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AUTOMATIC SYSTEM FOR DC AND NOISE CHARACTERISATION OF SOLID STATE DEVICES IN THE RANGE 4K-300K

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ABSTRACT
We have developed a DC and noise measurement system to investigate the performance of various semiconductor devices fabricated with different technologies (Si JFETs, Ge JFETs and GaAs MESHFETs), in the range 4K-300K. The system is computer controlled and integrates various interfaces to a PC using GPIB interface. While a device is being measured the temperature remains stable within ±1.5mK.

1. INTRODUCTION
Knowledge of the behaviour of semiconductors devices at cryogenic temperatures gives valuable information for various research activities and instrumentation development. For instance, amplification of signals from infrared and visible sensors, as well gamma detectors, can be improved with the use of cooled transistors (Ref.1). Radio astronomy low noise amplifiers were designed using semiconductors in cryogenic environment (Ref.2). The characteristics of those devices are very low temperature dependent on the operating temperature and some cases this dependence is extremely strong. Measurements obtained by direct immersion of the device under test (DUT) in a liquid nitrogen (LHe, LN2, LAr) gives only a trendline about the dependence between devices performance and temperature. Also, investigation of long-term G-R noise spectra in JFETs requires a continuous variation of temperature in a small range with high accuracy and repeatability. Moreover, spectral noise measurements at various temperatures, and a proper curve fitting, give valuable informations about defect centers in the DUT. This technique (called Low Frequency Noise vs.-Temperature spectroscopy) is an alternation to Deep-Layer-Transient Spectroscopy (DLTS) method when devices of critical interest for circuit applications are investigated. Using this approach is possible to evaluate how the impurities introduced in the DUT during the fabrication process degrade the noise performance, when the device investigated is biased and cooled to a low temperature where carriers freeze-out inhibit DLTS (Ref.3). To fill this need we have developed an automatic system, computer controlled, able to keep the temperature of the DUT stable within ±1.5mK in the range 4K-300K while measurements, lasting about 15 min. are performed.

Still, once stabilized, the temperature can remain stable even for a few hours. When the temperature is stabilised the system is able to perform various measurements using different instruments under computer control. Different FT algorithms have been developed.

2. SYSTEM DESCRIPTION
The automatic system is based on an Oxford Compact VTI continuous-flow cryostat and various instruments interfaced via GPIB for temperature control and measurements (Fig 1).
A software has been developed using National Instrument LabVIEW as visual programming environment in a general purpose Win 95 computer. This approach provides a ready-to-use toolkit which allows a fast development of a graphical interface, based on C++ logical structures, able to operate in real-time mode when the process controlled is considerably slower than computer's runtime internal operations. On the contrary, custom programmed microcontrollers or DSP solutions should be used when fast operations are required.
The evolution of the temperature as well the results of the measurements (noise spectra and DC curves) are shown on the Internet at http:// sócietà.mi.infn.it/ . This way it is possible to remotely monitor measurements done even overnight when environmental noise is at minimum. The system is able to send the data obtained during characterisation as an e-mail attachment in spreadsheet-compatible ASCII format.

2.1 Temperature readout and control.
Temperature in the sample space is controlled using a Proportional-Derivative-Integral (PDI) control algorithm tuned for liquid Nitrogen(LN) or liquid Helium (LHe) operation.
Temperature control is performed using two Oxford Instruments three-point calibrated Rh-Fe sensors. This kind of sensors are resistant to radiation, non-linear, Resistance vs. Temperature behaviour (Fig 2).
A sensor is placed in the copper sample space near the DUT, thermally coupled using sapphire "N" type gasket. Another Rh-Fe sensor is placed inside the cryostat near the heat exchanger. Temperature readout in the sample space is performed using resistors's four-wire measurement method. The bias current (≈1mA in order to avoid sensor self-heating), fed by an Oxford JPC 253 temperature controller, is measured using a Keithley 4317A Electrometer, the voltage is measured by a Keithley 2180 Nanovoltmeter.
Fig. 2 A typical Rh-Fe sensors $Z_{ref}$ vs. Temperature plot.

$Z_{ref}$ is defined as $Z_{ref} = \frac{R_{t}}{R_{ref}}$, where $R_t$ is the sensor resistance at temperature $T$, $R_{ref}$ is the sensor resistance at reference temperature $R_{ref}$, and $R_{ref}$ is the sensor resistance at the reference point of the water (Ref 3).

This approach allows for the selection of correct source and the resistance readings is affected with an error of $\pm 1.5\%$ (at LN temperature). A software includes the resistor values into Kelvin using a curve interpolation between two successive points of Zerf's model data. The look-up table is composed of 110 points.

Using this interpolation method, the accuracy of the temperature result is $\pm 1.5\%$ (Ref 4).

Fig. 3 Example of operation of PID controller. The controller was 100% after a first cooldown at LN temperature. As $T_{set}$ the oscillations around the sequent had an amplitude of $\pm 1.5\%$.

PID control software drives two heater resistance receiving temperature information from the sensor placed near the DUT. The power of the first filter, placed at the bottom of the sample space, is delivered by a Kibele 3410 SourceMeter. The maximum power dissipated is 13.3 W and the resolution is 3.8 W per step. A second heater is
placed near the heat exchanger in order to avoid thermal gradient between heat exchanger and the sample which would cause temperature instabilities. This resistor receives a software selectable fraction of the power dissipated by the first one using the programmable power source of the Oxford ITC 590. The power is fed in steps of 33mW. The total cycle time for temperature data acquisitions, PID algorithm's calculations and heaters power regulations is 350s. A software switch can automatically shut down this heater when the temperature is stabilized. The temperature in the sample space is stabilized within ±5 mK around the setpoint. The time needed to reach the steady state temperature depends on the difference between the start temperature and the setpoint. Normally it is preferable to operate the cryostat in fast cooldown mode (with maximum gas flow) first, in order to evacuate any residual air contamination in the heat exchanger and in the sample area.

After, with an adequate tuning of the needle valves placed at the bottom of the cryostat and in the top, the temperature rises with a rate of 60°C/min. After the system reaches a coarse temperature stabilization of ±1.5K, a resolution of ±0.5mK is obtained in 18 Min (Fig.3,Fig.5).

![Fig. 5](image)

**Fig. 5** Once the temperature is stabilized, a residual drift of ±0.5mK is obtained, lasting for at least one hour.

2.2 Noise measurement setup

We have built a system (Fig.4) for simultaneous noise and transconductance measurements on FET’s, based on (Ref.5). The DUT is connected in common-source configuration. Trimmer R1,R2 set the required Vgs value to zero the op-amp output. When a test signal is injected, the output voltage Vout:

\[ V_{out} = V_{in} R_j = R_f G \]

(1)

The transconductance, \( G \), is given by:

\[ G = \frac{V_{out}}{R_f} \]

(2)
5. EXPERIMENTAL NOISE DATA

As an example of the capability of the system we show noise spectra of a Ge JFET, taken at different temperatures of a Ge JFET (Fig. 6). This device is a sample of a batch developed in the frame of a project aiming at the realization of JFETs for signal processing applications capable to operate with low noise at cryogenic temperatures (Ref.5). It exhibits an interesting variation of noise spectra with temperature, rather than exhibiting the lowest noise.

4. SUMMARY AND CONCLUSIONS

We have developed a system to determine static and noise parameters of solid state devices in the range 4K-300K. The structure is stabilized by a continuous flow cryostat using either LN or LHe. A temperature stability of 1mK at 100K has been verified with LN, over a period of about one hour. The capability of setting precise small steps in temperature allows us to perform Low-Frequency-Noise vs Temperature spectroscopy. This work is in progress.

3. ACKNOWLEDGEMENTS

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6. REFERENCES


2. O. N. Polupinin et al. Super Low Noise Cryoelectronic Amplifier for Radio Astronomy and Spectroscopy in a 21-23 GHz range with conversion of frequency in 0.5-2.5 GHz, Proceedings of WOLFE J.S. Minato Italy, 189.


4. Rhodium-Iron Reference scale 0.3 to 100K revised to ITS-90, Oxford Instruments Co, Tresay Woods OK.
