Computer Integrated Analogue Electronics Laboratory for Undergraduate Teaching

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***Abstract*—Computer system for laboratory exercises in basic analogue electronics was developed. It is aimed to emphasize the learning of electronic component and circuit behavior and to develop other praxis to teaching measurement skills. Hardware part of the system is based on PC computers with acquisition cards and circuits whose parameters are measured. The software part is realized using LabVIEW programming tool. The main goal of this system is to simplify manipulation of instruments, faster measurement and acquisition of the results, providing students to concentrate on measurement essence.**

***Index Terms*—component characteristic tracer, LabVIEW, scalar network analyzer, virtual instrumentation**

I. Introduction

Computer integrated analogue electronics laboratory for undergraduate teaching is realized using National Instruments PCI-6014 acquisition card. This card has 16 analogue inputs with 200kS/s sampling rate, two analogue outputs with 10kS/s sampling rate, 8 digital I/O channels and two 24-bit counters. PCI-6014 is a PCI based acquisition card. External signals or devices under testing can be connected with acquisition card using CB-68LP block panel and SH68-68-EP cable.

Software part is developed in LABVIEW package. LABVIEW provides intuitive developing interface with possibility of developing GUI applications.

The system integrates various virtual instruments that are created from scratch: functional generator, component characteristic tracer, network analyzer, signal analyzer, oscilloscope and frequency meter [1,2,3]. Although this is an educational system, it can be used in research purposes, too. The functional generator, oscilloscope, signal analyzer and frequency meter are realized as basic virtual instruments in LABVIEW environment, and will not be considered in this paper.

II. Component Characteristic Tracer

A. Hardware implementation of component characteristic tracer

The analogue outputs of PCI-6014 acquisition card [4] are used as DC voltage generators for power supply and stimulus voltage. Maximal DC output voltage is limited to ±10V. This voltage is adequate for power supply, polarisation and measurement of static characteristics of the semiconductor components.

The analogue inputs can be connected using NRSE – non-referenced single-ended, RSE – referenced single-ended and differential measurement method. Differential method is used in implementation of the characteristic curve tracer, in order to decrease noise and increase the CMRR. This noise influences to measurement precision of small current and voltage values, such as saturation current of the germanium diode. Both of the connection points of a differential system are tied to instrumentation amplifier. There are no terminals connected to a fixed reference. With differential method, the number of analogue inputs is limited to 8. In order to increase CMRR, a resistor can be connected between inverted input of instrumentation amplifier and ground. The resistance must have value of hundred equivalent Thevenin's resistance between connection points (inverted and non-inverted terminal of instrumentation amplifier). It is also possible to connect the second resistor between non-inverted terminal and ground. This configuration provides greater CMRR, but there is a systematic error in measurement caused by serial connection of resistors.

The measurement of voltages can be performed directly. Maximum input voltage is limited to ±10V. The measurement of currents can be performed only indirectly, by transforming current into voltage using parallel resistor. In this implementation we used 100Ω, 1% tolerance metal-film resistor, due to better precision of measurement. Consequently, the value of 1mA is equivalent to 0.1V. The value calculation is performed as software function.

B. Software implementation of component characteristic tracer

Software part of the component characteristic tracer is realized in *National Instruments* LabVIEW developing package, which provides simple realization of virtual instruments. Virtual instruments consist of interface to acquisition card and application with graphic user interface.

Interface to acquisition card is realized as device driver. PCI6014 cards are supported by Traditional NIDAQ and NIDAQmx drivers. All the measurements are performed using virtual channels. A virtual channel is collection of property settings that can include name, a physical channel, input terminal connections, the type of measurement or generation, and scaling information. A physical channel is a terminal or pin at which an analogue signal can be measured or generated. Virtual channels can be configured globally at the operating system level, or

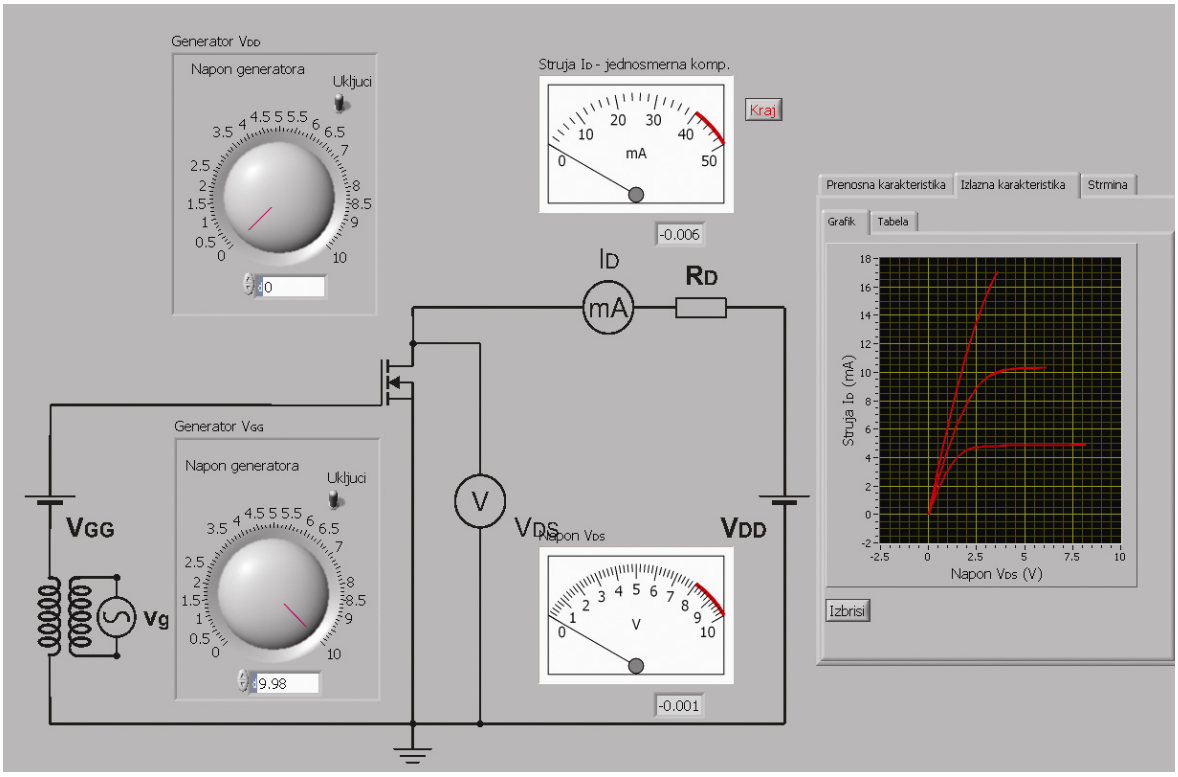

Figure 1. User interface of component characteristic tracer – MOSFET characteristic

using application interface in the program. Every physical channel on a device has a unique name.

When using NIDAQmx drivers, a number of similar virtual channels can be aggregated into a task. A task is a collection of one or more virtual channels with the same timing, triggering, and other properties. A task represents a measurement or generation process. As well as virtual channels, tasks can be configured globally at the system level, as well as using application interface.

The user interface, Fig. 1, of the component characteristic tracer consists of visual controls and indicators. It provides basic functions for measurement. Visual controls – knobs and switches – provide control of analogue signal generation. The indicators – gauges and graphs – show measured values. All measured values are placed in a table, and after the measurement process in appropriate file. User interface also provides controls for data manipulation and saving measured values.

For better performance, the main application has been separated in two threads. The first thread has functions for file manipulation and saving measured values, Fig. 2. All measured values will be saved in HTML file format.

III. Scalar Network Analyzer

A. *Hardware implementation of scalar network analyzer*

Sampling rate of the analogue inputs of the acquisition card is limited to 200kSmpl/s, and for the analogue

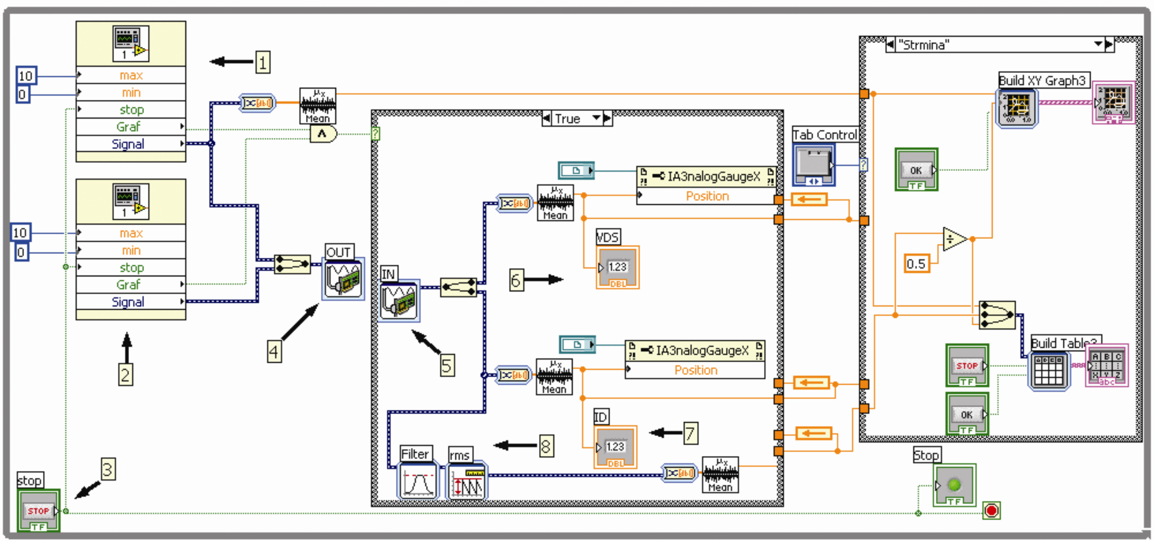

Figure 2. Main thread of application

outputs to 10kSmpl/s. The sampling rate limits the maximal frequency of input and output channels to 100kHz and 5kHz, respectively. The frequency measurement range of the acquisition card can be extended using external generator and external AC voltmeter.

The external generator and AC voltmeter used here are not stand-alone devices. The external generator transforms DC signals generated by acquisition card in AC signal with defined frequency and amplitude. The AC voltmeter transforms measured AC signal in DC voltage equal to RMS value of input signal. The measurement process performed by acquisition card is reduced to DC voltage measurement. The frequency measurement range of the whole system is determined by minimal and maximal frequency of external generator and frequency bandwidth of AC voltmeter.

The external generator is realized using XR2206 integrated circuit, Fig. 3. The XR2206 is a monolithic function generator integrated circuit with capability of producing sine waveforms of high-stability and accuracy [5]. The output waveforms can be both amplitude and frequency modulated by an external voltage. In this application, frequency of operation can be selected externally over a range of 1Hz to 1MHz. The oscillator frequency is linearly swept with a 1000:1 frequency range with an external control voltage. Frequency of generated signal V_{gen} is proportional to the total timing current, I_T, drawn from timing terminal (pin 7), and can be represented with empiric equation:

$$f = \frac{320 I_T \left[mA\right]}{C\left[\mu F\right]}\left[Hz\right] \qquad (1)$$

where C is a value of timing capacitance connected between pin 5 and 6. Timing terminal is low impedance point, and is internally biased at +3V, with respect to pin 12. Frequency varies linearly with I_T, over a wide range of current values, from 1μA to 3mA. The timing current I_T, can be controlled with external DC voltage V_{freq}, generated by acquisition card. The timing current is proportional to V_{freq}:

$$I_T = I_{DSS}\left(1 - \frac{U_{freq}}{U_T}\right)^2\left(1 + \lambda U_{DS}\right) \qquad (2)$$

where U_T and λ are constant, and U_{DS}=3V. Following the equations (1) and (2), the frequency of oscillation can be represented with empiric equation:

$$f = \frac{320 I_{DSS}\left(1 - \frac{U_{freq}}{U_T}\right)^2\left(1 + \lambda U_{DS}\right)}{R_2\left[k\Omega\right]C\left[\mu F\right]}\left[Hz\right] \qquad (3)$$

The frequency range can be changed by switching timing capacitor. The external TTL signal V_{range} generated by acquisition card controls the switching relay [6]. The relay driver is realized using simple BJT. When the TTL signal V_{range} is at low level, the current I_R is equal to zero, and the relay is opened. When V_{range} is at high level, the

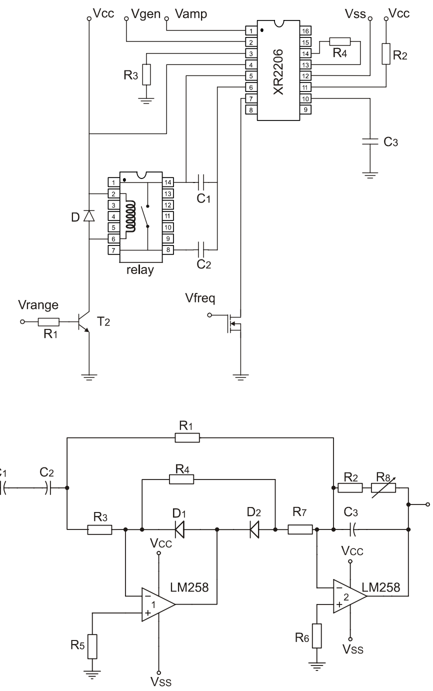

Figure 3. External generator (up) and AC voltmeter (down)

current I_R is equal to $\frac{V_{CC} - V_{CES}}{R_1}$, where R_R is resistance of relay coil, so the relay is closed. In first case, the total timing capacitance is equal to C_1, and in second to C_1+C_2.

The AC voltmeter is realized as precision rectifier with low-pass filter (figure 3). The first operational amplifier is used for full-wave precision rectifier, first presented by *Millman* and *Halkias* [7]. The output signal of the rectifier is full-wave rectified signal, with DC component U_{DC} proportional to root mean square of input AC voltage:

$$U_{DC} = \frac{2U_{RMS}\sqrt{2}}{T}\int_0^{T/2}\sin\left(\frac{2\pi}{T}t\right)dt = \frac{2\sqrt{2}}{\pi}U_{RMS} \qquad (4)$$

The second amplifier is used as active low-pass filter, which rejects the AC component of rectified signal. The trimmer R_8 is used for calibration. All resistors used in configuration of the AC voltmeter are low-tolerance (less then 1%) metal-film resistors. Integrated circuit LM258 is used for operational amplifiers [8].

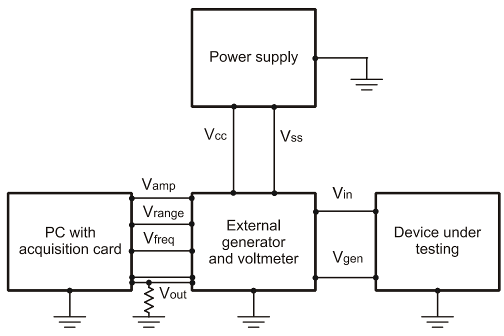

Figure 4. Complete scalar network analyzer

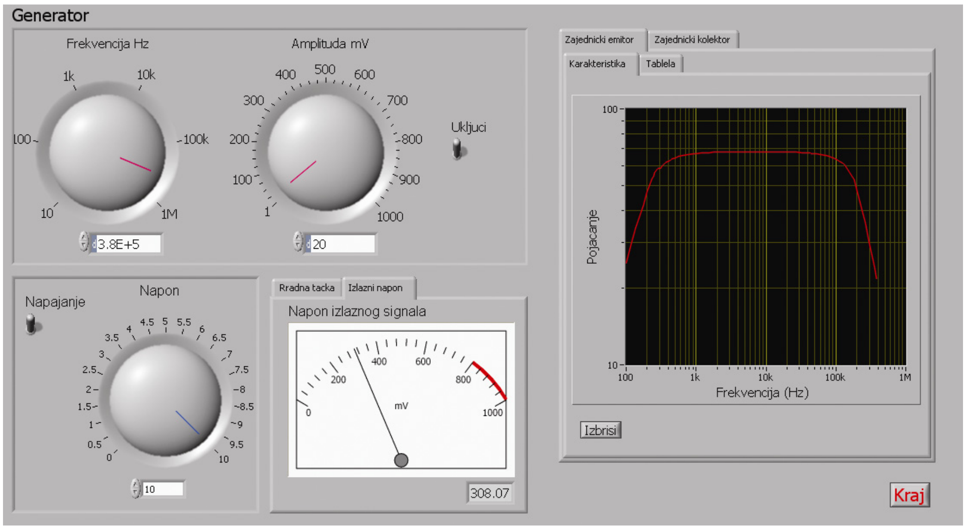

Figure 5. User interface of scalar network analyzer – BJT amplifier

External generator and voltmeter are placed at printed circuit board. PCB has connectors for input control signals V_{amp}, V_{freq} and V_{range}, generator AC output signal V_{gen}, measured AC signal V_{in} and output DC signal V_{out}. V_{amp} and V_{freq} are connected to analogue outputs of acquisition card, V_{range} to the TTL logic channel of acquisition card, V_{out} to analog input of acquisition card, V_{gen} to the input of device under testing, and V_{in} to the output of device under testing, Fig. 4. There are connectors for power supply V_{CC}, V_{SS} and signal and power ground, too.

The acquisition card can supply only +5V/500mA, so it is necessary to use external ±12V split power supply, or isolated DC/DC converter for power conversion.

The analogue inputs of acquisition card can be connected to AC voltmeter using NRSE – non-referenced single-ended, RSE – referenced single-ended and differential measurement method. Differential method is used in this implementation, in order to decrease noise and increase the CMRR. This noise influences to measurement precision of small voltage values. Both connection points of a differential system are tied to instrumentation amplifier.

There are no terminals connected to a fixed reference. In order to increase CMRR, a resistor can be connected between inverted input of instrumentation amplifier and ground. The resistance must have value of hundred equivalent Thevenin's resistance between connection points (inverted and non-inverted terminal of instrumentation amplifier). It is also possible to connect the second resistor between non-inverted terminal and ground. This configuration provides greater CMRR, but there is a systematic error in measurement caused by serial connection of resistors.

B. *Software implementation of scalar network analyzer*

Software of scalar network analyzer, Fig. 5, is realized in National Instruments LabVIEW developing package. Everything relating to software implementation of scalar network analyzer is the same as mentioned in section II B.

IV. Conclusion

Computer integrated laboratory for analogue electronics has educational purpose. The main goal of this system is to simplify manipulation of instruments, faster measurement and notation of the results, providing students to concentrate on measurement essence.

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