

The computer on-line technique for the measurements with the two-beam photoelectric reflectometer

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This paper gives a description of an up-to-date on-line computer technique adapted for the measurements with two-beam photoelectric reflectometer. We obtained high measuring accuracy better than 0.1%.

Nowadays, a great development of new experimental techniques is observed. A progress has been made especially in the computer on-line techniques. Over the last decade the CAMAC has become very popular [1]. The CAMAC (Computer Application to Measurements and Control) is a modular instrumentation system for data handling, which provides means of data acquisition, control and measurements for any experiment or process. CAMAC system can work autonomously or be controlled by an external minicomputer. In the paper we describe the computer-controlled CAMAC system which drives two-beam photoelectric reflectometer and is able of driving any experimental set-up using lock-in technique for the signal detection. The idea of the two-beam photoelectric reflecto/transmissiometer has already been presented elsewhere [2] and will not be repeated here. We describe only these changes and improvements which are directly related to the new possibilities offered by the computer-based technology. It is also to be stressed that the whole set-up consists of the components readily available from the domestic manufacturers.

The measuring set-up consists of the photoelectric reflectometer, the CAMAC system, two minicomputers MERA-60 and MERA-305 and the dedicated software. The input analog electric signals are taken from the two-beam photoelectric reflectometer [2, 3, 4] by the lock-in detection. They are converted to the digital form by A/D CAMAC converters. The computer program divides the voltage of the first signal by the second one in order to obtain a spectrum $Z(E)$. The reflectivity or absorption spectrum is obtained by dividing the spectrum $Z(E)$ by the instrumental function $F(E)$ [2]. The instrumental function is obtained in the same way as the normal spectrum $Z(E)$ in the absence of a sample.

The control system is shown in Fig. 1. It consists of the main minicomputer MERA-60 (equivalent of PDP 11/03 model of Digital Inc.), subsidiary MERA-305 minicomputer and two-crate CAMAC subsystem. The MERA-305 minicomputer always works in the SLAVE-mode and acts essentially as a controller

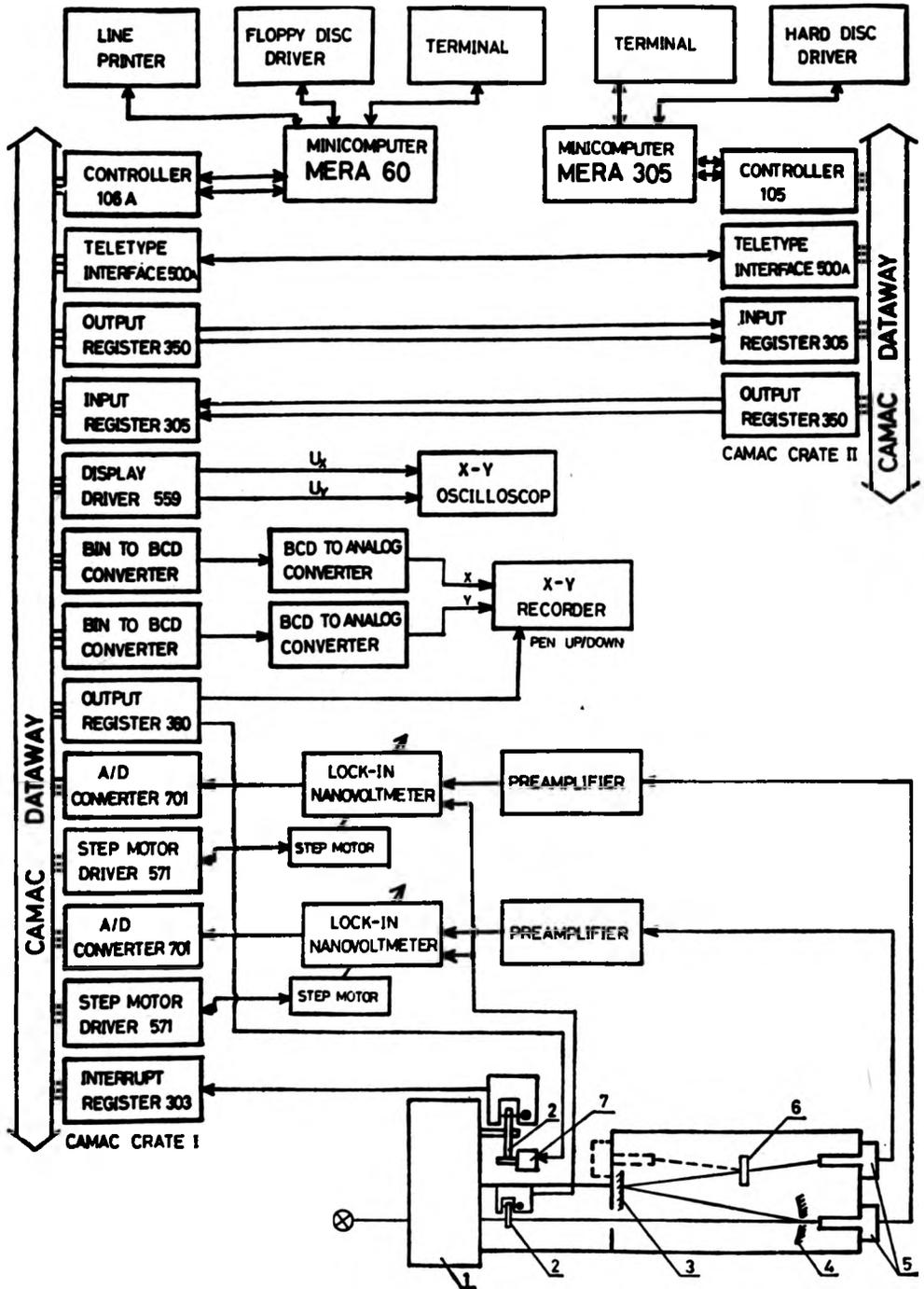


Fig. 1. Experimental arrangement: 1 - monochromator, 2 - chopper, 3 - mirror, 4 - concave mirror with a hole, 5 - photomultiplier, 6 - sample, 7 - servomotor

of peripheral devices. It controls 5MB hard-disc driver (MERA-9425), which is the basic system, mass storage device and the operator terminal from which the computer program (but not the operating system) can be controlled. The connection between the computers is physically realized via CAMAC-crates. The MERA-305 minicomputer controls one crate via 105 controller [5], the inter-crate communication is realized via two pairs of 305-350 blocks [5] (input and output 24-bit transmitters) and one pair of 500A blocks [5] (teletype interface). The main MERA-60 minicomputer works under the RT-11 V04 operating system. The necessary handlers have been written - one of them takes care of the communication with hard-disc system device and the second one with the terminal of MERA-305. This part of software is entirely transparent to the RT-11 system because it emulates the standard PDP system devices of the RK-type. The configuration of the minicomputer includes 56kB core memory, the processor with FIS (Floating Instruction Set) capability, floppy-disc driver, operator console, paper tape unit, line printer and Q-bus - UNI-bus adapter. The last item allows the connection with the main crate of the CAMAC-subsystem via 106-type controller [5]. The main crate contains the modules directly connected with the experimental setup: two A/D converters (701-type), two step-motor drivers (571-type), interrupt resistor (303-type), output resistor (360A-type). Additional peripheral devices (X-Y recorder and CRT oscilloscope) are also controlled by the CAMAC-modules (559-display driver and two 610A BIN-BCD converters).

The software controlling the experiment has been written in two languages: FORTRAN and MACRO ASSEMBLER. Many routines in MACRO ASSEMBLER had to be written, because it was the only right way to control properly and quickly the CAMAC system by the computer program. We have created for CAMAC the FORTRAN System Subroutine Library in which all written routines were collected. In the computer program many subroutines from the RT-11 FORTRAN System Subroutine Library [6] are also used. Therefore the computer program shares many features of the RT-11 Foreground/Background Monitor. The simplified flow diagram of the computer program is shown in Fig. 2. It consists of the main unit, some ordinary subroutines and some so-called completion routines [6]. The latter is a subprogram which executes its task asynchronously with the main program and is scheduled to run as soon as possible after the event, for which it has been waiting, occurred or is completed. In our computer program these routines work as the ones of a CAMAC interrupt service. During the experiment the program has very often nothing to do but to wait for an interrupt from the CAMAC system which comes when some action is completed, e.g., at the end of the conversion of A/D converters. When the program waits for an interrupt, having nothing else to do, it is suspended until its arrival. The computer program consists of some overlays; it means that during the experiment only the actually needed part of the program is loaded into memory. In order to run the program requires only about 24 kB of the memory of the MERA-60. Owing to all the above

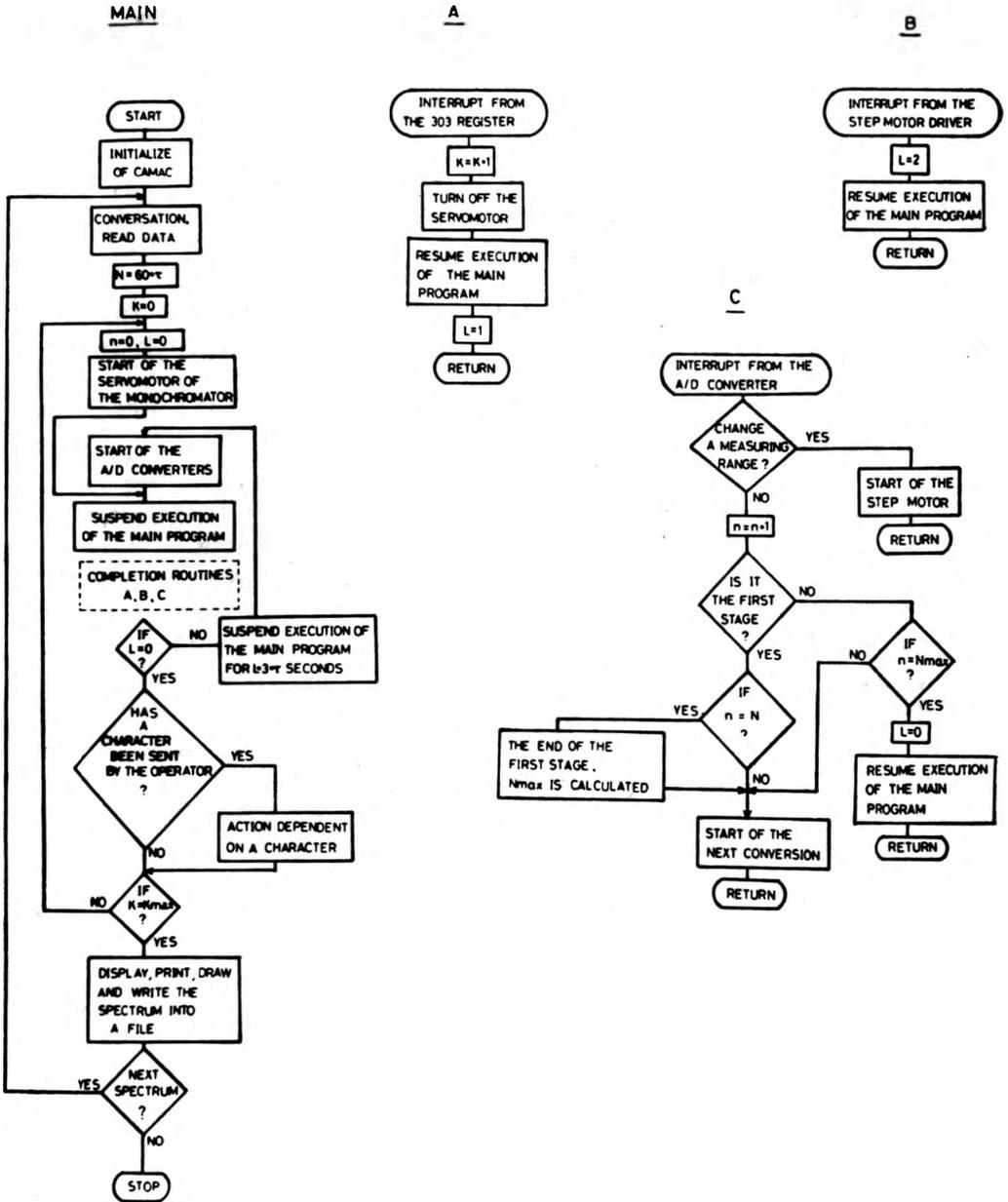


Fig. 2. Simplified flow diagram of the computer program

described features computer program controlling experiment is able to run as foreground job while another computer program can run simultaneously as a background job. Since the computer program is very often suspended, the background job works only with a little loss of speed. This feature of the system is greatly facilitated by the second terminal dedicated for the foreground jobs and controlled via MERA-305 minicomputer.

The computer program needs some input data before the measurements are starting. In particular, it must set the value of the relative accuracy which the final spectrum ought to have. Since the program uses the A/D converters with 11-bit register of the measured figure with its sign, 0.05% is the ultimate value of the spectrum $Z(E)$ accuracy. The reflectivity or absorption spectrum being obtained by dividing the spectrum $Z(E)$ by the instrumental function $F(E)$, the value 0.1% is the ultimate one of the accuracy for the final reflectivity or absorption spectrum. After obtaining the requested information from the operator the program sets the energy of the light beam for the first point by using the servomotor of the monochromator. Next, the program is suspended for a period three times longer than the value of the time-constant of the lock-in nanovoltmeters. Thereupon, the program starts to measure. When the output analog signal from any nanovoltmeter is too high (above 4.5 V) or too low (below 0.9 V), the program changes the measuring range of that nanovoltmeter using the step motor. The program is suspended for a period six times longer than the time-constant of the nanovoltmeter after any change of the measuring range. The conversion of both A/D converters is always started at the same time. Each converter makes about twenty conversions per second.

For every point of the spectrum the measurements consist of two stages. During the first stage the A/D converters make as many conversions as defined by the product of the predefined number (typically 60) and the time-constant (in seconds)

$$N = 60 \times \tau. \quad (1)$$

When the first stage is finished the program calculates a number of measurements N_{\max} , necessary to obtain a final measured value with the requested relative accuracy

$$\varepsilon = \frac{\sigma_x}{|\bar{x}|}. \quad (2)$$

First, the measuring error [7] is calculated

$$\sigma_x = \frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2. \quad (3)$$

Next, the number N_{\max} is calculated

$$\sigma_x^2 = \frac{\sigma_x^2}{N_{\max}}, \quad (4)$$

$$N_{\max} = (\sigma_x / \varepsilon_x)^2 = (\sigma_x / \varepsilon_x). \quad (5)$$

If N_{\max} is bigger than N the program makes $N_{\max} - N$ measurements during the second stage. When in some cases the light intensity is very low, the number N_{\max} calculated from the formulas (2)–(5) can be unreasonably big. For such cases the upper limit of measurements is predefined. The program always checks whether the number of the measurements does not exceed the upper limit of measurements set for one point. After completing the second stage of the measurements the energy of the light beam is changed to the next point of the spectrum. Again the program is suspended for a period three times longer than the time-constant of the nanovoltmeters, which is sufficiently long for the analog signals from the nanovoltmeters to become stable. When the spectrum $Z(E)$ is measured it can be divided at once by the instrumental function to obtain the reflectivity or absorption spectrum.

In the way described above the whole spectrum is measured for every point of the spectrum with a constant relative error. For one point the number of measurements giving 0.1% accuracy usually varies between 40 and 4000. The requested accuracy can be achieved even at the end of the range of spectrum, where the signal-to-noise ratio is usually unfavourable.

The operator can check the results at any time by sending some special characters from the keyboard of the minicomputer. As a result of that action the measured part of the spectrum is displayed on the screen of the oscilloscope. In the similar way the operator can change some control data of the running

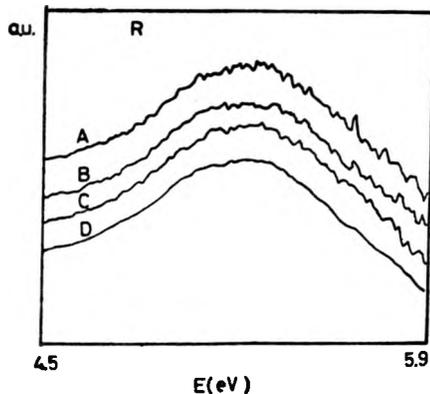


Fig. 3. Influence of the number of measurements on the spectrum (A – 10, B – 50, C – 150, D – varies to obtain constant relative error)

program (for example, the relative accuracy and the upper limit of the measurements for one point). After the whole spectrum is measured it is recorded by the X–Y plotter, printed by the line-printer and is displayed by the oscilloscope. The spectrum is also written into a file as data for other programs.

Figure 3 shows the influence of the number of measurements on the spectrum of a tested sample. The influence on the relative error is shown in Fig. 4. The relative error was calculated by the computer program using the sample formula (2). The measurements were made in the energy range in which the signal-to-noise ratio was unfavourable. The time-constant was set to 3 seconds. In the cases

A, B, C the number of measurements per one point was constant (accordingly equal to 10, 50 and 150). The spectrum of the case D was obtained in a normal way by the computer program. The differences among the curves are seen clearly. The reflectivity spectrum of CdTe obtained by the new set-up, shown in Fig. 5, can be used as a final test for the whole set-up.

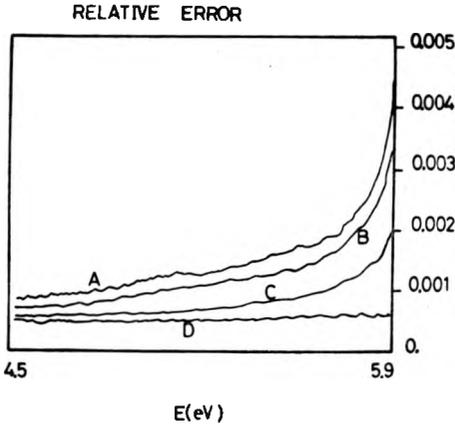


Fig. 4. Influence of the number of measurements on the relative error (A - 10, B - 50, C - 150, D - varies to obtain constant relative error)

We also want to say that owing to the FORTRAN System Subroutines for CAMAC, which has already been written, the rules of the program action can be changed as to perform some other experiments using the same CAMAC modules. The program can work with a one-beam photoelectric reflectometer without any modification. It can also carry out a photoconductivity experiment without any modification. After a small modification the electric resistance can be measured depending on the temperature of the sample. It is needless to say that the whole process, once started, does not practically require any attention.

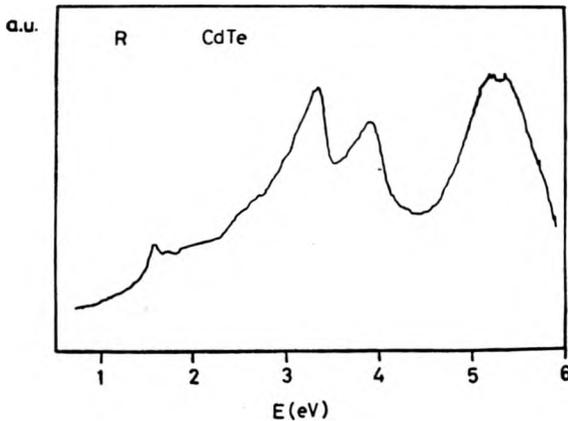


Fig. 5. Reflectivity spectrum of the CdTe obtained by the new set-up

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