system have resulted an intensively growth of technology scaling that continuously pushes the device to the higher level of performance in the market. Majority application in the microwave technology includes communications, broadcasting, radar navigation, RF identification, remote sensing, automobiles and highways, sensors, surveillance, medical and astronomy and space explorations (Chang, Bahl, & Nair, 2002). One of the most significantly usage of the RF modules are in mobile phone applications which shows the rapid growing of technology from 2G in early generations until recently which been developed until 4G devices for advance features such as High Speed Downlink Packet Access (HSDPA), Evolution Data Optimized (EV-DO) and Long Term Evolution (LTE).

Due to the remarkable advancement in the market, latest generation of Power Amplifier (PA) module evolves advance technology was implemented with bypass, mid and high-power modes with lower power consumption. It consequently covers the multiple bands and multiple modulation modes compare to older generations which involving single band and single mode modulation in mobile application. This plays crucial part in extending the talk time and battery life of mobile phones. However, the features enhancement lead to the complexity and limitations of testing the devices in order to produce an accurate result which becoming an essential in communication circuits applications (Rumiantsev, Sweeney, & Corson, 2008). Because of these, the engineers have to optimize and minimize measurement errors by taking other alternative methods to achieve the desired overall performance of PA.

Therefore, this research presented a TRL calibration method over the current conventional calibration method for the measurement of the PA to achieve better accuracy, precision and consistency. The existing method has limitations when it correlated with nonlinear parameters. This is the most effective technique applicable using Vector Network Analyzer (VNA) calibration (Arkadiusz Lewandowski, Wiatr, & Dobrowolski, 2010). It can be widely utilized to improve the testing results and eliminating measurement errors by developing a custom device with specific calibration standard. In addition, the quality of the calibration standard is important for an accurate S-parameter measurements by the VNA calibration (Jamneala & Voo, 2007). Hence, this has become the convenient technique to implement which will enhance the accuracy of the PA.

1.2 Problem Statement

Generally, measurements are related to uncertainty especially when dealing with RF and Microwave circuit measurement module. In production environment, industry recently face a problem of measurement accuracy and consistency for analog devices. Prior to this, the production lines have been operated days and nights to focus on the process and calibration which delayed the overall production outcomes. In addition, the error occurred was contributed by the different types of calibration techniques which also degrade the module performance. Due to that, the industrial always want to test the device in an ideal condition whereby no parametric errors contribution and instrument uncertainty occurred.

Hence, in this project, an effective Calibration Technique was introduced for the RF PA measurement. The calibration method was proposed is Thru, Reflect and Line (TRL) which is the network analyzer co-axial calibration method (Agilent Technologies, 2000b). This TRL calibration method is one of an alternative method that provides highest accuracy in non-coaxial measurements environment. The application for this type of calibration method allows the PA measurement to take account the effects associated to the connectors and cables which able to calibrate until the leg of the transistor compare to other conventional SOLT calibration method.

Because of the enhanced calibration methods, some sort of virtual uncertainty and modelling is neglected when getting nature behavior of the DUT performance. In addition, it improves the DUT performance margin by reduce the unnecessary errors in the test system or fixture environment.

After the calibration comparison, it can be known that which approach method will bring the pro and cons during production manufacturing. The industry can identify those defects parts directly without any further verifications procedure by applying correct fixture. It is also very important to know the DUT nature performance for customer to do the board level tuning. They can choose which impedance to be matched in order to get the expected performance from the DUT.

In conclusion, research through the different calibration method on the different specifications is needed to choose the best approach for characterization of the Power Amplifier performance.

1.3 Objectives

The main goal of this research work is projected to build a TRL Calibration kit board that able to calibrate the PA circuit board. Therefore, TRL calibration method is one of the alternative effective methods compare to specific existing calibration method which is called SOLT. The SOLT calibration method is able to calibrate the Power Amplifier until the SMA connector compare to TRL calibration method which is able to calibrate until the transistor lead. By using this TRL calibration method, the performance of the PA will be improved in terms of test measurement accuracy and consistency. To achieve the above goal, the listed objectives are necessary to be executed:

1. To design and fabricate Power Amplifier module for Avago Technologies IC (ACPM-5007).
2. To design and fabricate TRL calibration kit board based on the characteristic of the Power Amplifier Module.
3. To characterize the Avago Technologies IC (ACPM-5007) S-parameter characteristic using TRL calibration kit and compare with the SOLT calibration kit.

1.4 Scope of work

The main scope of this research focuses on the designs of the PA module and TRL calibration kit based the given specifications. This work carried out in the research is to address the performance issues of the PA which related to the measurement accuracy in particular RF parameters by providing an enhanced method of existing test system calibration at the production environment. By developing TRL calibration method, it can help to reduce errors and improving Power Amplifier efficiency.

The designs were implemented using microwave substrate from Roger Corporation for double layer topology and Hitachi MCL E-679 laminate microwave for multilayer topology. The layout designing process was done by using Advanced Design System (ADS) software.

The main characteristic was applied in this designs process by building the RF 50-ohm transmission line with same width and length for both TRL calibration kit board and Power Amplifier board. This is done to make sure that the TRL calibration standard kit matches the particular PA modeling device characteristics. Other than ADS, Mathcad software was used to calculate the width and length of the transmission line for both circuits. Finally, the circuit was fabricated, measured and characterized. The fabricated module was analyzed and compared with the existing method results to verify the effectiveness of the proposed TRL calibration method.

1.5 Thesis Outline

This dissertation is divided into five chapters appropriately. It is organized accordingly to development of the work progress carried out in this research. Chapter 1 briefly introduced the fundamental background study, problem statements, objectives, research methodology, and scope of work as well as the research contributions.

Chapter 2 reviews the detailed of theoretical background which includes the power amplifier concepts, features, and characteristics. It also introduces the theory of calibration measurement methods such as TRL calibration method, SOLT calibration method and other calibration methods which are indeed a backbone of this project. Besides, it maps out the details about the material that been used in this experimental study. Furthermore, this chapter also contains the previous relevant literature review that is related to the studies.

Chapter 3 describes the methodology and procedures applied to achieve the objectives that were set. This chapter also illustrates in detail about the experimental process including the designing procedures which was done by using the ADS software, fabrication process as well as the measurement technique procedures.

Chapter 4 exhibits the measurement results from the fabricated design of the Power Amplifier board with the TRL calibration kit board by using network analyzer. The results were analyzed and compared with the measurement results of prototype board by Avago technologies. The accuracy and consistency of the measurement was investigated accordingly in this chapter. The discussions of the results between two methods are presented.

Chapter 5 summarizes the results, discussions and analyses of the designs from the previous chapter. This chapter also presents the overall conclusions that carried out from this research studies. Finally, suggestions and future work recommendation also presented in this chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter presents an overview of the research, fundamental theories and basic principles for designing a TRL calibration kit for RF PA Measurement. The theoretical background has been divided into several subsequent topics that are vital and adequate to describe in detail in order to achieve the objectives of this dissertation. The topics are mainly focused on the concept, characteristics and types of calibration method, network analyzer Measurements Errors and techniques, and also including the PA review which is very important in the design of the TRL calibration kit. Meanwhile, there is several published research and previous works have been discussed and reviewed in this section. This works is related and similar to this dissertation. Thus, those selected references are essential to provide ideas, basic understanding and details in improving the current proposed designs.

2.2 Calibration Techniques Review

Nowadays, applications in microwave wireless communication system requiring a measurement with high accuracy and performance as the data rates capacity are increase significantly so that it can endow with tremendous development of technology, particularly in mobile application features such as web browsing, social networking, music download and video teleconferencing (Cheng & Young, 2011). The higher the speed of the data rates the more information can be transmitted smoothly without buffering through the system while maintaining the high quality of transmission. Technically, it is impossible to build a perfect hardware without any error and deficiency. This makes an extremely difficult and expensive to have a good enough hardware that capable to eliminate the need for error correction(Agilent Technologies, 2006). Due to the issue, calibration technique is an important and basic procedure before measurements process which needs to be applied in order to eliminate the unwanted subsequent errors and improve the performance of a device with higher accuracy.

In other words, the calibration plays an essential role in measurement process which mathematically derives the error model, measures precisely and stores the vector differences between the measured and actual values at the network analyzer(Agilent Technologies, 2001). In addition, this calibration procedure is applied by characterizing the error boxes before the measurement of the DUT for the suitable intended application. When the measured data is obtained, the actual error corrected S-parameters can be calculated from those data depending on particular applications and requirements(Pozar, 2005). However, inaccurate S- parameter measurement will lead to higher losses at a specific device. Thus, the network analyzer has an important role to play in calibrating the DUT incorporation with the calibration kit that is characterized according to the particular properties using mathematical methods. Hence, this makes the calibration method become easier while improving the performance of the devices rather than applying the most common used techniques compared to the advanced techniques by using network analyzer.

2.3 Network Analyzer Measurement Calibration Technique

As described in the previous section that network analyzer plays a vital role in the measurement calibration process which able to execute a task according to the proposed applications. In order to excite the calibration process efficiently a complete understanding of the network analyzer operation and execution are very important. This network analyzer is measuring instrument that tests the electrical performance of the high frequency components precisely in microwave communication system and millimeter –wave electronic circuits or in other words, it is specifically used in which it measure and characterize the transmission responses or S- parameter, reverse and forward reflection of RF components (Agilent Technologies, 2006). The measurement of the S-parameters constitutes a complete description of the small signal properties of an electronic circuit (Erdtman & Sorsa, 1967). This covers a wide range of frequency bandwidth equivalently according to the limitation of the devices itself depending on the particular application for different type of electronic circuits. If an electronic circuit is assigned to a specific frequency of bandwidth the appropriate properties of devices needed to be used in order to avoid any kind of damages for both applications.

Apart of the primary S-Parameter measurement, the network analyzer also capable in characterizing the nonlinear model behavior such as amplifier gain compression or intermodulation distortion along with the noise parameters (Agilent Technologies, 2006). This means high performance of DUT can be evaluated and test while maintaining the quality and specific application due to stringent demanding of new hardware solutions. For the applications which demand a highest speed and accuracy, the network analyzer is the one of the most widely used RF measurement tools that improved the testing procedure by applying the most important technique which is calibration. By means of network analyzer measurement not only depends on