An automatic equipment for nanoelectronic devices electrical characteristics measurement

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***Abstract* – An automatic equipment for semiconductor device voltage-current characteristic measurement was described. Diode current sensor for current measurements was used and sensor calibration technique was presented. It provides relative accuracy 1% in wide current range (10^{-2}A..10^{-10}A).**

***Index Terms* — measuring systems, current sensor, voltage-current characteristic, nanoelectronic devices, semiconductor, integrated circuits**

I. INTRODUCTION

Integrated circuits (IC) electrical characteristics measurements occur over all steps of technology process, including testing and qualification control. The parameters of military and space application devices must be controlled more strictly because of hard demands on reliability in radiation, humidity and high temperature environment. Special application IC must be passed testing and qualification through these factors. During this process it's necessary to control the electrical parameters of testing devices. It is especially important for analog ICs where parametric faults electrical characteristics are occurred. For example, radiation impact on operation amplifiers (OP) leads to increasing of input currents and input offset voltages shifts [1]. It is necessary to measure current-voltage characteristics of test transistor structures to research radiation effect in nanoelectronic devices [2].

Because of essential non-linear voltage-current characteristics of semiconductor nanostructure it is necessary to provide this measurements in voltages range ±10V and accuracy ±1mV and to provide current measurements in wide range 10^{-10}A...10^{-2}A and relative accuracy 1%. Nanoelectronic semiconductor devices characteristics are strongly temperature depended. Therefore temperature setting and stabilization during measurements are required.

To avoid the influence of electrical noise during the near 1nA current measurement the use of special techniques are required, such as shielding and filtering of spurious signals that can distort the measurement results and special routing board methods to eliminate leakage. These requirements leads to limitations on the length of the interconnects and measuring stand design. Requirements for precision voltage setting and a wide range of currents connected with significant nonlinearity of the current-voltage characteristics of the transistor structure due to the exponential dependence of the current on voltage.

Even a slightly change in the ambient temperature can significantly affect on the measurement results. The problem of providing the recurrence of the measurement

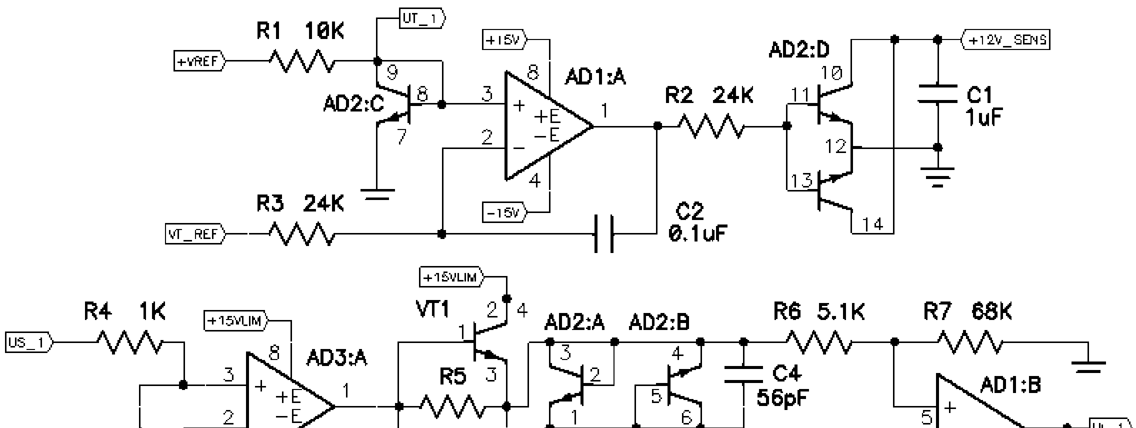

Fig.1. Circuit diagram of the device measuring channel.

results is particularly important when dealing with high currents and long-term radiation experiments due to temperature drift.

In this paper device for measuring the parameters of integrated circuits and test transistor structures is described. Presented device meets all the formulated requirements and can be used for research purposes and qualification testing of analog integrated circuits including the effects of ionizing radiation.

II. CURRENT MESURENTS

The measuring device as a current sensor uses a logarithmic current-voltage converter on a diode-connected transistors. Circuit diagram of the device measuring channel presented at fig.1.

Chanel COM_U1 output voltage controlled by AD3:A operation amplifier. Depending on output voltage polarity channel load current passes through one of the transistors AD2:A, AD2:B and lids to current-dependent voltage drop on sensor elements (transistors). Sensor transistors are part of transistor array 198HT1 microcircuit. Sensor output voltage transmits to differential amplifier inputs, which based on resistors R6, R7, R8, R9 and operation amplifier U1:B, forming logarithmic current dependence of UI_1 signal voltage level.

Temperature of transistors AD2:A, AD2:B must be maintained constant. For this purpose, thermal stabilization system is implemented. Temperature sensor output voltage transmits to non-inverting input of operation amplifier U1:A. This sensor is made of a serial-connected resistor R1 and transistor AD2:C, located in a single chip with current sensor transistors. UT_1 voltage level decreases with increasing temperature. For setting mode temperature reference voltage transmits to operation amplifier (U1:A) inversing input. If UT_1 < VT_REF then output signal of U1:A opens transistors AD2:D, which heats up transistors AD2:A, AD2:B и AD2:C. As a consequence the voltage level UT_1decreases. Thus, the above negative feedback keeps the temperature sensor circuit current at a constant level.

Implemented technique permits to measure currents in a wide range, without switching the measuring range.

To determine the current dependence of voltage UI_1 transistor sensor must be calibrated. The calibration procedure requires a connection to measuring channel an external calibrator. In calibration process to provide serial connection (one by one) calibration resistors to measure channel output control signals transmits to calibration device control inputs. Calibration process starts from minimal resistor. It's electrical resistance measure by multipurpose tester. Channel output voltage is set so that the cannel current corresponds to signal UI_1 voltage level 9V. The current value is calculated according to Ohm's law. Similarly we define the current corresponding to the next value UI_1. During calibration, the voltage varies in range ±9V with step 0.1V. If channel output voltage in selection current process decreases bellow 0.2 V, then occurs transmit to next resistor. There are eight resistors it calibration device. Resistors values presented in table 1. The described technique allows to calibrate the measuring channel for currents in the range of $10^{-2}..10^{-10}$A. Measure devise includes three channels. Channel transfer characteristics obtained in calibration process presented at fig.2.

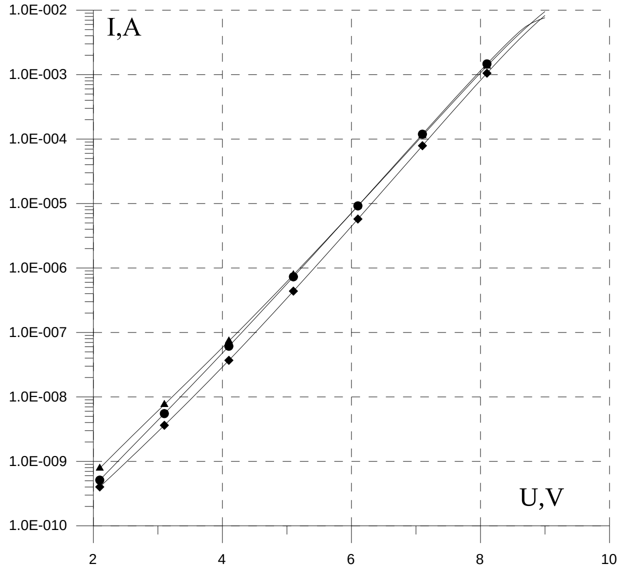

Fig.2. Channel transfer characteristics obtained in calibration process.

TABLE 1. CALIBRATION RESISTORS VALUES.

Resistor number	Value, Ohm
1	$5,1\cdot10^{2}$
2	$1,0\cdot10^{3}$
3	$1,0\cdot10^{4}$
4	$1,0\cdot10^{5}$
5	$1,0\cdot10^{6}$
6	$1,0\cdot10^{7}$
7	$1,0\cdot10^{8}$
8	$1,0\cdot10^{9}$

III. VOLTAGE SETTING TECHNIQUE.

Analog to Digital convertor module based on IC AD7694 (Analog Devices) is used for reading current sensors outputs and for testing nano-electronic devices output voltages measurements. Because of AD7694 input voltage is limited by reference voltage level 4.5V, formed by reference module IC REF194, and analog to digital converter module output range is ±10V inverting amplifier circuit is used to convert module input voltage value to AD7694 input voltage range.

Differential and integral nonlinearity (DNL and INL) of AD7694 according specification less, then 3 LSB (Last Significant Bit), that corresponds voltage measure error less, then 0.5mV in full range ±10V. Therefore analog to digital convertor module transfer characteristic is linear with sufficiently accuracy. Next calibrating technique for determining zero code and LSB value was used. Zero level voltage sets on module input and corresponding code ADC_ZERO_CODE save in memory. Measured reference voltage ADC_FEF and transmits to module input, corresponding code ADC_REF_CODE after conversion saved in memory. LSB value determined by relationship:

ADC_STEP = ADC_FEF /(ADC_REF_CODE - ADC_ZERO_CODE). (1)

Using calibration results values ADC_STEP and ADC_ZERO_CODE module input voltage determined as:

U_IN = (ADC_IN_CODE – ADC_ZERO_CODE) ADC_STEP, (2)

ADC_IN_CODE is conversion code, corresponds to input voltage U_IN. For voltage calibration external modules are not required. Voltage calibration procedure can be run by user command.

To install require voltage levels in experimental researches software controlled voltage sources are used. They are implemented on the basis of integrated circuits 16-bit DAC (Digital to Analog convertor) DAC8532. Inversing amplifier stage is used to provide output voltage range ±10V, while DAC reference voltage level is 4.5V.

DAC8532 is to channel R-string digital to analog converter without missing codes with excellent INL value. The main disadvantage of this type of DAC is the most integral nonlinearity, which, according to the data sheet can be up to 1% of full scale output voltage, which gives an accuracy of a voltage ± 0,1 V to ± 10V. This accuracy is determined by the spread of the resistors used in the converter is not random, and can be reduced by calibration. The converter DAC8532 uses two-stage R-string matrix. First stage of the matrix consist of 1024 resistors and converts ten first bits of input data to output voltage. Second interpolation stage is applied to refine the output voltage. Second stage consist of 64 resistors and provides conversion of six last bits of input data. During the calibration digital to analog converter output connected to the analog-to-digital convertor input. As the result of 1024 measurements assemble table of corresponding input DAC codes and output ADC data. Step of DAC code variation is 64. This table uses for determination DAC code for required output voltage level. Code DAC_CODE for voltage U_DAC determined by relationship:

DAC_CODE = DAC_REF+ ((ADC_CODE-C_PREF)/(C_NEXT-C_PREF)) ·64, (4)

DAC_REF is table DAC code, corresponds closest to required voltage level, ADC_CODE is code, corresponds required ADC voltage, C_NEXT and C_PREF are table codes, closest to ADC_CODE value. To install require voltage obtained from (3) code (DAC_CODE) transmits by SPI interface to digital to analog convertor. DAC calibration do not requires external devices and runs if necessary by user command. The difference between the reference and the measured transfer characteristics of the digital to analog conversion module before and after calibration are shown in fig.3.

VI. MEASURING EQUIPMENT STRUCTURE DIAGRAM

Structure diagram of measure equipment presented at fig 4. To automate the measurement process software control measuring system with a computer (PC) is implemented. Computer’s COM-port connected to board 1 of the device. Power supply provided by standard power module (12V, 25W) produced by MW. For comfort connection different nanoelectronic devices to measure equipment commutation device was designed. It allows user to connect for electrical characteristics measurements devises in different packages.

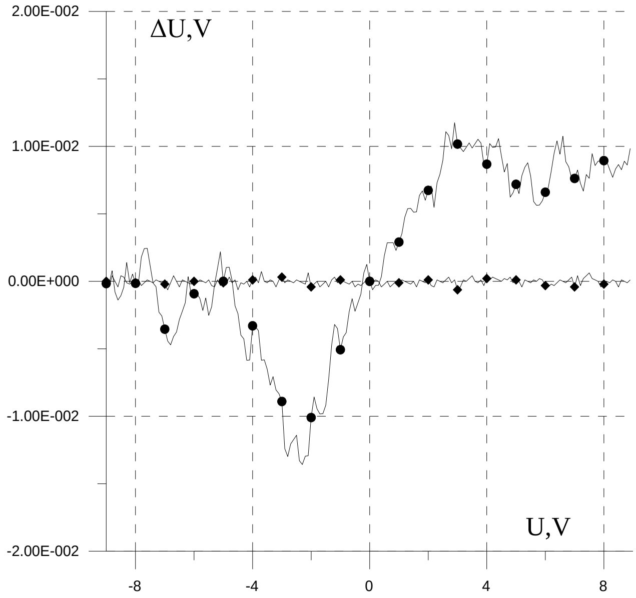

Fig.3. The difference between the reference and the measured transfer characteristics of the digital to analog conversion module before (●) and after calibration (♦).

Measure functions are provided by board 1 and board 2 (fig.4). Board 1 includes three digital to analog conversion modules E1, E2, E3 and three current sensors A1, A2, A3. Therefore there are three measure channels on board 1. Together with analog ground and digital voltmeter V measure channels connected to commutator II inputs, which provides connection every input to every selected output. In IC electrical parameters measurements it is necessary to external device control. To implement this feature on board 1 of measurement system designed digital input-output block, which can send and receive standard logic signals (0..5V) through terminals DIO1 ...7, connected to X1. Each terminal is able to perform both input and output according to a user-defined configuration. IC often have a large number of lids. Board 1 measuring system has 5 output lines, which can be connected to analog outputs IC. In most cases this is not enough and it is necessary to have a greater number of output measuring lines. To address this issue to the board 1of measuring system is connected board 2, which includes a switch III, more powerful than a switch II of board 1. Switch III has 16 output measuring lines.

Each board of measuring device includes a power management circuit for temperature stabilization, the principle of which is described in [3]. This circuit based on LM335 temperature sensor and BCX51 heat up transistors, that allows to set the temperature of the testing devices with ± 0,1 C accuracy. Terminals SN-, SN+, +12V, GD, BS (fig.4) are used for this propose.

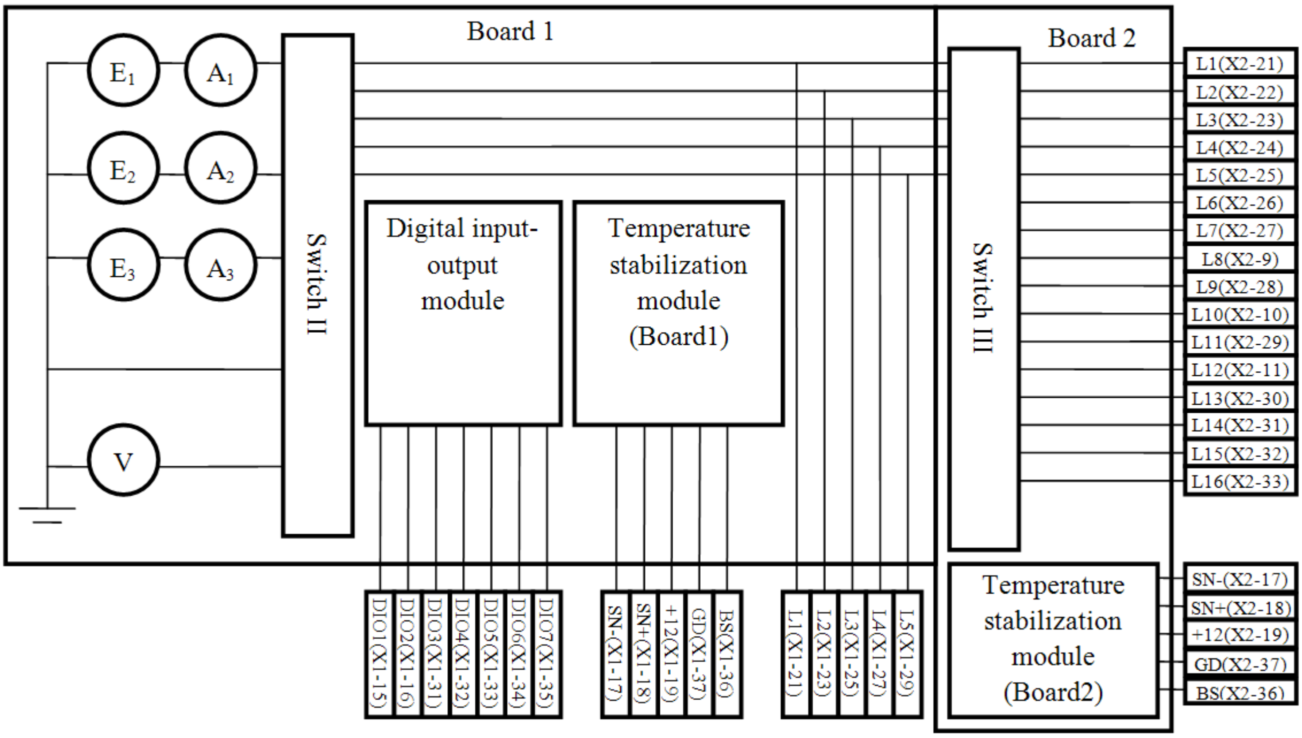

Fig.4. Structure diagram of measure equipment.

V. CONCLUSIONS

An automatic equipment for semiconductor device voltage-current characteristic measurement was described. Current measure technique using diode logarithmic sensor was considered and sensor calibration procedure was presented. This technique allows to measure currents in a wide range of 10^{-2}A…10^{-10}A with a relative error less than 1%. Calibration method for digital-to-analog converters to reduce more than order differential nonlinearity of conversion and achieve the accuracy of voltage setting ± 1 mV in ± 10V range was obtained. Voltage setting accuracies before and after calibration are presented for comparison. Full structure diagram of measure equipment was described.

Commercially available measuring devices with similar electrical characteristics have cost an order of magnitude or more than the cost of the developed device. Using commercially devices for building large measure complexes it is necessary to solve additional electrical compatibility problems to achieve the required accuracy of the measurements. Besides in that case it is necessary to use additional external thermal stabilization modules and develop commutation equipment. Presented device has compact size and includes all the features described above.

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