An Automatic Test System for Schottky Diode Variability Characterization

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***Abstract*—The dropping in the supply voltage of the electronic circuits brings the need to study new topologies for voltage reference circuits. These topologies seek the use of devices normally alien to this kind of application, like Schottky diodes, which are usually found only in circuit protection for integrated circuits (ICs). Aiming to this use it, it is mandatory for the variability parameters to be well known and, due to the lack of this data from the industry side, arise the need to develop structures for the characterization and obtaining of the application relevant parameters. This paper brings light to the development of a system to measure and characterize custom designed electronic circuits. Systems to characterize custom microelectronic circuits are developed with a parameter analyzer in mind, bringing the need to develop bridges between measured circuit and a desktop computer. This bridge make use of a test chamber, made to conform the environment to the desired needs, an isolator between the measured chip and desktop computer system, a microcontoller system for interpreting routines and the desktop computer itself which will interpret the routines developed for the system. This system is developed with a particular circuit in mind, a Schotkky diode matrix, but can be generalized to the use of several other different circuits like digital-analog (DA) converters and even for radio-frequency (RF) applications. The modular developed structure enables the automated characterizaton of the Schottky diode matrix and offers many future exploits of this technology.**

***Keywords*—Ingrated circuit testing, characterization, Schotkky diode, measurement.**

I. Introduction

The decrease in supply voltage (Vdd) for integrated circuits, due to the growing use of integrated circuits in Energy Harvesting and in the Internet of Things (IoT) market, allied to the Vdd^2 dependency of dynamic power consumption motivated several kinds of research in the field of new topologies for voltage references. Some of this topologies make use of Schottky diodes (with a metal-semiconductor junction) like the one in [1] the advantage of this diodes over the regular PN junction counterpart is that their voltage drop between terminals is approximately half than the regular one, as we can see in [2].

Schottky diodes are used mainly for protection circuits making foundries not to focus on its models and so not providing all the accurate data required in the Product Design Kits (PDKs). Based on this, it was developed, and further sent to production, the test matrix for Schottky diode variability characterization viewed in [3]. The values obtained from the matrixes will then be used not just to characterize the production technology but also be put to use in future works from UFRGS Analog and Mixed Signal (AMS) group and other designers that may refer to it. This work proposes a testbench that can be used to measure and characterize several types of circuits, focused on statistically reliable measurements of produced chips.

This testbench consists of a Keysight 4156C Precision Semiconductor Parameter Analyzer, a personal desktop computer (PC), a Thermal Chamber TUJR, a protection system and a circuit for controlling the device under test (DUT) inside the matrix that will be measured, this system is inspired by the one in [4].

The test protocol consists of setting a temperature inside the test chamber and allowing it the proper time to stabilize, followed by selecting which diode will be measured. The diode is selected using a CMOS switch controlled by a shift-register according to [3], which in turn is controlled by our software described under "Select DUT" and set by an Arduino Uno that acts like an interface via a serial digital bus combined with our Protection System. The next step consists in the Parameter Analyzer 4156C, commanded by the measurement program from inside the desktop personal computer (PC), setting the voltage output and measuring the current through the diode using a swipe protocol and a force-sense measurement system to characterize several points described as the diodes characteristic curve.

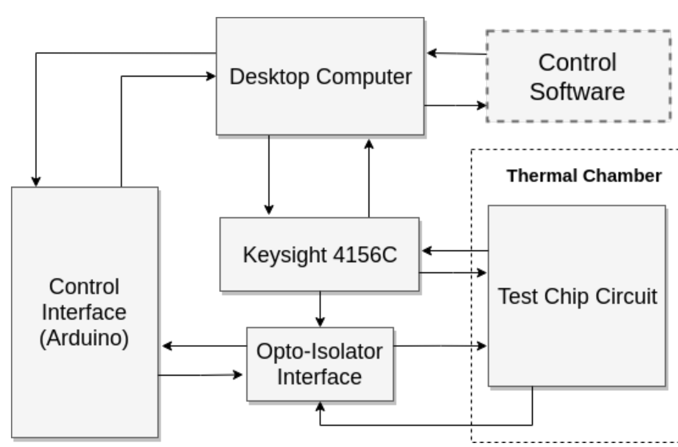

Fig. 1. Block Diagram of the Measurement System.

After validation of the device measured, this data is stored in a text file inside the external PC for later processing. This paper is organized as follows: after this introduction, the next chapter provides an overview of the developed Measurement System, including the equipment used like the parameter analyzer and test chamber, next we will see the the measurement protocol to be followed, and we afterwards present the conclusions obtained from the work described here.

II. MEASUREMENT SYSTEM

The measurement system is shown in Figure II-B, where we can see the seven large blocks that make up our Measurement System. In this section we will present each of these blocks and their main functions.

A. *Keysight 4156C*

The parameter analyzer used is the 4156C from Keysight which features four high-resolution source monitor units (SMUs), two voltage source units (VSUs) and two voltage monitor units (VMUs). It fits the requirement of having the force-sense feature, which sets the analog terminal with a known voltage and the current resulted from it is estimated in order to ensure a compensation of the resistive drop on the stimulus path.

B. *Thermal Chamber*

Aiming to obtain reliable and statistically relevant data it is imperative to have a controlled environment for the tests, in order to achieve it, the project will make use of a test chamber. For the present projects, the test chamber used is a Tenney TU-Jr thermal chamber from Thermal Product Solutions (TPS) industry.

The chosen equipment features a control tolerance of $\pm 0.3^{o}C$ after stabilization, using a platinum RTD sensor, and the resolution is $0.1^{o}C$ for both, setpoint and display. The temperature inside the chamber can reach values from $-75^{o}C$ to $200^{o}C$. The uniform conditions inside the chamber are assured through the use of vertical-down recirculating condition stream. The information here provided can be found in [5].

C. *Control Software*

There is what can be considered as a pseudoconnection, as it is not a physical connection, between the desktop computer and the control software. The control software controls what is sent by the computer hardware via its physical connections and decides how to deal with the received data.

D. *Test Chip*

The manufactured chip in [3] uses a PLCC 68 package. The chip features 400 Schottky diodes divided in four groups of 100 diodes each with the same geometry. The first group is composed by diodes with geometry of 2umx2um, the second of 5umx5um and the third of 10um x 10um while the last one also

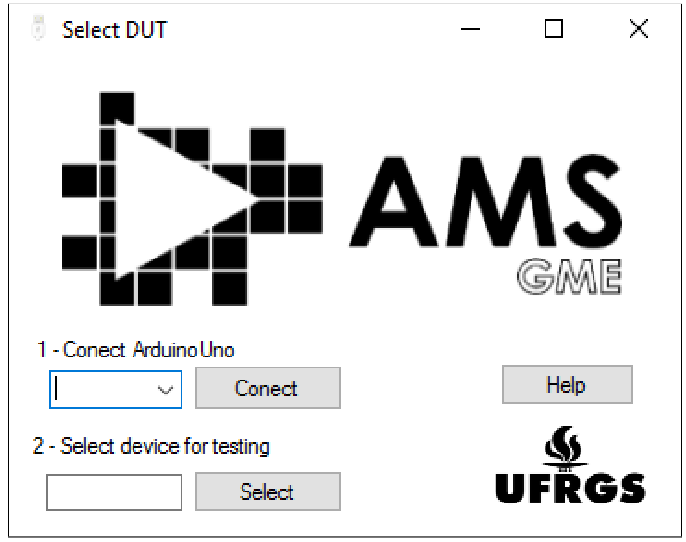

Fig. 2. Graphical interface between Arduino and the user.

featurs diodes of size 10um x 10um but of fingered topology. The diodes are selected by CMOS switches controlled by programmable shift-registers shown in Figure 3.

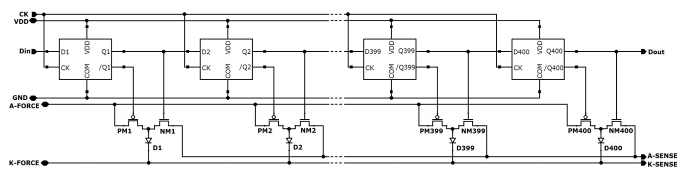

Fig. 3. Shift-register, CMOS switches and the diodes of the test matrix.

The measurement system makes use of the force-sense mode aiming to compensate the voltage drop in the switches and connections which can be seen in Figure 4 also known as four-wire or Kelvin measurement. To create good connections we intend to develop a board with the socket suitable to access all the pins available in the test chip.

E. *Control Interface*

As we can see in [3], the device under test will be selected by a set of CMOS switches and a shift-register, which will be loaded by a 400 bits word. The generation of the word is done with the help of a desktop computer, through software created in $C\#$, as we can see in Figure 2.

This program creates an interface between the user and the program recorded in the Arduino through the serial connection of the computer, the user is also able to select through this interface which Arduino platform will be connected to this program, which is the next device to be measured and also perform the verification of the vector signal sent, to ensure that the word sent confers with the word received by the

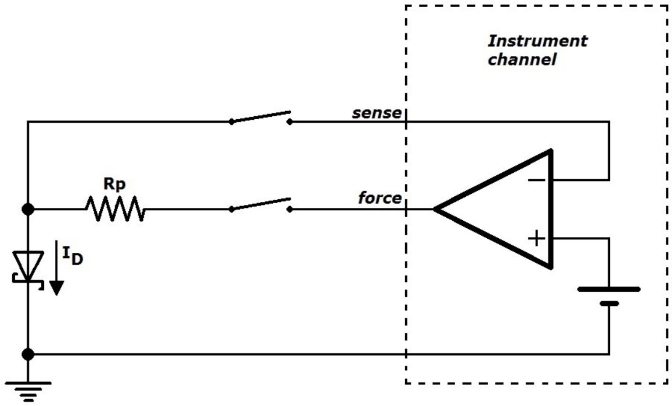

Fig. 4. Force-sense measuring technique to avoid resistive drops in the stimulus path.

CHIP. It is worth noting that the verification and validation step between the sent and received signal are only possible due to the structure created by the shift-register developed in [3].

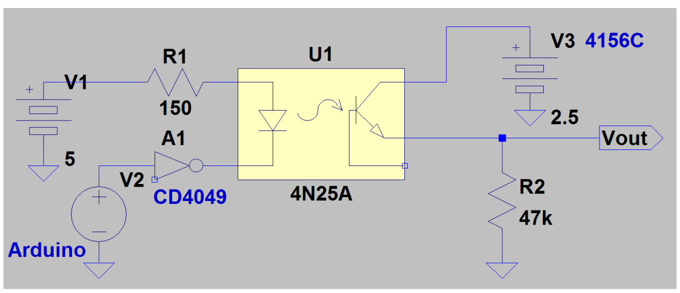

Fig. 5. General electronic circuit for the Opto-Isolator Interface.

This process is perfomed by serially sending the word containing the information about the device to be selected, this word is sent twice in sequence. The first word sent is placed inside the shift-register, and when it is forwarded, we will have exactly the same word at the output of this shift-register. This signal will be handled through an interrupt with the Arduino, compared to the word that should be sent to the system and returns the status of the operation to the user, indicating if something goes wrong. This step though fairly simple is crucial.

The signal always will comprise of only one high bit that will be shifted to the right position, one of the 400 possibilities. In addition to the signal containing the device to be measured, the Arduino system also generates a clock signal which allows the right shifting of this first signal. Within the program recorded on the Arduino we can still define the frequency of the clock signal and the type of signal to be sent to select the device. For the project described in [3], we use a 2^n counter type, which allows only one high bit at every word, but it is also possible to select different binary counters that can be utilized, for instance, in future group works that may contain A/D or D/A converters.

F. Opto-Isolator Interface

To protect the CHIP circuit from overvoltages and possible interference from the PC in the measurement process, as in [6], we developed an opto-isolator interface, responsible for lowering the voltage level at the output. The Control Interface constructed by the Arduino Uno has its high level equivalent to 5V, which can damage several of the circuits manufactured by the group. The printed circuit board was built so that its pins fit perfectly to the Arduino's board, attenuating the noise produced by the connections and cables.

The electronic circuit is quite simple, as we can see in Figure 5 it consists of an opto-isolator, a logic inverter and current limiting resistors. We use the 4N25 as an opto-isolator and guarantee its correct polarization through resistors R1 and R2. The logic inverter used was the CD4049. Note that this circuit has been replicated three times on the printed circuit board because three signals need to be isolator, signed as Vout: Clock, Data and Verification. The last one is sent from the test chip to the arduino, so it increases the voltage level different from the other attenuating channels. The voltage level in this circuit is done with the aid of 4N25, where we connect the collector and the emitter of its internal photo-transistor to the two channels of the Keysight 4156C, responsible for providing the expected voltage level necessary for CHIP to operate. So, in the opto-isolated circuit, we will have two isolated ground signals

G. Desktop Computer

A computer is needed to perform the Control Interface, between the user and the Arduino, because it is through this interface that we will be alerted to any eventual problem that may occur in the sending of the test signal. Also, the Keysigth 4156C is connected to the computer, saving the acquired data directly to text files and manage all the data as we can see in [7].

III. PROTOCOL OF MEASUREMENT

The measurement follows a simple process shown in Figure 1 where, after all the connections have been made, we first set the temperature inside the test chamber, for the Schottky diodes the temperatures to be used will range from -20^oC to 100^oC. We follow this step by setting via the interface of measurement the diode that will be measured, which in turn will send the signal to the shift-register in the chip.

After this two initial steps it will start the measurement configured via the measurement program, which follows the parameters showed in [8] and modified to our needs. The measurement program is developed over a template program also set following the orientation provided in [8]. The routine for the Schottky diode process will consist in a sweeping of voltage values and measurement of the derived currents for a voltage-current pair.

If the verification of the shift-register value yields an invalid value, the measured data will be discarded, in case of a positive response, the measurements are to be stored in the desktop computer for future processing. Particularly in the case of the Schottky diodes, the data will be processed to obtain the statistical model for the particular fabrication process.

IV. Preliminary Tests

As at the writing of this paper the device to be tested is not available and the structure described here is not fully integrated, the tests and validation were made in blocks or independently. Here we describe the tests made to the opto-isolator interface while integrated with the control interface. The program used for testing uses 8 bits instead of the 400 for the fully functional one, but is easily scalable.

We can see in Figure 6 two signals, the bottom one is the Clock signal coming from the control interface to the device under test. The signal was measured before the opto-isolator interface in order to comparate with the top one. The top one is the information signal, it is responsible for selecting which device to be measured. We can see that the amplitude of the top one is significantly lower in comparison to the Clock signal. The reason for this behavior is the second purpose of the opto-isolator interface, to regulate and control the level of the output signal. The designed opto-isolator circuit has an independent control for the output voltage. The reference for this output voltage will be set by the parameter analyzer in order to prevent overvoltages in the signals reaching the device under test.

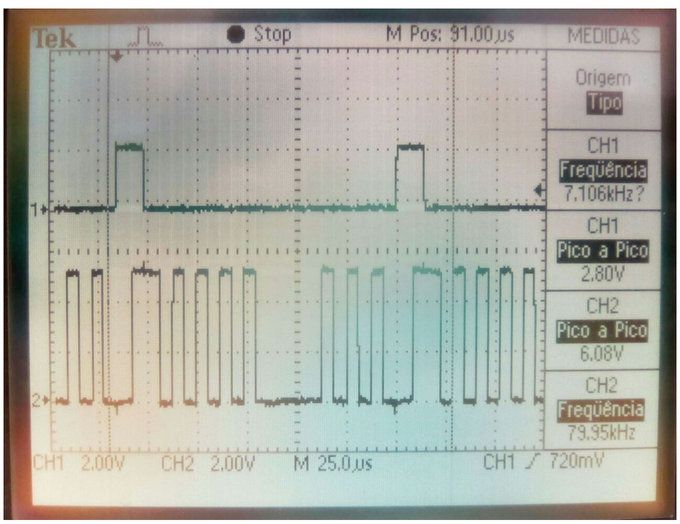

Fig. 6. Testing Signals on Oscilloscope.

V. Conclusion

The testing routine for a quality product is vital. Our goal in this work is to develop a system capable of managing the necessary test signals and through a well-established method, generate instructions for the responsible device by performing the characterization of the devices under analysis. In a second moment, it will be equally exciting to be able to evaluate the results of the CHIP manufactured by our colleagues in [3]. Through a more detailed statistical analysis, we will generate a more precise model for the Shotkky diodes and finally estimate the very likely effectiveness of using these devices in some voltage reference topologies in order to reduce their supply voltages. We can understand this as our motivation behind our goal of developing the testing system.

For this work we are developing a measurement system, which together with a thermal chamber and the semiconductor parameter analyzer will provide us with a more accurate model for Schottky diodes. This system consists of a Control Interface, developed with an Arduino Uno and with an interface that allows the user to configure the parameters of this test signal. This interface also validates the signal sent to the CHIP, ensuring that the signal sent and the received signal is the same. When the circuit is powered with the correct test signal, we will have a device connected via CMOS switches to the analog stimulus and measurement buses of a Semiconductor Device Parameter Analyzer. The resistive voltage drops over the switches, wires and conectors is compensated through a force-sense scheme of the equipament. And it is in this way that we intend to obtain the electrical voltage-current characterization in the thermal chamber for the Schottky diodes. The temperatures to be used will range from $-20^{o}C$ to $100^{o}C$. In the course of this work we can understand that test stage begins in the design laboratory rather than in the factory. The development of structures within CHIP that facilitate this work can not be overlooked.

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