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ULTRA-LOW NOISE TWO CHANNEL NOISE MEASUREMENT SYSTEM

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Abstract: The computer-controlled system for low-frequency noise measurements has been presented. All major functions for adequate polarisation of a device under test are programmable providing complete flexibility and automation for biasing. The inherent noise parameters of the main modules are enclosed. The system enables to measure input-output noise relations for BJTs, JFETs, MOSFETs, MESFETs, HEMTs, and, in general, also other two-ports.
Keywords: low-frequency noise, noise measurements, low- noise preamplifiers, automation of noise measurement

1 INTRODUCTION

The aim of the low-frequency noise investigation in semiconductor devices (e. g. BJTs, JFETs, MOSFETs, MESFETs, HEMTs) is:

- an analysis of noise mechanisms to find the possibilities for improving a technology,
- finding links between 1/f noise and quality of semiconductor devices, enabling often the individual prediction of their quality by means of low-frequency noise measurements,
- to study possible noise non-linearities in a measured two-port.

For currently manufactured semiconductor devices it is needed to construct a noise measuring system with a very low inherent noise level. For example, the gate current noise level for MESFETs is usually as low as a few nA. In order to estimate the coherence function between two noise signals of a semiconductor device two separate channels for simultaneous noise measurements are necessary [1]. The computer-controlled (under the LabVIEW NI software) noise measurement system has been built for these purposes [2].

2 MEASUREMENT SYSTEM - GENERAL DESCRIPTION

The block diagram of the system is shown in Fig. 1. The system consists of two independent measurement channels (channel **0** and channel **1**) in which measured noise signals appropriately gained can be simultaneously introduced into acquisition part of the system.

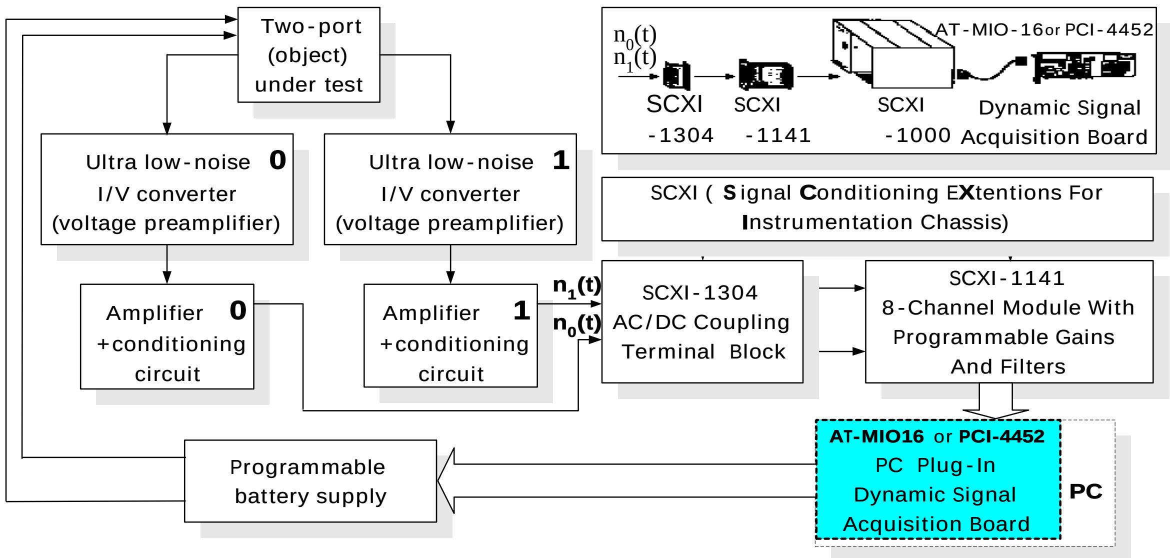

Figure 1. Simplified block diagram of the measurement system

The analogue part of the system is totally battery supplied and contains especially shielded, ultra low noise preamplifiers (for noise signals driven from low impedance sources) or current-to-voltage (I/V) converters (for high impedance noise sources). Using I/V converters enables to investigate directly the spectrum of current noise for input and output terminals of a two-port (important for noise models of semiconductor devices), their cross-spectrum $G_{xy}(f_k)$ and coherence function $\gamma^2(f_k)$ (see Fig.4). A properly selected configuration of the measurement system enables to achieve an enough high level of noise signals from the device under test to be processed in the digital part of the system. It allows also measuring directly the power spectral density of voltage or current signals in an every channel $G_{xx}(f_k)$ and $G_{yy}(f_k)$.

The antialiasing filter SCXI-1141 (having eight software-controlled input channels with the software-selectable cut-off frequency $f_a = 100/m\ kHz$, where m is an integer - m ≥ 4) gives an output signal range ±5 V. The low noise and low distortion Dynamic Signal Acquisition Board PCI-4452 (used optionally instead of AT-MIO16 for noise characteristics estimation in the wider frequency range) simultaneously digitise input signals (within the range from ±10 mV to ±42.4 V) by means of a 16-bit resolution, 64-times oversampling, delta-sigma modulating Analog Digital Converter (ADC) over a bandwidth from DC to 95 kHz. The data can be next processed on-line or stored on a disk as time series with a required number of samples according to the accuracy of noise parameters and characteristics estimation.

The virtual instruments are programmed in the LabVIEW environment.

The main mechanical frame and enclosure of the system were selected (and modified) in standard EMI-Shielded 3U 19” with hinged front and rear panels (subracks can be chosen in different dimension versions). The modules of DUTs (Device Under Test), preamplifiers and current-to-voltage converters were prepared for measurement of different devices (one-ports, BJTs, JFETs, MOSFETs, MESFETs, HEMTs), therefore their parameters and construction complexity is also different. These modules are interchangeable according to user requirements.

3 LOW-NOISE PREAMPLIFIERS AND CURRENT TO VOLTAGE CONVERTERS

Depending on a device under test and on the method of noise characterisation the different types of low-noise preamplifiers and current to voltage converters can be included in the front-end part of the system. The analogue part for transistor noise measurements is shown in Fig. 2. For FETs noise measurements in the gate channel an ultra low-noise I/V converter with the appropriate conversion factor is required (for example, the gate current noise level for MESFETs

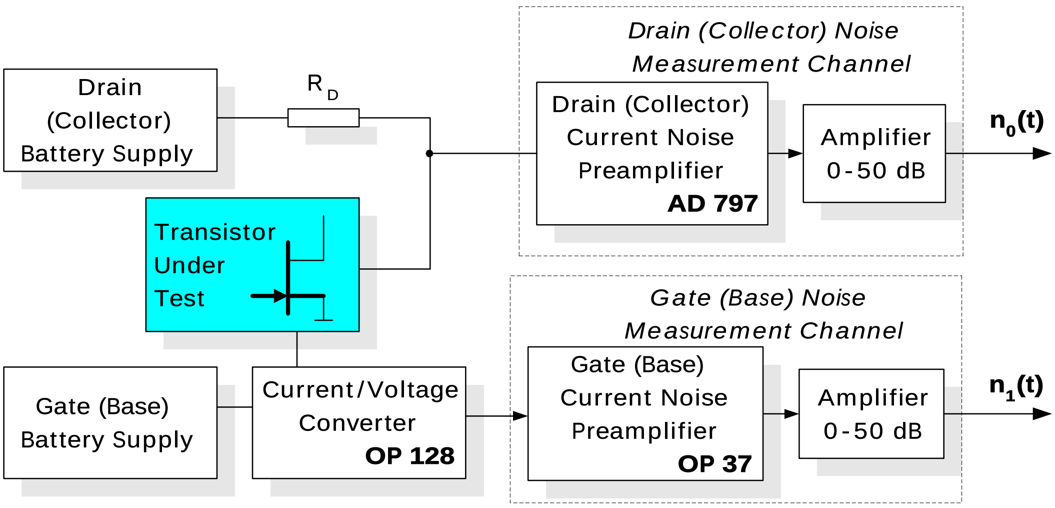

Figure 2. Analogue part of the system for FETs (BJTs) noise measurements.

equals often only a few nA). The equivalent input noise voltage of the drain current noise preamplifier (AD797) was estimated as $U_{ni} \approx 0.67\ nV/\sqrt{Hz}$ whereas the equivalent input noise current of the converter circuit (OP 128 as the transimpedance amplifier) as $I_{ni} \approx 41\ fA/\sqrt{Hz}$ for the feedback resistor $R_F = R_D$ of the converter having the resistance *10* MΩ. The results of the noise analysis were confirmed experimentally. The inherent noise of the measuring system can be subtracted from the results of the noise measurements. The final amplification factor is settled by means of the output amplifiers.

4 COMPUTER-CONTROLLED OPERATION OF THE SYSTEM

The fraction of the system for automatic polarisation of the measured devices consists of the following main subassemblies (Fig. 3): CPU (µP), ADC, DAC1 up to 10.24 V and DAC2 up to 5.12 V (DAC- Digital-Analog Converter)- enclosed in the very carefully shielded and grounded mechanical Schroff modules.

All major system functions are programmable and executed by means of the local controller (CPU) MINI535 with two-directional ports. As an ADC the device MAX132 (18 bits with multi-slope integration) with the multiplexer MAX399 was applied. Coupling to ìP effects of stray capacitance were minimised by keeping digital lines as far from analog components as possible. Two separate modules for the gate (base) bias DAC1 and for the drain (collector) bias DAC2 on PCM1702P Burr-Brown (20 bits, ultra low distortion plus noise: -96 dB with a full-scale output) were implemented. The idle channel SNR for the PCM1702 is greater than 120 dB making it ideal for low-noise application. Suitable filtering of the inherent system noise at the output (giving only -140 dB of background noise) for biasing separately the base (gate) and the collector (drain) of the measured transistor was provided. The resolution of biasing current setting of 10 points per decade in the range $10^{-9} \div 10^{-5}$ A for base or gate current and $10^{-7} \div 10^{-2}$ A for collector or drain current brings a complete flexibility and automation for the required polarisation of the transistor under test. To minimise interference separate batteries for all main modules and optoisolation between analogue and digital part of the system have been provided. The battery recharger "refreshes" batteries before an every long time measuring cycle.

The automatic setting of DUT (Device Under Test) polarisation is controlled under the LabVIEW software.

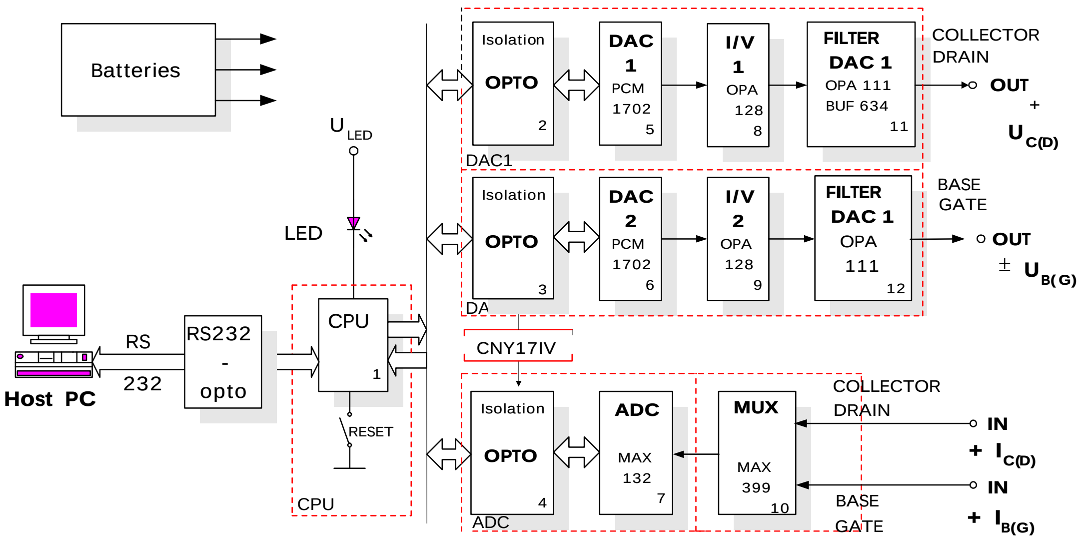

Figure 3. Block diagram of the programmable biasing system of the measured transistor (DUT)

5 DATA ACQUISITION AND PROCESSING

The computer-controlled system operates under the LabVIEW NI software. Before starting a noise measurement the system enables an initial monitoring of the measured noise waveforms from both channels transposed to its input to properly choose the required gain of the analogue part of the system. The scanning frequency and the number of acquisited samples from an each channel can be selected by means of the virtual instrument (VI) *Two-ChannelAcquisition.vi* programmed in the LabVIEW environment. Using this VI one can additionally increase the software-selectable gain of the amplifiers in the filter module in a case of very low-level noise signal measurement. It has been included as a sub-VI to the main LabVIEW application Two-*ChannelAnalyzer.vi* (Fig. 4). This virtual instrument is intended to acquisit and process the two noise time series (noise records) $n_0(i\Delta t)$ and $n_1(\Delta t)$ as samples of gate (base) current noise and drain (collector) current noise. To achieve the accepted accuracy of estimation the proper number of time records (segments) to be averaged should be selected. Noise characteristics for a single noise signal can be estimated as well as statistical characteristics for noise data from both channels.

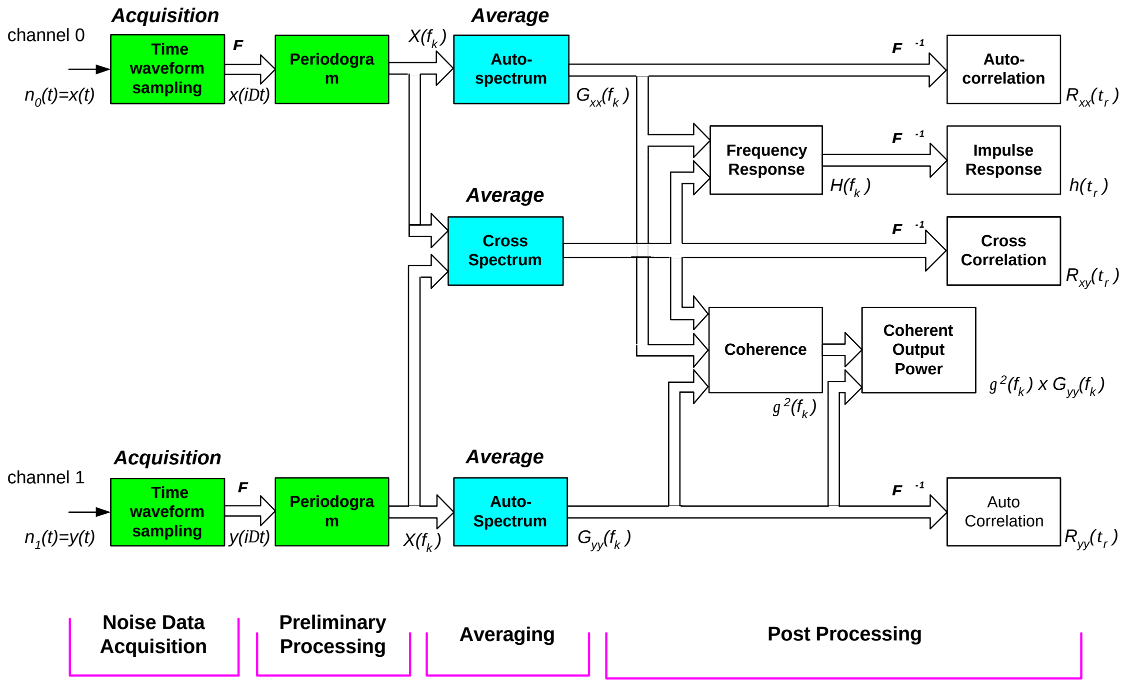

Figure 4. Two-channel noise analysis in frequency domain (in the spectrum averaging mode)

6 EXPERIMENTAL VERIFICATION OF THE SYSTEM

The noise measurements were carried out for BJTs, MESFETs, HEMTs and also for Schottky diodes in presented system.

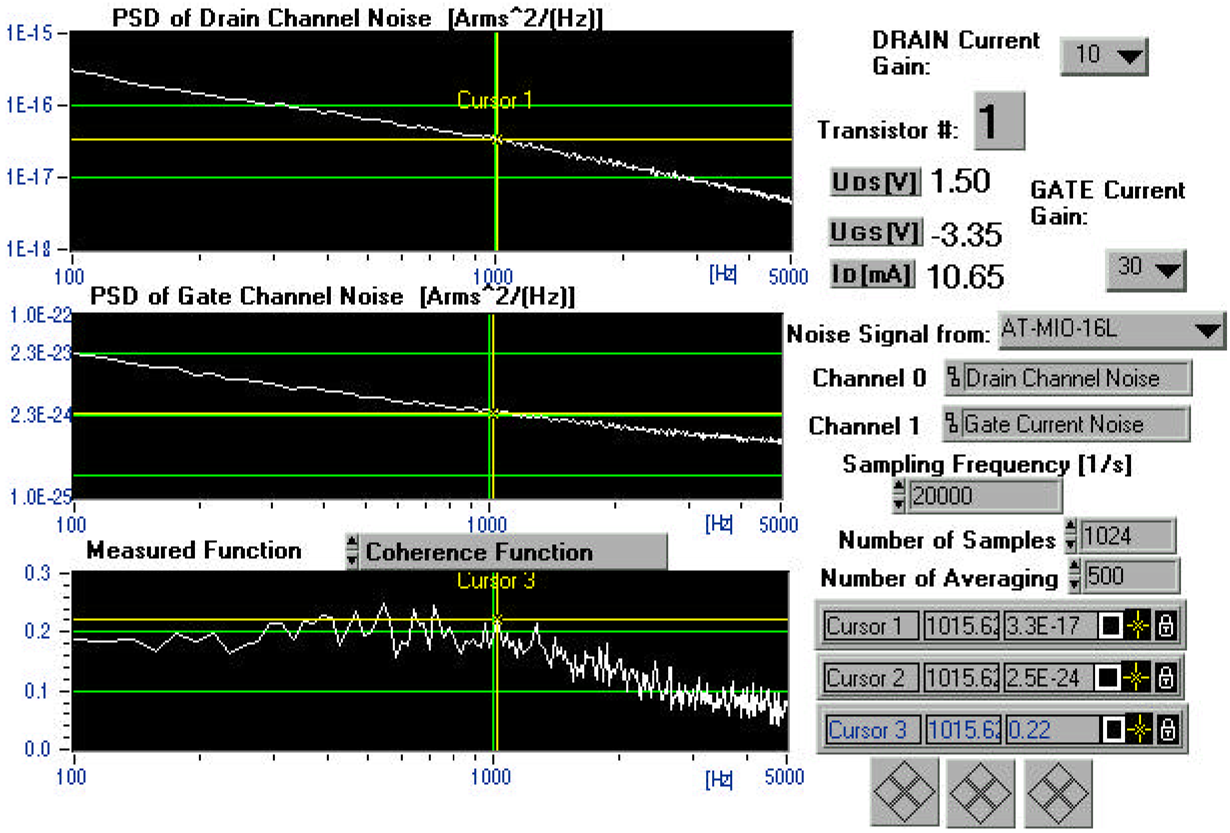

Figure 5. Results of noise measurements for transistor No. 1 type CFYP01; PSD of drain current noise, PSD of gate current noise, coherent function.

For example, the results of measurements of the gate current noise, drain current noise and the coherence function between them for transistor No 1 type CFYP01 (GaAs MESFET) are presented in Fig. 5 [1]. The leakage current path between gate and drain circuit of the transistor has been detected as it can be seen in the coherence function below approximately 1 kHz. The obtained results suggest that for transistor No. 1 the most influential noise source at the output is related to the surface leakage between gate and source. It is also referred to the greater than for other transistors value of power spectral density of gate current noise [3]. Based on the results of measurements it can be justified to classify the transistor No. 1 as a poor quality one [1].

The elaborated measurement system is a suitable tool for quality evaluation of transistors. Due to the low level of the gate current noise the channel measuring this noise signal should be much more sensitive and has lower level of inherent noise. It was found that for MESFETs the gate current noise is much more important than the drain current noise in a quality aspect.

7 CONCLUSIONS

The presented noise measurement system enables to measure noise simultaneously in two channels and as the results the cross-spectrum and the coherence function as a input-output noise characteristic of a two-port can be estimated with the appropriate accuracy. The parameters and the operation of the system were verified for GaAs MESFETs, HEMTs and BJTs noise measurements.

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