

## AUTOMATED MEASUREMENT LABORATORY ACCESSED BY INTERNET

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*Abstract: The Automated Measurement Laboratory implements the newest methods of open and distance learning in engineering. The information Internet servers are extended by laboratory servers, that allow complete experiments on the 4 automated measurement centres - interconnected locally by GPIB and integrated with National Instruments LabView 5.1<sup>®</sup> (by the built-in Web Server) in virtual instrumentation configurations with Internet access. Real-time monitoring and control is accomplished by web pages, accessing the web-site of the "Virtual Laboratory" – by built-in MS - FrontPage<sup>®</sup> WebBot components "Save Results Form" Handlers to the server and, from it, by publishing the Virtual Instruments' panels as HTML files – or by data socket transfer protocol (dstp). It incorporates CCD cameras that send images of the remote-controlled systems to the web-page of observation. An economical alternative was implemented as e-mail access (POP3 and SMTP) services: the user completes and sends a message including the programmed stimuli to the laboratory server and test-bench that perform the automated measurement and return the experimental data in an e-mail reply. The user post-processes this information using his specific software.*

*Keywords: automated test & measurement, virtual instrumentation*

### 1 INTRODUCTION

Modern education is more distributed and less time and space restrictive. Engineering seems to be one of the last domains to be reluctant to distance learning, due to a great number of hours that have to be spent in laboratories.

The present paper presents an automated test & measurement laboratory, that can be remotely accessed by Internet. Automated measurements have the well-known advantages of speed and precision, eluding subjective (human) errors and enabling computer-aided data tele-transmission, mathematical post-processing and experimental data-base creation [1].

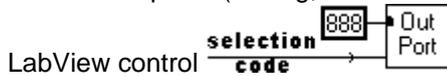
The student or engineer can extract a system's family of characteristics, with the possibility to detail a specific segment or regime. An interactive presentation can be delivered in a lecture theatre or to the pupils of a high-school or college, accessing the remote laboratory by general-purpose web-browsers.

### 2 LABORATORY EQUIPMENT

The configuration used was one of four automated measuring centres of the Electronics and Computers Department, each of them coordinated by an IBM-PC compatible computer (with National Instruments PCI-GPIB<sup>™</sup> card) in a local IEEE488 network [2],[3]. Each configuration includes:

- Digital Multimeter ("DMM") –Hewlett Packard –HP34401A<sup>™</sup> (with built-in IEEE488 interface) – SCPI (Standard Commands for Programmable Instruments [4]) compliant
- Power Supply –HAMEG –HM8442<sup>™</sup> (with HO88 - IEEE488 interface)
- Function Generator –HAMEG –HM8131<sup>™</sup> (with HO88 - IEEE488 interface)
- RF Synthesised Generator –HAMEG –HM8133<sup>™</sup> (with HO88 - IEEE488 interface)
- Digital Oscilloscope –HAMEG –HM1007<sup>™</sup> (with HO79 –IEEE488, RS232 & Centronics interface)
- Creative "WebCam"<sup>™</sup> digital camera (with USB interface) driven by software for video-conferencing and web-publishing of acquired images
  - the chosen solution is the expedition of the .JPG file of the acquired image by FTP (the camera driver is configured with the URL, account name and password allocated to the virtual laboratory).

- Relay bench (fig.1) - (with Centronics interface), implementing part of the IVISwitch (Interchangeable Virtual Instruments) functionality: ("TP") *test points multiplexing* (to the unique input of the DMM), *load adjustment* (e.g. selective parallel connection of binary weighted resistors) and *reconfiguration* (jumpers' emulation) to re-route signals and connect/disconnect sub-circuits.
  - mechanic relays were chosen because of their larger bandwidth, of their better separation between the control circuit and the controlled one; the relays are controlled via parallel port of the lab-computer (having, in the following example, address 378h = 888 (10) ) by the simple



- TP-s are connected to common relay terminals; in order to multiplex them, "normal opened" terminals are connected to DMM input by appropriate DIP switches.
- test software ("SW") implements "exclusion lists" that prevent simultaneous connection of two TP-s to the DMM input.
  - general features of exclusion lists implement "SW protection" against over-charge; the lists can be "vectorial" (e.g. for maximum allowed voltages) or even relational (e.g. "hyperbolic", avoiding large dissipated power by limiting voltage x current products).

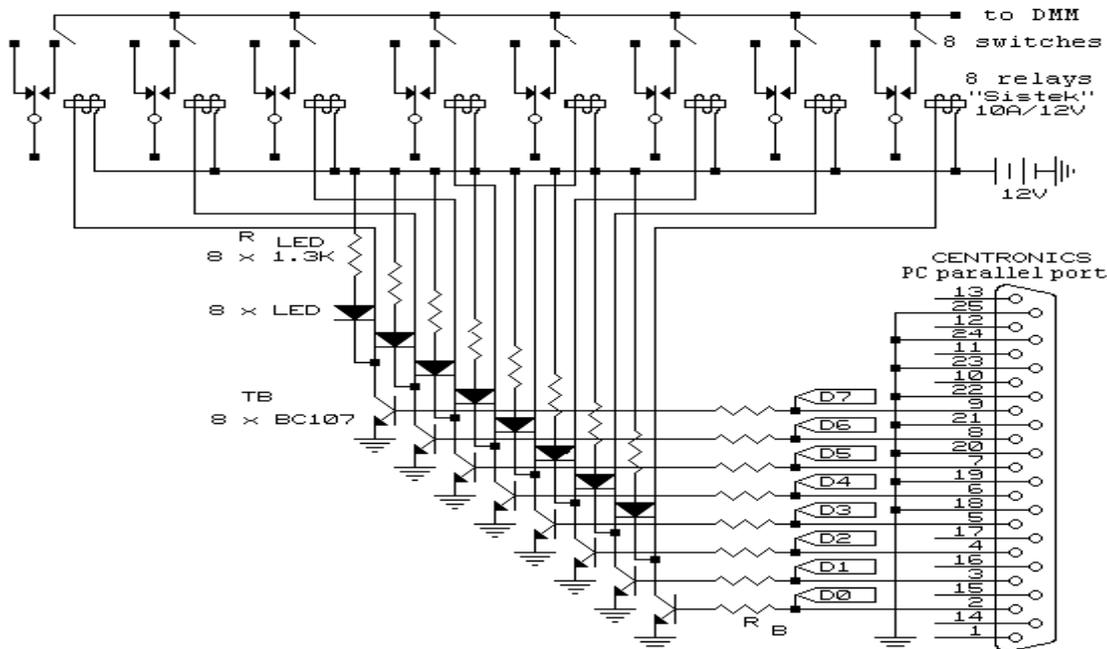


Figure 1. The relay bench built for the automated test & measurement laboratory with Internet access.

### 3 POP3 / SMTP IMPLEMENTATION

The most economic solution (in respect of user's *shortest access to Internet*) is based on *e-mail services* with the advantage of simplicity and robustness:

- 1 the user completes and *sends an e-mail message*, at [vlab@vega.unitbv.ro](mailto:vlab@vega.unitbv.ro), preceded by an preamble containing his/her e-mail address and a password (given by our department when he/she was registered for distance learning) including the programmed *stimuli* – the "headers of the tables" to be filled.
- 2 the *laboratory server* processes this e-mail, controls the test-bench that performs the automated measurement and *sends an e-mail reply* with *the experimental data* ("the tables' content").
- 3 the user gets this information, *de-structures* it (according to the "subjective" structure of the primary e-mail he/she sent) and performs local computer-aided post-processing (sort, plot, interpolate, statistical computations etc.), using his/her own software for mathematics, data bases, signal & image processing etc., or can invoke the expert systems that are distributed in the servers of the university, for diagnosis, shape- & pattern-recognition or automated classification.

The chosen format of the user's message is, with labels in brackets < ... >, the *unwrapped* text:

```
<Password-given at user's registration>* <Reply address - user's e-mail address> *%<Relay's configuration-a binary, 8 bit word, with 1 for each connected relay>*#<Two-figures GPIB address-with 0 on first position for instruments 0 to 9><GPIB instruction>*$*
```

Excepting the password & reply address fields and, on the other hand, the final part, \*| , of the message, the other fields can be repeated as much times as necessary, with adequate contents.

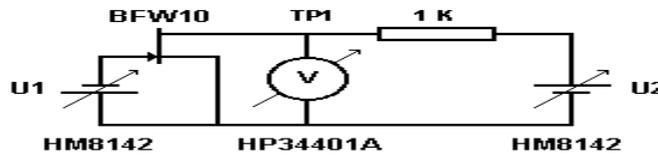
- Relays' configuration is recommended to be set from the beginning and will be *latched* as long as another \*% isn't inserted. The field \*\$, means, in the operation sequence, the command for a measured value's record (it isn't advised to acquire measured values after each GPIB instruction or relays' reconfiguration takes effect, although it isn't any other problem but a more complicate task of data de-structuring from the reply e-mail message).
- It is the users' choice to prepare their messages. There are, nevertheless, offered an "electronic form" (in MS Word™ or MS Excel™), with automatically included separators, to be filled like, e.g.,

Relays' Configuration	GPIB Address	GPIB Instruction	Record Value
*%10000001	*#22	MEAS:VOLT:DC?	*
*%	*#04	SU1 12.34	*\$

- Excel™ embedded routines can generate automatically stimuli lists (with pre-programmed start, stop and increment values etc.) or Word™ MACRO-s can be used to complete repetitive instructions, (e.g. the ones beginning with SU1, for HM8142 power supply -whose column of numerical values can be generated by Pascal, C, BASIC MathCAD, MatLab etc). A mixed approach could begin by filling the fields' content in Excel™, then by "Merging Mail" (with the contents poured into a template completed by Word™, as "Catalogue", with no separators.
- the imposed sequential operation of the measurement system corresponds to the left to right and up to down order in this table. The last column should be completed with a simple \$, when the value measured by the DMM is to be recorded in the text of the reply e-mail. After the form is completed, only the table is kept (deletion of all other lines and auxiliary text, then table selection, converting to text, unwrapping the text by deleting all [Line-Break]-s or [Paragraph-End]-s) and \*<Password>\*<Reply e-mail address>\* is added at the beginning:

Example: *Remote experiments for the study of a J-FET*

The lab configuration is presented in fig.2:



**Figure 2.** The circuit for BFW10 J-FET-N characterisation. TP1 corresponds to MSBit in relays' code

The primary e-mail message contains programming instructions for HM8142, setting U1 (= -U<sub>GS</sub>) = 0 ; 1 ; 2 ; 3 ; 4 V. For each value of U1, there are set 20 values of U2 (=0; 0.5; 1 .. 9.5 V):

```
From sandu@vega.unitbv.ro Sat Jun 26 00:56:35 1999
Date: Sat, 26 Jun 1999 00:52:49 +0300 (EET DST)
From: SANDU Florin <sandu@vega.unitbv.ro>
To: vlab@localhost
Subject: Study of J-FET
```

```
*< USER'S PASSWORD>*sandu@vega.unitbv.ro*%10000000 *#04 SU1 0 *#04 SU2 0 *$*#04 SU2 .5 *$
*#04 SU2 1 *$*#04 SU2 1.5 *$*#04 SU2 2 *$*#04 SU2 2.5 *$*#04 SU2 3 *$*#04 SU2 3.5 *$*#04 SU2 4
*$*#04 SU2 4.5 *$*#04 SU2 5 *$*#04 SU2 5.5 *$*#04 SU2 6 *$*#04 SU2 6.5 *$*#04 SU2 7 *$*#04 SU2
7.5 *$*#04 SU2 8 *$*#04 SU2 8.5 *$*#04 SU2 9 *$*#04 SU2 9.5 *$*#04 SU1 1 < ... > *#04 SU1 4 *#04
SU2 0 < ... > *#04 SU2 9.5 *$*|
```

The laboratory server runs, in continuous mode a National Instruments – LabView 5.1™ Virtual Instrument, (fig.3) that reads the e-mails and splits them at the level of chosen delimiter characters (\*), extracting (the preamble,) the user's password (that is compared with the original reference, stopping the execution if there isn't a perfect match), the e-mail address (used to automatically compose the reply) and the body containing GPIB commands and relay configuration bytes.

"Read e-mail" sub-VI (fig.4) implements TCP data flow in communication with the Unix e-mail server of the Electronics & Computers Department. The functional blocks ("pipelining" the "connection ID" and "error" information) are "TCP Open Connection" (to the e-mail server, referenced by its IP address and by the port 110, dedicated to POP3 services), "TCP Write" (of the e-mail handling commands described below), "TCP Read" (of the e-mail content) and, respectively, "TCP Close Connection". As it can be seen in fig. 4, the 1<sup>st</sup> e-mail arrived at [vlab@vega.unitbv.ro](mailto:vlab@vega.unitbv.ro) (not processed yet) is **retrieved** and **deleted** afterwards. So, a simple FIFO stack was implemented, with queuing solved in an implicit way.

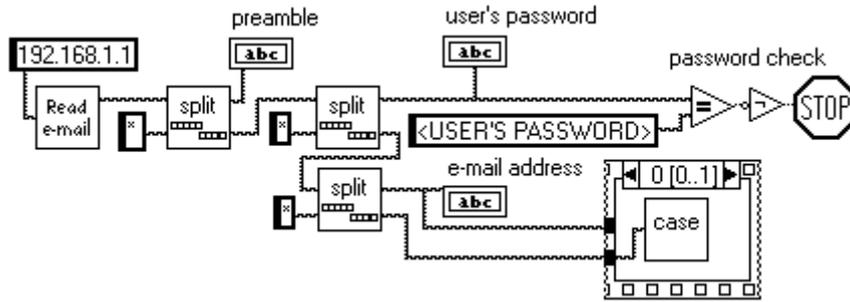


Figure 3. Diagram of the main Virtual Instrument (“VI”) for the POP3-SMTP implementation.

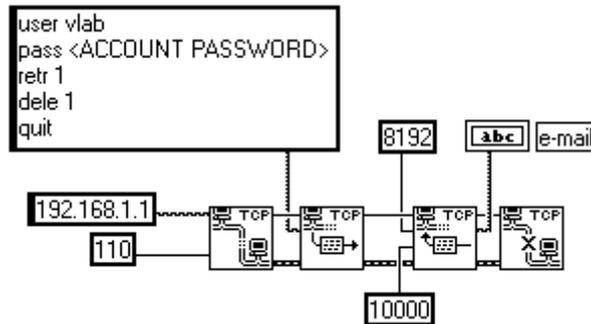


Figure 4. Diagram of the “Read e-mail” sub-VI implementing functions of Communication/TCP type.

The “case” sub-VI of fig. 3 is treating the GPIB commands and relay configuration bytes according to different prefix character cases (% , # , \$ or |). The main parts of # and \$ cases are presented in fig. 5. The lab-computer separates the GPIB commands and executes them, assembling the results in the C:\OUT.TXT file. The final sub-sequence of “Case.VI” automatically sends (by the sub-VI built around the sub-diagram of fig. 6) the data from C:\OUT.TXT to the extracted reply e-mail address, accessing the Unix mail server through specific port 25, dedicated to SMTP (Simple Mail Transfer Protocol).

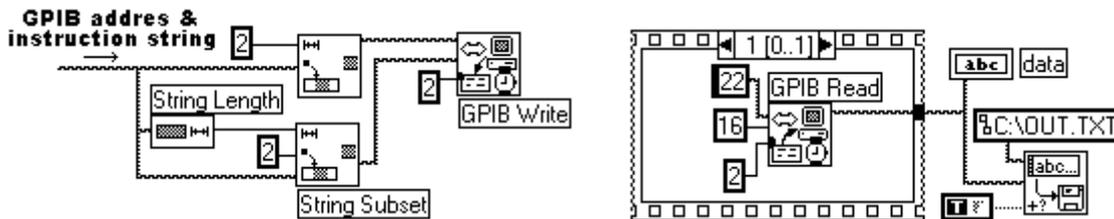


Figure 5. Sub-diagrams (# and \$) of “Case.VI”. “Sequence” structures are specific to GPIB control.

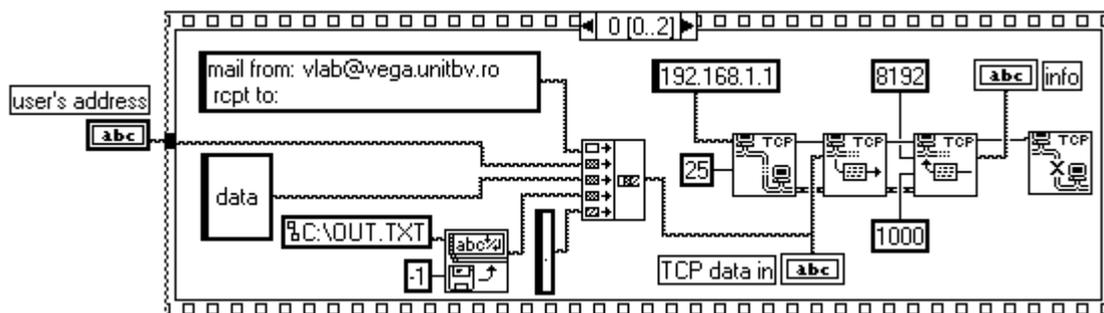


Figure 6. Sub-sequence of the e-mail reply sub-VI. It can be noticed the TCP “pipeline” of fig. 4.

Considering the J-FET characterisation example, the reply to the e-mail sent by the user (with the above given specimen), is obtained in the following structure (the preamble can be rejected by simple text editing, in order to process the results list with a general-purpose mathematics SW):

From: Virtual Laborator <vlab@vega.unitbv.ro> Sat Jun 26 00:56:06 1999  
Date: Sat, 26 Jun 1999 00:54:12 +0300  
+3.55180000E-05  
.  
+7.99381700E+00  
+8.49211880E+00  
+8.99282460E+00  
+9.49170560E+00

It can be noticed that last measured values of  $U_{DS}$  increment by the same steps (of 0,5V) done by  $U_2$ , so the  $1k\Omega$  voltage is constant, then  $I_D$  is constant, being saturated !

Mathematical post-processing of the experimental data could be done like in fig. 7:

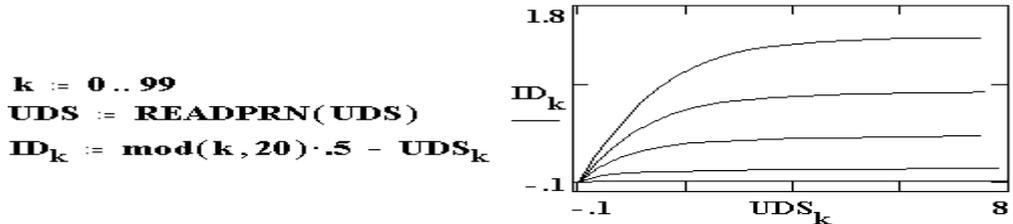


Figure 7. MathCAD™ de-structuring and plot of experimental values,  $I_D ( U_{DS} )$  with parameter  $U_{GS}$ .

Re-programming finer measurements can emphasise the parabolic zones or wider curves [ e.g. to compute the convergence point (on the horizontal axis,  $I_D = 0$ ) of the saturation obliques or  $g_d$ , their slope ]. Interpolation and spline graphic representation or statistical processing can be done as well.

#### 4 WEB-BROWSER / SMTP IMPLEMENTATION

A mixed solution, developed from the e-mail based one, implements *real-time monitoring* and *step-by-step* control via a dedicated web-page, <http://vlab.unitbv.ro> (fig. 8) built including MS - FrontPage™ WebBot components - "Save Results Form" Handlers (by SMTP) - to send GPIB commands and relay configurations to the remote test-bench controlled by a LabView web-server. The Web Document Tools (available starting with version 5 of LabView) generate HTML documents containing text and embedded pictures of the VI panel, that have been put together with the time-stamped image of the real experiment, taken by the "Web-Cam" and published over the Internet.

The published virtual display panels of "rack & stack" instruments (relay bench, HP34401A, HM8131 and HM8142, positioned top-down in this example) can be checked by the user. Controls can be done sequentially by, filling the forms with the GPIB commands and relay-configuration bytes.

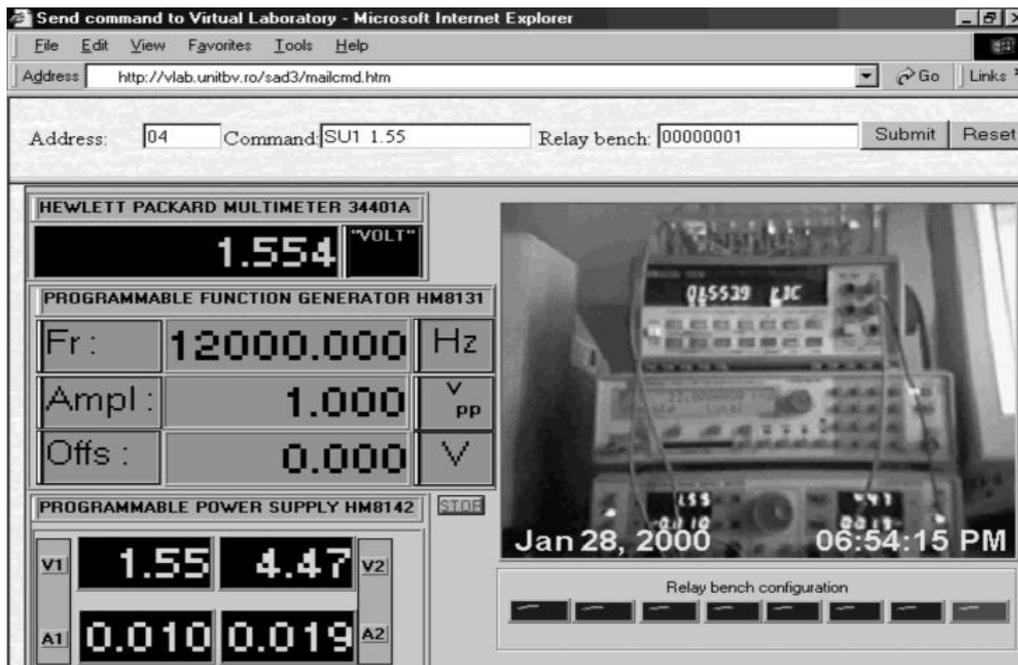


Figure 8. Web-page (with self-refresh) for Internet remote-control of the automated test bench

## 5 VISUAL BASIC / COMPONENT WORKS / DSTP IMPLEMENTATION

National Instruments "Component Works"™ is grouping 32 bit ActiveX controls (dedicated to data acquisition ("DAQ"), processing and display) that can *complete* (can be "plugged in") ActiveX compatible software development packages (Visual C++, Delphi etc.) - in our case MS Visual Basic™. Active (eXchange) of software components and of data between applications is possible by unified format and dynamic communication techniques - OLE (Object Linking Embedding).

Visual Basic ("VB") panels were completed with specific Component Works components. Besides *user interface controls, DAQ controls, signal processing controls and instrument drivers engine*, the most important for this application were the *GPiB, VISA and serial controls* (for the data flow between the controller PC and automated test & measurement equipment connected to GPiB – by a National Instruments IEEE488 interface, in our case PCI-GPiB – to serial port or in VXI systems) and *DataSocket controls* - to exchange and distribute data between different "targets" as there are *unified* by dstp (files, applications, web-servers of different kinds).

Complete, *real time duplex control / monitoring* of instruments by dstp was implemented in VB emulated panels (fig.9). Another advantage of this implementation is remote reconfiguration of relays not with an eight bit code yet by mouse-clicking on *TPn* and *switch* icons integrated in a "*hyper-schematic*" of the system under test (this "event" doesn't only switch the relays but also, in a very suggestive way, changes the colour and respectively the position in the associated "hyper-schematic").

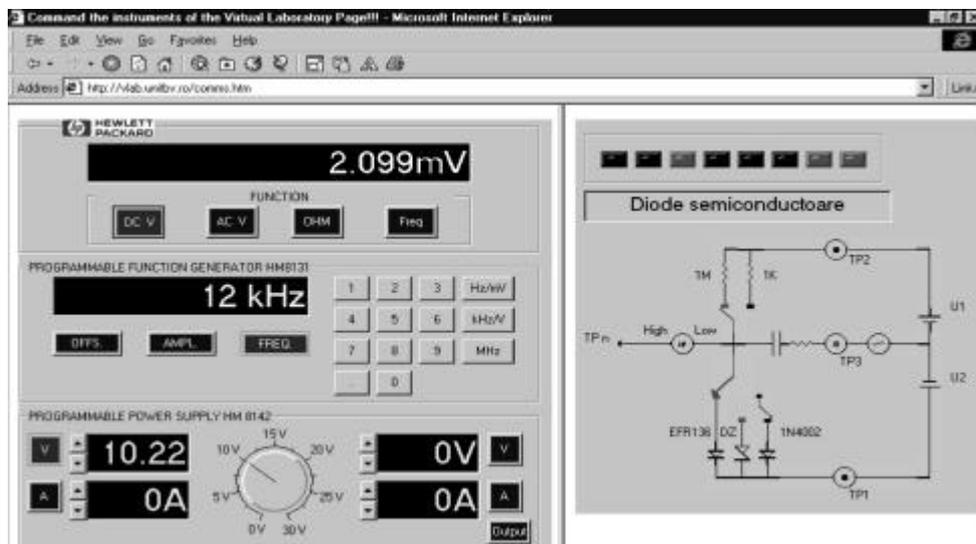


Figure 9. Visual Basic / Component Works implementation for duplex remote control by Web-Browser

## 6 CONCLUSION

Remote experiments – *real, not simulated* – are possible on test-benches, provided with automated measurement equipment and integrated in virtual instrumentation configurations with Internet access. The users have to access the web-site (and video-conferencing facilities) of the "Virtual Laboratory" (based on a special schedule for *vocational training* – large time intervals, in the evening and practically during the whole week-end). The e-mail approach is very economic and robust (no problems due to concurrent access). The web-browser access is done in real time but if there is something "*to be observed*" (in the didactic or research process) this can be done only *step-by-step*.

## REFERENCES

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