Integration of Agilent PNA-X Vector Network Analyzer for Power Amplifier Non-linear Characterization and Load Pull Analysis

Zulhazmi A. Mokhti, Jonathan Lees, *Member*, *IEEE*

***Abstract*—This report describes the outcome of the Cardiff University MSc student project that was awarded a scholarship from MTT-S as part of its 2012 Undergraduate/Pre-Graduate Scholarship program. The project involves integrating an Agilent N5242A PNA-X Vector Network Analyzer (VNA) as the core instrument in the non-linear measurement system for power amplifier characterization and load pull analysis at the university's Center of High Frequency Engineering. The driving factors of this project are supportability, arising from the discontinuance of the HP70820A Microwave Transition Analyzer that is used in the previous system, as well as the measurement throughput and dynamic range improvements. All of the essential deliverables are met in this 3-month project. Correlation analysis is performed with another established non-linear measurement system to verify the performance of the newly built system.**

I. INTRODUCTION

CHARACTERIZING the non-linear behavior of a radio frequency power amplifier (RFPA) requires a measurement system that is capable of capturing the incident and reflected waveforms at its input and output ports under certain excitations and load conditions. From these waveforms the information about the harmonic content can be extracted and post-processing data analysis uncovers key properties of the device performance. At the core of this system is the measurement receiver, an instrument used to acquire these waveforms. The choice for the receiver can either be a time-domain instrument such as a high-bandwidth sampling oscilloscope, or a frequency-domain instrument such as a vector network analyzer (VNA). Using VNA for non-linear measurements requires the use of a phase reference module to correlate the phases of the harmonics to the fundamental.

Load pull techniques can be used to further analyze the behavior of the RFPA under different load conditions. An impedance tuner is connected at the output of the device to present it with any impedance on the Smith chart, a method called passive load pull. The losses of the passive system may limit the targeted impedance to some distance away from the edge of the Smith chart. An active load pull system utilizes external signals that are injected at the output of the RFPA to emulate the reflected waveforms, and has the advantage of covering the whole Smith chart impedance range.

II. PROJECT OBJECTIVES

The main objective of this project is to replace the discontinued HP70820A Microwave Transition Analyzer (MTA) which was used as the receiver, with the PNA-X, and at the same time upgrade the system's performance in terms of dynamic range and measurement speed. The new system needs to have active load pull capabilities up to the 3rd harmonic, and must produce comparable results with other measurement systems in the university that uses sampling oscilloscopes as their receiver.

III. SYSTEM INTEGRATION PROCESS

The integration of PNA-X, which is a frequency-domain acquisition instrument to replace the time-domain operation of the MTA means that modifications to the control software are necessary. New calibration methods are required because of the different signal routing and instrument architecture. To mitigate the risk of such significant changes, the project leverages the control software developed by Mesuro Ltd., a spin-off company from Cardiff University that specializes in load pull measurement systems. A working version of the software was recently developed for a load pull system for a customer, and can be leveraged in this project. Figure 1 shows the block diagram of the newly built system that has a capability of performing active load pull up to the 3rd harmonic, and Figure 2 shows the system in place.

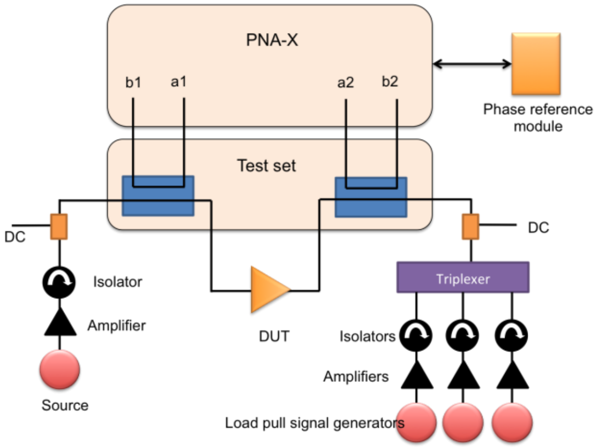


Figure 1: The block diagram of the non-linear measurement system using PNA-X as a receiver.

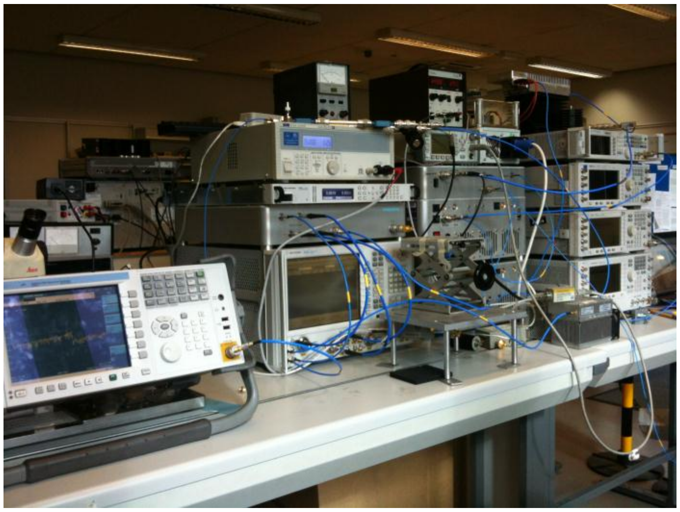
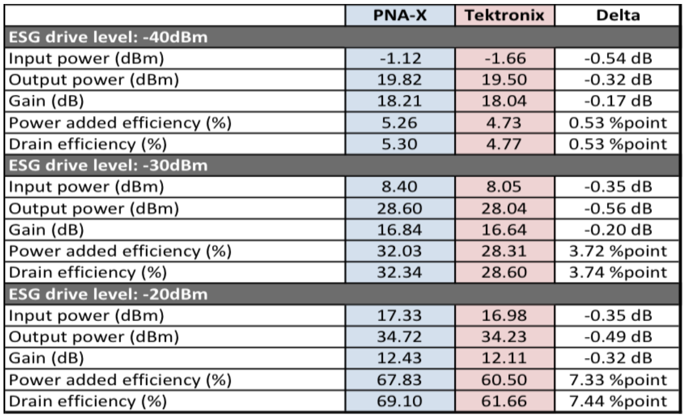


Figure 2: The newly setup measurement system based on PNA-X.

IV. Correlation Analysis with Other Non-linear Measurement Systems

Once the integration is completed, a critical aspect of the project is the verification of the newly built system. For this purpose, measurements of a known device made on this system are compared with measurements made on another established non-linear measurement system within the university, which is based on a Tektronix high bandwidth sampling oscilloscope and runs on the same Mesuro software.

To make the comparison valid, these parameters are kept constant: the device under test, bias conditions, drive level, load conditions, test set used, frequency definition, calibration kit, de-embedding files, test accessories, temperature, and the signal generators used for load pull. The only differences allowed for the two systems are the receiver itself and the source used for calibration. This is because the PNA-X only recognizes its own internal source for calibration, whereas the Tektronix oscilloscope uses an external signal generator. Table 1 lists the measurement comparison between the two systems.



	PNA-X	Tektronix	Delta
ESG drive level: -40dBm			
Input power (dBm)	-1.12	-1.66	-0.54 dB
Output power (dBm)	19.82	19.50	-0.32 dB
Gain (dB)	18.21	18.04	-0.17 dB
Power added efficiency (%)	5.26	4.73	0.53 %point
Drain efficiency (%)	5.30	4.77	0.53 %point
ESG drive level: -30dBm			
Input power (dBm)	8.40	8.05	-0.35 dB
Output power (dBm)	28.60	28.04	-0.56 dB
Gain (dB)	16.84	16.64	-0.20 dB
Power added efficiency (%)	32.03	28.31	3.72 %point
Drain efficiency (%)	32.34	28.60	3.74 %point
ESG drive level: -20dBm			
Input power (dBm)	17.33	16.98	-0.35 dB
Output power (dBm)	34.72	34.23	-0.49 dB
Gain (dB)	12.43	12.11	-0.32 dB
Power added efficiency (%)	67.83	60.50	7.33 %point
Drain efficiency (%)	69.10	61.66	7.44 %point

Table 2: Comparison of measurements made between both systems.

Overall, the device performance figures are comparable between the two systems, with all power measurements differing by less than 0.54dB. There were noticeable differences in the phases of the harmonic signals which require further investigation on the effectiveness of the calibration method for the PNA-X.

V. Summary of Project Accomplishments

Table 1 summarizes the project accomplishments against the planned deliverables. All key objectives have been met. An on-wafer measurement capability will be included as future plan for this system due to resource and time constraints.

PROJECT DELIVERABLES: PLANNED VS. ACTUAL

Defined deliverables	Must/ Want	Achievement summary
Integrating PNA-X as core instrument replacing MTA	Must	Completed, using Mesuro's C#-based control software
Coaxial measurement capability	Must	Completed. APC3.5mm connection is used
General s-parameter capability	Must	Completed. Remaining 2 ports are available with bias tees
Non-linear measurement capability up to 26GHz	Must	Completed. Frequency limitation is set by accessories
External DC supply for bias	Must	Completed. Used Agilent N670x DC supply
Active load pull capability	Must	Completed. Used 3 signal generators with Mesuro's control software
On-wafer measurement capability	Want	Not completed due to resource and time constraints. Added as future enhancement.
Correlation analysis with other system	Must	Completed. Correlation with Tektronix's oscilloscope-based system is performed

Table 1: Project deliverables: planned vs. actual.

VI. Next Career Plan

After completing the MSc program in October 2012, I have opted to do my PhD at the same university. My research focuses on the development of linear and efficient RF power amplifiers for LTE applications using envelope tracking architecture. The research will also look into improving the non-linear measurement system to suit this architecture under modulated signal excitations. The MTT-S scholarship has provided me with an added incentive to work on this project, which had strengthened my research interest in the field of RFPA design. It also presented me with an opportunity to attend the International Microwave Symposium (IMS2012) in Montreal. Participating in this conference exposed me to the level of standard required of the research community and the rapid advancements of RFPA technology. Also, the various collaboration prospects with industry and academic partners provide exciting opportunities for a research student. As such, I would like to express my deepest gratitude to MTT-S for the support and opportunity.