Emulating an Agilent™ 4142 on a Keithley™ 2600 Series Source Measurement Unit

Jorge Moreno, Osvaldo Gonzalez, Rafael Vega, Rogelio Palomera, and Manuel Jimenez

Electrical and Computer Engineering Department
University of Puerto Rico at Mayaguez
Mayaguez, PR 00681-9000, USA

Abstract—**This paper presents the development of an emulation software downloadable onto a Keithley 2600 series SMU, allowing it to emulate the functionality of an Agilent 4142 unit. The emulation system was developed as a series of scripts written in Lua, the native scripting language for Keithley 2600 series. A two-folded validation procedure is presented to ensure the emulated commands perform as the original commands. Results show a nearly perfect match between both results, highlighting the validity of the developed emulation system.**

Keywords - SMU Emulation, Agilent 4142 emulation, Keithley 26xx compatibility

I. INTRODUCTION

Source Measurement Units (SMU) are precision instruments that combine current/voltage sourcing and measurement capabilities in a single unit. SMUs can source and measure voltages or currents in the order of tens of volts or amperes with resolutions down to µV and pA. They can operate in diverse modes that include continuous and pulsing output, current limiting, four-quadrant outputs, remote sensing of voltage, and several other features that facilitate testing and characterization of a wide array of electronic devices. These instruments also allow for programmability via interactive interfaces or scripts that facilitate lengthy and repetitive tasks.

The Agilent™ 4142 has been a widely used SMU for over a decade. After so many years in the market and a broad acceptance, its production and support were discontinued and replaced with more advanced units. Competing, newer SMUs can be found in the market offering equivalent functionality, added features, and smaller size at a lower cost. However, such units rarely provide drop-in replacement capabilities, due in most part, to the use of different programming languages. This limitation makes them difficult to be used as drop-in replacements for 4142s in established testing and characterization set-ups. One such case is the 2600 series SMUs from Keithley Instruments.

In this paper we describe the development of an emulation system downloadable into a Keithley 26xx SMU that allows for making the latter a nearly drop-in replacement for an Agilent 4142 SMU. The developed emulation system considers the many differences between the units, both in hardware and software, to allow for an easy migration path for Agilent 4142 users wishing to use Keithley 26xx Series SMUs without resorting to time consuming code rewriting.

This paper describes how our emulation system handles the syntax differences between Lua and HTBasic, the architectural dissimilarities between units, their different command management strategies, and the communication issues arising when using a remote host computer.

The emulation system functionality was two-way validated. First, a command-by-command verification was performed ensuring the proper equivalence between each supported 4142 command and the equivalent emulation library entry. Second, a script-mode validation was performed through the execution of a 4142 command sequence on a 2612 SMU.

The rest of this document discusses the key differences between the original and emulation units, followed by a section where the implementation of the emulation system is discussed. In Section IV, we discuss how the emulation system was validated to then present our conclusions.

II. DISSIMILARITIES AND CHALLENGES

The dissimilarities between the 4142 and 2600 units posed a challenge to the development of an emulation system. Below we describe the most salient differences between them.

A. Networking Capabilities

Keithley 2600 Series units have two independent source meter channels and can be connected in a network of up to 16 units with resolutions down to µV/fA, depending on the application [1]. The Agilent 4142 SMU can be configured to use up to eight plug-in units per card cage with a resolution down to µV/fA, depending on the application [2].

B. Language and Syntax

Keithley 2600 Series use the Lua scripting language. The syntax of a function has the following format:

```
Function(parameter1,parameter2,…)
```

Agilent 4142 units accept HTBasic and use the following command format:

```
<Command> <Parameter>{<Parameter>,…}
```

The {} brackets indicate optional parameters.

C. Command Management

The Keithley 2600 Series units use a resident Test Script Processor (TSP) that runs codes written in Lua scripting language. This enables the units to run as a standalone device. Agilent 4142 units, on the other side, utilize control software, a library of subprograms and user defined functions written in BASIC. These units cannot function independently.

D. Communication

Keithley 2600 Series units utilize either a General Purpose Interface Bus (GPIB) or an RS-232 (Serial) as a communications interface. The user can select either interface from a communications setup menu or the unit can do the selection automatically by sensing activity in the ports. The 2600 Series units also have a TSP-Link which allows communication between units in a Master/Slave configuration, in which both the GPIB and the RS-232 interfaces are disabled on the Slave units. Agilent 4142 units only provide a GPIB interface for the computer.

III. EMULATION STRUCTURE

The emulation of the Agilent 4142 on the Keithley unit is accomplished by a data flow scheme with four major components, as illustrated in Figure 1. Of these components, the input script, the parser, and the command library were developed as part of this project. The text script processor is included in the Keithley unit.
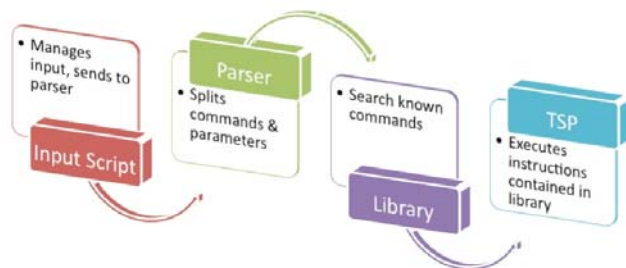

Figure 1: Emulator flow diagram.

To provide for simple debugging and modification characteristics, individual scripts were developed for each component. The scripts run in a sequence, passing their respective outputs over to the next one. Below we briefly describe the developed components.

A. Input Script

This module is in charge of accepting the commands issued for the 4142 and passing them in the appropriate format to the parser. Although the GPIB is the fastest communication interface in the Keithley unit, its current firmware version cannot read from the GPIB port while data is being sent. To fix this we developed a Visual Studio/C# program on a host computer which sends the 4142 commands through the serial port to the SMU, where the input script receives them.

Since Agilent 4142 commands are sent line by line from the external host, the input script can iteratively receive them and re-format them in order accepted by the parser. Upon

initialization of the emulation mode, the input script resets the units and waits for an input. As commands and parameters are received, they are stored in a string variable and then passed to the parser. The Input Script repeats this process until the user terminates input by either typing in EXIT or pressing the EXIT key on the SMU.

B. Parser Script

The task of the parser is to separate the 4142 commands from the parameters. Inputs have the 4142 syntax:

<Command> <Parameter>{<Parameter>,…}

The first word in the string is identified as the command, which is extracted from the input script string and stored in a variable. The rest of the string might contain one or more optional parameters. These parameters are iteratively separated into a variable length vector. The extracted command, the parameter vector and the iteration length variable are then sent to the library script.

C. Library Script

The library is organized as a table where command definitions for the 2600 unit are stored. The library script contains a search function to find the command sent by the parser on the list and the different limits, compliance, and ranges for voltage and currents of the Keithley unit. It also maps the addresses of the available units. For each case, when an equivalent 2600 command is found, it is assembled with the parameters vector and then executed. However, many 4142 commands require a group of 2600 commands. In this case, the equivalent 2600 commands are individually retrieved, assembled with the parameters vector and sent for execution.

D. Test Script Processor

The code in each command library for each command definition corresponds to the normal functions used by the Keithley unit. These functions are executed directly by the Keithley's internal processor.

IV. RESULTS & ANALISIS

A total of 29 Agilent 4142 commands were embedded in the emulation library, as shown in Table 1 below. These allow emulating most common tasks performed in SMU-based tests.

Table 1 : Agilent 4142 commands in emulation library.

Emulation Library Command List				
BC	FL	PT	RI	*TST?
CL	FMT	PV	RV	TV
CN	*IDN?	PWI	*SRE	WI
DI	*OPC?	PWV	*SRE?	WT
DV	PA	MM	*STB	WV
DZ	PI	*RST	TI	

The emulator was validated in two ways: first in a command by command fashion, and second, via execution of a 4142 script to obtain the characteristic collector curves of a

bipolar junction transistor (BJT). Details of these validations are discussed below.

A. *Command Library Validation*

Each implemented 4142 command was tested in emulation mode. Their equivalent Keithley commands were also tested to compare results and verify the implementation. Commands sent to the Keithley, while in emulation mode, were displayed on the unit's screen to confirm the received command and parameters. The tasks performed by executed commands had to match the specifications provided by the 4142 command manual for that specific command to ensure proper functionality [4]. Commands that involved simple sourcing and measuring were verified with the aid of power supplies and multimeters for proper functionality.

B. *Transistor Characterization*

The script was also validated with a transistor characterization test. The test program was derived from an example code from the Control Software Programming Manual [3]. The example was modified to comply with the communication software to obtain the 2N3904 NPN transistor characteristic curves.

Two sample transistors were used (denoted DUT1 and DUT2). Each DUT was characterized first on an Agilent 4142 unit, and then on a Keithley 2612 running the emulation code. The same set of 4142 commands was issued to both units. The characterization consisted of measuring I_C for $I_B = \{1,3,5,7,$ and $9\}\mu A$, sweeping V_C from 0 to 2V in 0.05V steps, with V_E grounded. Figure 2 shows a superposition of the curves obtained with DUT1 for both units, denoting the nearly identical results.
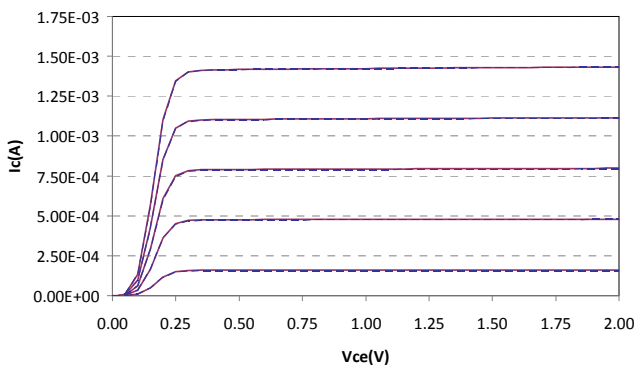

Figure 2: $I_C = f(V_{CE})|_{IB=Const}$ curves for a 2N3904: Agilent 4142 Vs Keithley 2612 in emulation mode.

A closer analysis of the obtained data showed that the Keithley unit had a maximum error of 1.3% at the very low V_{CE} range but kept below a 0.3% difference for measurements in upper saturation and active regions. This error could be caused by inherent differences in the units, but nevertheless it nearly negligible, denoting validity of the results in the emulation mode of the Keithley unit. Table 2 lists the deviations measured for the different current values of the test.

Table 2: Relative deviations in measured currents for 2612 unit with respect to 4142 values.

Device & Deviation	Base Current				
	1uA	3uA	5uA	7uA	9uA
DUT1	0.215%	0.222%	0.269%	0.173%	0.298%
DUT2	1.372%	0.677%	0.391%	0.284%	0.137%
Max. Dev.	1.372%	0.677%	0.391%	0.284%	0.298%
Avg. Dev.	0.794%	0.449%	0.330%	0.229%	0.218%

CONCLUSION

An emulation system to enable running on a Keithley SMU series 2600 code written for Agilent 4142 has been discussed. Key differences between the units have been addressed and the structure of the emulation system discussed. Results of validating the emulation system have been presented for both a individual command-level and script mode. The obtained results denote nearly identical measurements when running the same characterization script on both, original and emulated units, highlighting the validity of the emulated commands.

REFERENCES

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