

Instruments Go Virtual: Experiences on Educational Activities in the Field of Telecommunications at the University of Pisa

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Abstract – This paper illustrates the experience gained on educational activities in the field of telecommunications at the University of Pisa, Italy. The aim that drove the efforts of a team of teachers of telecommunications at the Engineering college was to allow the students to perform experiments, either in their college labs or at home, with virtual or remotely-controlled instruments. Starting from early lab demonstrations based upon single-copy hardware instrumentation, it is shown how the introduction of software interfaces, named virtual instruments (VIs), especially developed with National Instrument's LabVIEW™ environment, greatly improved the effectiveness of experimental activities in the framework of telecommunications engineering courses. The main features of the proposed educational system, the set of available VIs and the operational modes are presented and discussed, together with their utilization in education and the relevant pedagogical benefits. The system is being used in the Laboratory of Telecommunications of the Engineering college of the University of Pisa, Italy.

Keywords – Communication engineering education, e-learning, microwave engineering education, new technologies for education, virtual laboratories.

I. INTRODUCTION

A basic need in professional engineering courses is for the organization of a significant number of practical activities where the students, by using instruments and measurement systems in a laboratory, could verify and practice all those analytical concepts and methods learnt in theoretical courses. Unfortunately, one confronts various problems in meeting this need. Of these, probably the first is the unavailability of large capacity classrooms equipped with measurement instruments, which are usually very expensive, and need to be repeatedly distributed to form several work desks. Moreover, if they are available, educational laboratories can be used only for those hours that have been scheduled in the semester time-table. The risk of expensive instruments being damaged by inexperienced students through incorrect use should be also taken into account.

In order to solve the above problems, and at the same time to enable more effective teaching of technical subjects, a team of teachers at the Engineering College of the University of Pisa, has, since the mid '90s, devoted itself to the development of multimedia teaching activities [1]. In this context, they have developed an educational virtual laboratory to be used for experimental activities in professional disciplines within the framework of both the Bachelor and Master Degree Programs in Telecommunications Engineering [2].

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More in detail, the proposed educational approach is based on a set of suitable software interfaces, named virtual instruments (VIs), which are able to simulate/emulate or to support remote-control of hardware instruments. This represents a viable and very effective alternative to conventional laboratory practice, which requires a large amount of (costly) hardware equipments. The aim of the project is thus to allow the students to perform experiments, either in their college labs or at home, with virtual or remotely-controlled instruments. To implement the various software components of the virtual laboratory the team of teachers turned to National Instrument's LabVIEW™ development framework [3], taking advantage of its potential in terms of interactivity and flexibility, as well as the many functions available for data and signal processing. In fact, thanks to such attractive features, LabVIEW™ is a software environment which is also very popular for both industrial and educational applications [4]. For instance, some significant educational experiences in the field of information engineering disciplines are presented in [5], [6].

This paper, illustrates the experience about educational activities in the field of telecommunications at the University of Pisa, wherein the early experiments with single-copy hardware instruments have been replaced with LabVIEW™-based interactive software applications which simulate telecommunication systems and emulate measurement set-ups, also providing remote-control and data acquisition features. Such an evolution of the educational laboratory practice was pursued with the specific aim of achieving the following pedagogical goals:

1. to enable a learner to understand the behavior of a complex communication system and get a perception of the sensitivity of performance to parameters variation;
2. to let the learner practice with instrumentation, learn to use it properly, and correctly interpret the measurement results;
3. to let the learner process not only waveforms synthesized by a computer simulator, but also process real-world data.

The educational system presented in this contribution is hosted in the educational Laboratory of Telecommunications and Applied Electromagnetics and is used by the students attending both the Bachelor and the Master Degree Programs in Telecommunications Engineering. More details about the organization of the telecommunication studies at the University of Pisa can be found in [2] and [7].

The paper is organized as follows. After this introduction, a brief history of hardware-based educational exercises is presented in Sect. II. The rationale for the adoption of LabVIEW™ as the development system for the interactive VI

applications is illustrated in Sect. III. The library of stand-alone VI applications for the simulation of communication systems and devices is described in Sect. IV while Sect. V deals with the VIs for remote-control of instruments. Then, Sect. VI describes the use of the VIs for in educational activities, and some conclusions are eventually drawn in Sect. VII.

II. PROLOGUE: CARRYING OUT EDUCATIONAL EXPERIMENTS IN THE OLD-FASHIONED WAY

Since the '80s, the teachers of the telecommunication courses at the Engineering college of the University of Pisa have been concerned about the organization of experimental activities aimed at demonstrating the use of the instrumentation (analogue and digital signal generators, oscilloscopes, spectrum analyzers, etc.), the behaviour of communications systems, and the sensitivity of the system performance to parameters variation. However, the availability of single-copy instruments, forced the teachers to resort to demonstrations based upon hardware set-ups, like for instance that depicted in Fig. 1. The experiments were therefore carried out in front of the class of students, into a laboratory equipped with a closed-circuit television (CCTV) facility consisting of a video-camera that distributed the images of the test bench to several large monitors hung to the ceiling of the lab.

Figure 2 shows the video-camera (in the front), the hardware set-up (background) and one of the CCTV monitors (top) showing the eye diagram of a four-level digital signal (4-PAM).

The limitations of such an approach became apparent very soon. During the laboratory demonstrations, the students showed a bored and passive attitude, with minimal interaction with the teacher, and during the final examinations they revealed an unsatisfactory learning level of the concepts that were explained during the laboratory exercises. The lecturers tried then to devise an alternative and more effective way of teaching experimental activities, aiming at a more active involvement of the students into the educational practice.

III. THE KEY FOR INNOVATION IN EDUCATION: LABVIEW™ SOFTWARE ENVIRONMENT

The solution to this problem came in the early '90s, when the telecommunication teachers turned to LabVIEW™, the popular development environment by National Instruments (NI) [3], which allows a very flexible design, supports interactivity, makes available a wide range of signal and data processing functions and also enables remote-control of instruments. Thanks to these appealing peculiarities, starting from the mid '90s, a large set of LabVIEW™-based interactive educational applications for telecommunications was specifically developed in order to circumvent the abovementioned drawbacks of the traditional laboratory exercises. As matter of fact, by using LabVIEW™, several interactive applications have been developed so as to reproduce with a high degree of fidelity the functionality of equipments and workbenches, including dials, buttons, selectors, indicators, meters, graphs and so on, thus allowing easy parameter setting and signal

measurement with (virtual) oscilloscopes, spectrum analyzers, power meters, etc..

Nowadays, the educational applications developed with LabVIEW™ are available for both Windows and Mac OS X systems. Furthermore, a portable stand-alone version of the VI applications, implemented with LabVIEW™ Application Builder, allows the students to run exercises in classrooms or at home, simply by installing LabVIEW™ Runtime Engine, which is freely available from NI's website [3]. The VI applications are distributed to the students on a CD or can be downloaded from the web platform of the Bachelor and Master Degree Programs in Telecommunications Engineering [8], which is based upon Moodle. The latter is a free and open source web application which is designed to help educators in creating effective online courses and e-learning platforms with opportunities for rich interaction.



Fig. 1. An old hardware set-up used in the telecommunication educational laboratory for demonstrations about modulated signals.



Fig. 2. The CCTV projection system used during the early educational laboratory activities based on hardware set-ups.

Figure 3 shows some educational material available for download (upon authentication) from the Moodle-based web platform of the Bachelor and Master Degree Programs in Telecommunications Engineering. The list in the top part of Fig. 3 includes a package of LabVIEW™ applications (file CD_PSST_a.a.-2008-2009.zip) and the installer of the Lab-

VIEW™ Runtime Engine application (file LabVIEW821RuntimeEngine.exe).

The list in the bottom part of Fig. 3 includes a collection of exercise sheets (file testi_esame_psst_May2009.zip) describing VI measurement procedures, relevant to lab practices or examination sessions, as described in Sect. VI.

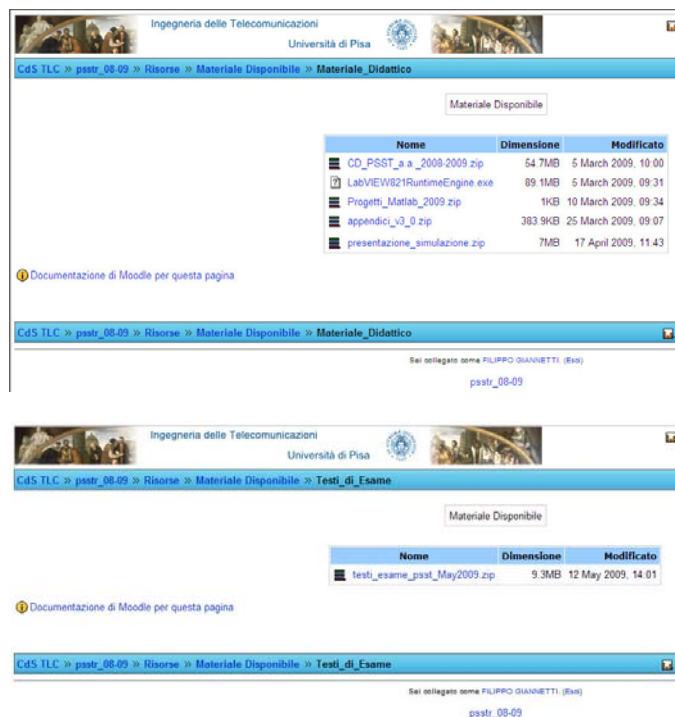


Fig. 3. Educational material available for download from the Moodle-based web platform of the Bachelor and Master Degree Programs in Telecommunications Engineering: VI applications and Runtime Engine application (top); exercise sheets (bottom).

IV. GETTING RID OF THE HARDWARE: VIRTUAL INSTRUMENTS FOR THE SIMULATION OF PHYSICAL INSTRUMENTS

The first step in the re-organization and innovation of educational activities, towards an enhanced interactivity, was then the development of VI software tools, realized with LabVIEW™, and featuring signal generation, processing, and measurement. Actually, this was the most straightforward way of allowing the students to directly interact with an instrumentation panel. A broad set of educational VIs was therefore developed for telecommunication students, including source and channel coding, simulation of transmission systems, with either analogue or digital modulations, simulation of antennas and microwave devices, and signal/image processing algorithms. Table 1 presents the list, grouped by categories, of the currently available VI applications for simulating/emulating communication systems, equipments, devices, and measurement instruments [9]. Most of the applications available in the VI library set are “test-benches” that simulate a complete transmission system, allowing easy interactive parameter settings and detailed signal monitoring capabilities.

TABLE 1
LIST OF VI APPLICATIONS

Source Coding GSM Vocoder , PCM-DPCM-DM Toolkit
Analogue and Digital Modulations AM Modulation , Angle Modulation , CDMA Modulation , DPSK Modulation , FM-PM Modulations , PAM Modulation , PSK Modulation , QAM Modulation
Receiver Signal Processing: Synchronization and Detection Coherent Detection , Correlation , Costas Loop
Error-Correcting Codes Coded System , Viterbi Processor
Transmission Systems Monte Carlo BER Measurement , File Transmission System
Radio Communications Multipath PAM Modulation , Multipath PSK Modulation , Multipath QAM Modulation , Signature of a Microwave Radio Link
Antennas and Microwave Devices Simulators Linear and Planar Array Simulator , Transmission Line Impedance Matching Simulator , Time-Domain Transmission Line Simulator
Image Processing Image Analyzer , Dual Image Analyzer
Instrumentation Simulators and Emulators Agilent 33220A Function/Arbitrary Waveform Generator (emulator) , Agilent 54641A Digital Oscilloscope (emulator) , Anritsu 37311A Vector Network Analyzer (emulator) , HP 3784A Digital Transmission Analyzer (emulator) , Measurement Instruments

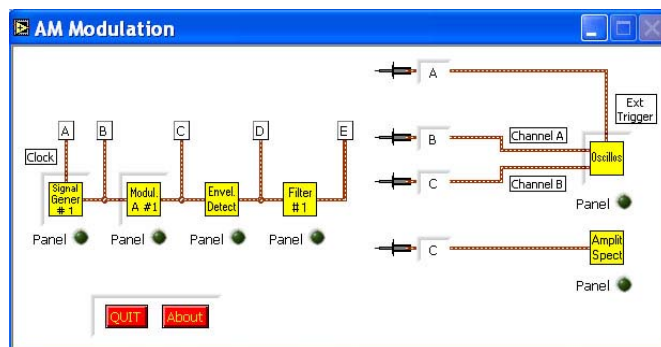


Fig. 4. The interactive block diagram of the AM modulation software simulator, that replaced the hardware set-up depicted in Fig. 1.

A. An Example of a Software Simulator: AM Modulation

For instance, the AM Modulation application simulates a complete transmission system featuring source signal generator, amplitude modulator, envelope detector, and baseband post-detection filter. Figure 4 shows the interactive block diagram of the AM modulation simulator, which replaced the hardware set-up depicted in Fig. 1. The led button labelled “Panel”, placed next to each block, opens the relevant control panel. For instance, Fig. 5 shows the interactive VI front panel of the AM generator module, labelled as “Modul. A #1”.

As apparent, the availability of intuitive controls such as selectors and indicators allows a simple use of the VI instrument. Moreover, the “virtual probe selectors” on the right side of the VI panel in Fig. 4, can be used to connect some virtual measuring instruments, namely. a two-channel oscilloscope and a spectrum analyzer, to the test-points (TPs), labelled from “A” thru “E” in the left side of the block diagram panel. Figure 6 shows the control panel of the virtual 2-channel oscilloscope while performing a measurement on the source signal at TP “B” (oscilloscope’s ch. A, white track) and on the AM signal at TP “C” (oscilloscope’s ch. B, red track).

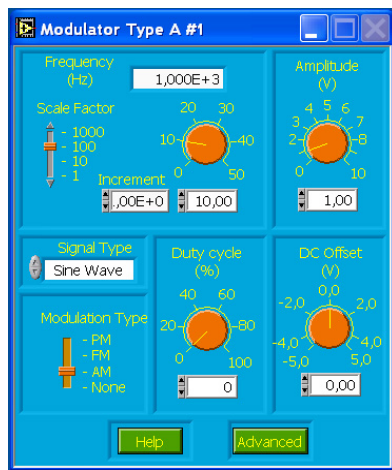


Fig. 5. The interactive VI front panel of the AM generator module in the block diagram depicted in Fig. 4.

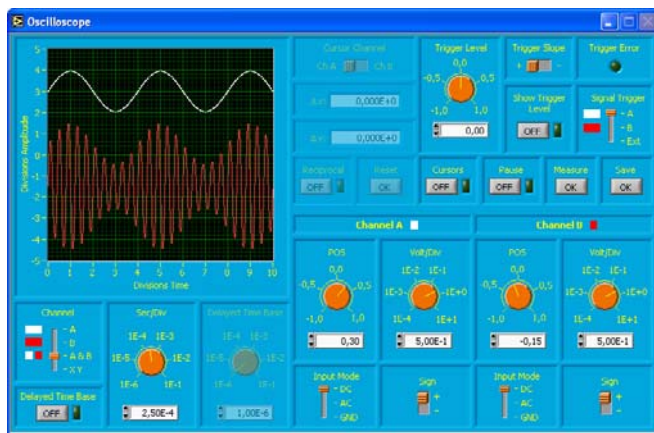


Fig. 6. The interactive VI front panel of the oscilloscope in the block diagram depicted in Fig. 4.

The oscilloscope is a fully functional measuring instrument which allows the selection of the channel(s) to be displayed, the setting of time base, amplitude scale, trigger and so on, via a user-friendly graphical user interface. Actually, as shown in the figure, the panel reproduces the appearance of the real instrument with all the relevant controls and indicators, providing the feeling of operating on a physical instrument.

In order to demonstrate the high degree of fidelity and accuracy attained by LabVIEW™-based software simulators in replicating the signal features and the behaviour of the communication systems, the graphs in Figs. from 7 to 9 compare the signals measured with physical instruments (on the left side of the graphs), like those in Fig. 1, with the simulated signals obtained using VIs (on the right side). As apparent, the interactive features of the VIs enable the students to carry out a deep investigation and to earn a better understanding of:

1. the signal features both in the time and in the frequency domains, and the relevant sensitivity with respect to variation of parameters, e.g., modulation index, modulating signal bandwidth and amplitude, carrier frequency, etc. (Fig. 7);
2. the system behaviour at different stages of the transmission chain, e.g., detector, receive filter, etc. (Fig. 8);

3. the behaviour in the presence of impairments or non-ideal operating conditions, e.g., distortions, over-modulation, etc. (Fig. 9).

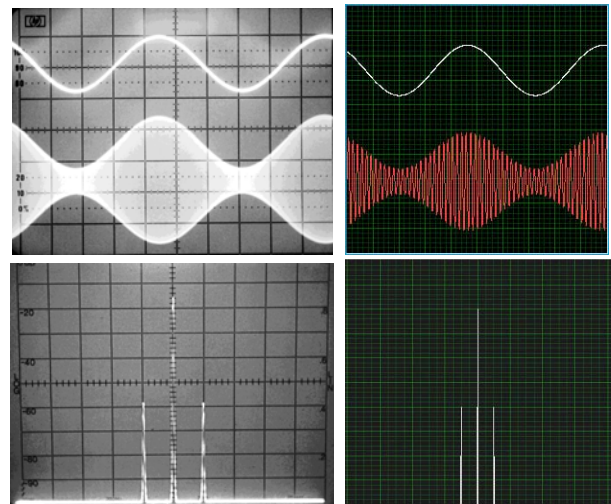


Fig. 7. Measured modulating signal (left, upper track) and AM signal (left, lower track) and the relevant VI simulated signals (right): time-domain representation (top); spectrum representation (bottom).

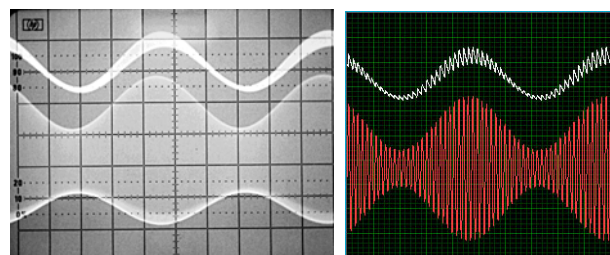


Fig. 8. Measured “rippled” signal at the envelope detector output of the AM receiver (left, upper track) and the relevant VI simulated signal (right, upper track).

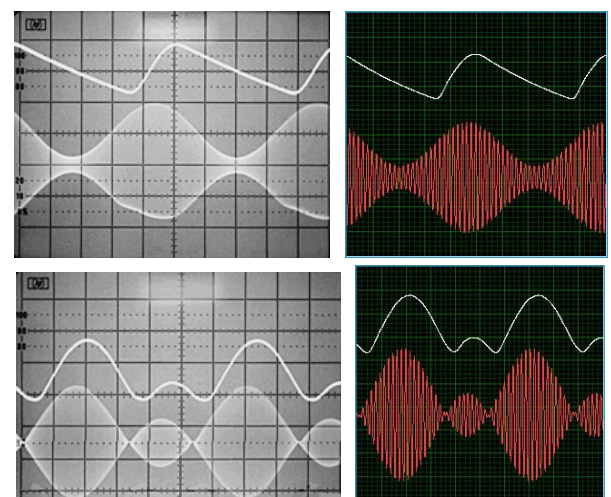


Fig. 9. Measured AM signals (left) and the relevant VI simulated signals (right): diagonal clipping effect in the detection of an AM signal (top, upper track); detection of an over-modulated AM signal (bottom, upper track).

B. Processing Real Data with Virtual Instruments

Another key feature of the VIs is the possibility of performing exercises using “real world” data. Actually, many VIs enable the PC to act very likely as a “physical” instrument performing (off-line) measurements and processing of (previously acquired) physical signals and measured data. Four types of inputs can be provided to the VIs of the virtual lab:

1. physical signals which originate from sources such as sensors, microphones, cameras, or lab generators of testing signals, and are acquired by a PC through standard audio/video (A/V) inputs, or, if required, a data acquisition (DAQ) module featuring analogue-to-digital conversion (ADC);
2. measurement results provided by physical instruments, such as a digital oscilloscope or a vector network analyzer, which are sent to the PC, e.g., via standard GPIB bus;
3. digital waveforms that are synthesized by the PC itself;
4. multimedia files (text, audio, pictures, videos).

V. BACK TO THE HARDWARE: VIRTUAL INSTRUMENTS FOR REMOTE- CONTROL OF PHYSICAL INSTRUMENTS

The approach based upon stand-alone VI applications revealed rather effective from the educational point of view, as the students positively reacted to the novelty, by showing an enhanced interest in lab activities and a more active participation. However, the complete absence of any physical instrument during the exercises was a non negligible flaw of the system that left the teachers team, and some students too, not fully satisfied. The need of addressing such an issue drove then the efforts for a further development of the educational system, that were undertaken starting from the early 2000s.

A. Architecture of the Remote-Control Lab

The envisaged solution, which became operational for lab exercises from the academic year 2004/2005, consisted in performing a remote-control of the instruments via standard GPIB (General Purpose Interface Bus) interface (also known as IEEE 488), either directly by the teacher’s PC or by the students’ terminals through a TCP/IP based network [10]. The most significant benefits of such an approach are the following:

1. expensive single-copy equipments can be effectively shared among several students;
2. exercises with real instruments can be remotely performed also by the students from their homes, via the Internet;
3. during the exercises the students work with real data, acquired by actual instruments, instead of a using “fake” signals synthesized by the PC itself.

The remote-control lab, whose general architecture is depicted in Fig. 10, consists of one (or more) measuring instrument(s), the teacher’s PC (server), and a cluster of student PCs (clients).

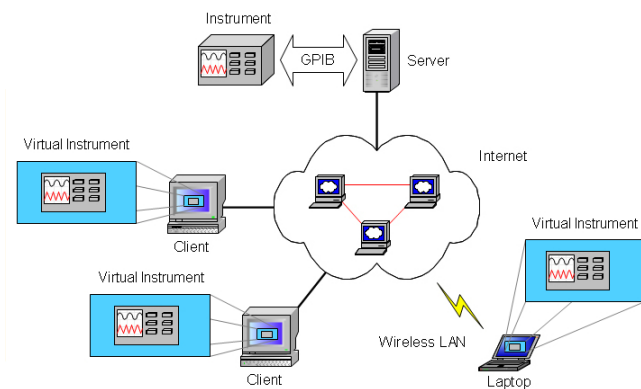


Fig. 10. General architecture of the remote-control lab.

TABLE 2
INSTRUMENTS OF THE REMOTE-CONTROL LAB AND THE FRONT
PANELS OF THE RELEVANT VI APPLICATIONS

Instrument	VI Front Panel
Agilent 33220A Function/Arbitrary Waveform Generator	
Agilent 54641A Digital Oscilloscope	
Anritsu 37311A Vector Network Analyzer	
HP 3784A Digital Transmission Analyzer	
HP 8566B Spectrum Analyzer	

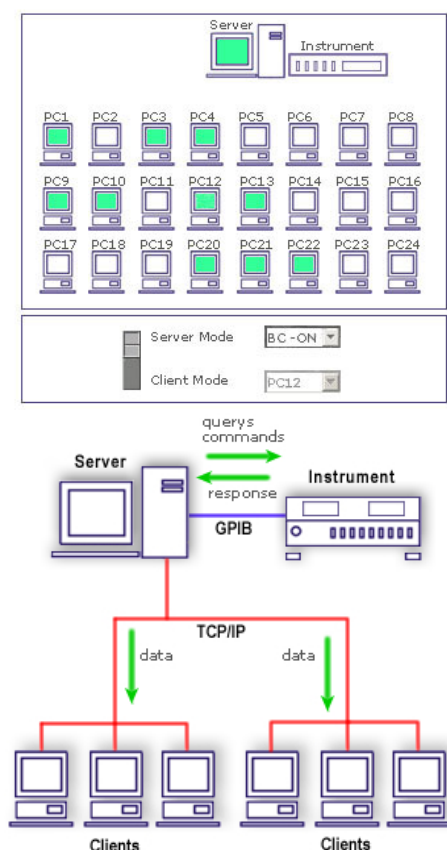


Fig. 11. The teacher's control panel (top) and the laboratory setup in the Server Mode (bottom) during the Training Phase.

The server controls the instrumentation via GPIB interface while the clients are connected to the server via TCP/IP protocol through the classroom's local area network (LAN) or, more in general, through the Internet.

The clients can communicate with the server in order to receive real-time measured data and, upon authorization from the server or authentication, take control of the instrumentation.

Every PC of the system runs VI applications featuring interactive panels which exactly replicate the appearance of the "physical" instruments' panels, with all the relevant functionalities, controls and displays.

The VIs accept then commands from the operator and graphically present measurement results exactly like the real instruments do.

Currently, the remote-control lab encompasses the measurement instruments that are listed in Tab. 2 together with the relevant VI applications. The lab can be used in remote-control mode from either the classroom PCs via LAN or students' homes via Internet.

B. Use of the Remote-Control Lab from Classroom PCs

When used in the classroom, via LAN, the remote-control lab supports two operating modes:

i) *Server Mode*. The teacher's server controls the instruments and broadcasts the measured data to the clients;

ii) *Client Mode*. One of the clients is allowed by the server to take the control of the instruments and to perform measurements.

The selection of the operating mode is accomplished by the teacher through the control panel shown in the upper part of Figs. 11 and 12, where the highlighted icons represent the clients machines that are turned on. The operating mode (Server or Client) is selected by the switch in the lower part of the panel. In Server Mode, the teacher can also turn the broadcast feature on/off by means of the "BC-ON"/"BC-OFF" control. In Client Mode, the teacher authorizes a single client (e.g., PC12 in Fig. 12) to control the instrumentation. The authorized client machine is highlighted in red in the teacher's control panel.

A typical session of lab exercises is organized into two phases, as outlined hereafter.

1. *Training Phase*. During this phase, whose duration is about 30'-40', the teacher operates the system in "Server Mode" in order to show the functioning of the instrument to the students. The control of the real instrument is thus fully devoted to the teacher's server that receives the measured data and broadcast them to all the clients (Fig. 11, bottom). The students can watch on their screens, through the local VI application, the instrument settings and the measured data. During this phase, the students are only allowed to adjust their VI's display options.

2. *Active Learning Phase*. At the end of the Training Phase, the teacher switches to "Client Mode", and the clients are then allowed by the server to take the control of the instrument, one at a time, and to perform measurements (Fig. 12, bottom). The student at the active client can remotely operate the instrument like being in front of the real equipment, while the other clients are off-line. The server communicates with the active client, manages connection and disconnection requests, and routes the commands to the instrument. Meanwhile, the teacher can monitor the procedure from the server and, if desired, take back the full control of the instrument in order to avoid incorrect measurement procedures.

C. Use of the Remote-Control Lab via Internet

Thanks to the support of the TCP/IP protocol provided by the server and the clients VI applications, the remote-control of the instrumentation can be performed also via Internet, thus allowing any student to access the instrumentation also from outside the academic facilities, as shown in Fig. 10. Conceptually, this operating mode is very similar to the classroom use, described in the previous paragraph. There are, however, a few significant differences, to be highlighted.

1. *Operating modes*. Internet access is intended for student's self-practice at any time of the day, with unattended server and instrumentation, and therefore the "Client Mode" only is supported.

2. *Authentication and access policy*. In a classroom equipped with a LAN, the remote-accesses of the students to the instrumentation can be easily managed by the teacher, but in the case of a remote-control via Internet a user authentication mechanism shall be implemented. Also, since the instru-

mentation can be controlled by only one user at time, and since the server is unattended, each measurement session shall be automatically terminated once a given time interval (set by the server administrator) is elapsed.

3. *Software requirements.* In order to perform remote-control via internet, the client PCs require only the prior installation of LabVIEW RunTime Engine and the execution of a client application that manages user authentication and the selection of the instruments to control, once at time. There is no need to install the VI applications on the client PC. Actually, once selected the desired instrument, the relevant VI panel is downloaded from the server and locally opened within a web browser page.

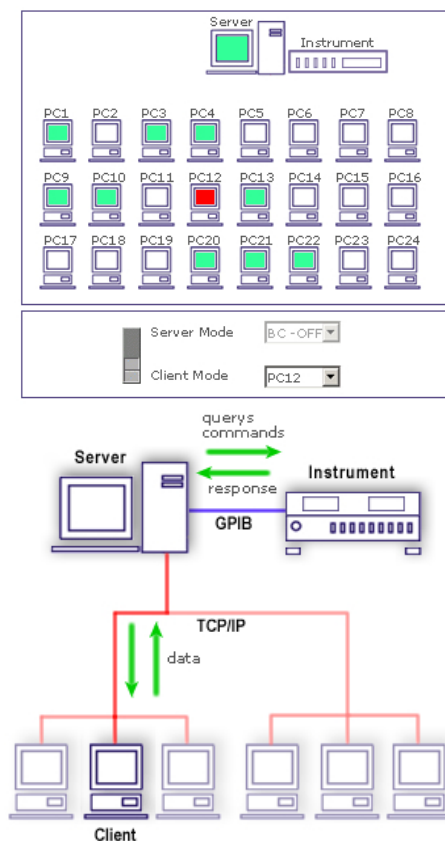


Fig. 12. The teacher's control panel (top) and the laboratory setup in the Client Mode (bottom) during the Active Learning Phase

D. An Example of the Remote-Control Lab

Figure 13 shows a possible hardware configuration for the remote-control lab, including the following instruments (in the background, from left to right): HP 3784A Digital Transmission Analyzer, Agilent 33220A Function/Arbitrary Waveform Generator, and Agilent 54641A Digital Oscilloscope.

The board in the front contains the system under test consisting of a two-section line regenerator (the grey box), with the relevant line impedance matchers (the small circuit boards on the left side), and a couple of passive filters (the small circuit boards on the right side) that emulate the attenuation and distortion effects of a transmission line.

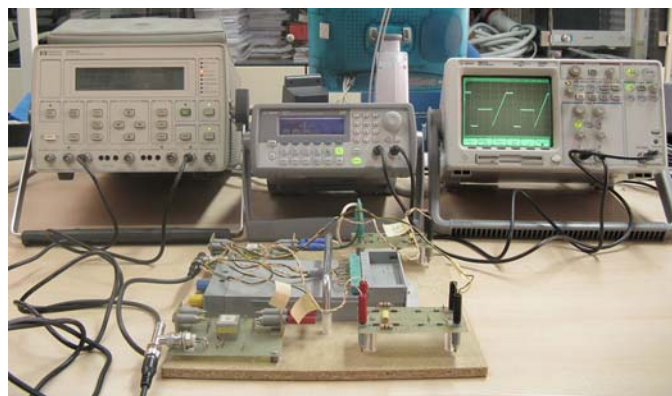


Fig. 13. The hardware components of the remote-control lab: the instruments (background) and the system under test (front).

The digital signal analyzer of the test-bench in Fig. 13 generates a programmable test pattern which is passed through the system under test (i.e., the regenerator, plus the impedance matching circuits and the line emulators). Also, it detects the data stream at the system output and provides bit error count and many other statistical performance figures of the digital link.

The 2-channel oscilloscope enables the monitoring of the signal waveform at two different test-points of the transmission chain. The function/arbitrary waveform generator can be optionally used for generating other signal formats, or for injecting calibrated additive white Gaussian noise into the system.

Figure 14 shows the authentication window of the client VI (top) and the menu window (bottom) which allows the selection of the instrument to be controlled, one at time, among those listed in Tab. 2. Upon selection of the desired instrument, the relevant VI panel is opened on the client PC and the user is then allowed to take the full control of the instrument for a fixed time interval. Once the allocated measurement time is elapsed, the user will be automatically logged-out.

The client application, the operating instructions, and further support material are available for download from the web site of the Multimedia Education and e-Learning Activities Group [1].

VI. EDUCATIONAL ACTIVITIES

The VI applications, both stand-alone and clients for remote-control, are accompanied by a set of sheets describing measurement exercises that are available for download from the Moodle-based educational web platform described in Sect. III. Figure 15 shows a sample of a laboratory exercise sheet relevant to the measurement of the bit-error performance for a digital link, by using the experimental setup depicted in Fig. 13. The sheet illustrates the block diagram of the test-bench, lists the settings of the instruments, describes the measurement procedure, and contains some tables and/or charts for the presentation of the measurement results. These sheets are used for exercises in the lab, for self-practice at home, and also for final examinations.

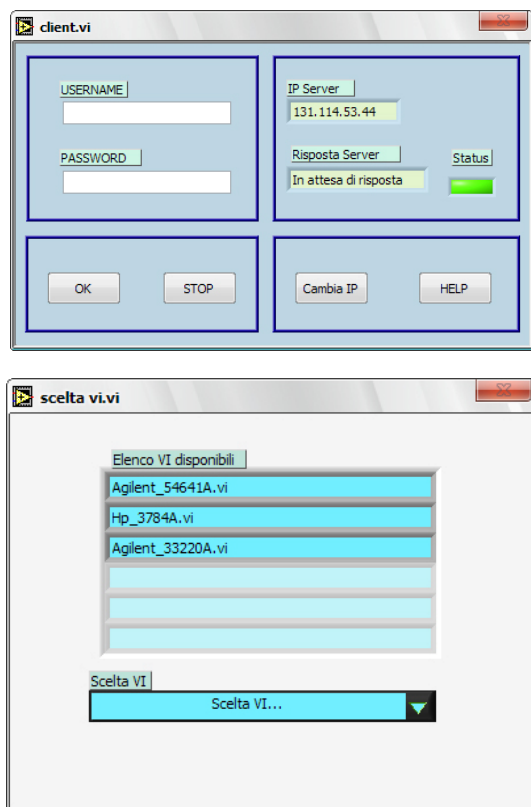


Fig. 14. The user's software component of the remote-control lab: the authentication window of the client application (top) and the menu for the selection of the instruments (bottom).

VII. CONCLUSIONS

The evolution of educational activities in telecommunication at the Engineering college of the University of Pisa (Italy) aimed at achieving a greater involvement of the students has been presented and discussed.

A LabVIEW™-based educational system has been devised with the aim of replacing ineffective lab demonstrations based upon single-copy instrumentation, so as to provide the learner with a better and stronger understanding of communication systems, equipments, and devices. More in detail, the novel educational system has been designed to allow the use of virtual (i.e., fully software) or remote-controlled instrumentation for measurements on both synthetic and real world data. The resulting educational system consists of a wide set of VI applications, both stand-alone simulators and client applications supporting remote-control of instruments via GPIB and TCP/IP protocols.

The teachers have found that such a VI approach fulfils the goals of the educational project, allowing the students to fully understand the operation of a measurement test-bench and the behaviour of a communication system, as in conventional educational activities based on the real physical equipments. The only significant left out aspect is the arrangement of the test-bed. Fortunately, in the case of communication systems, the preparation of the experimental set-up usually consists in just some cable connections, such as, for instance, in Fig. 13, and therefore it does not represent a severe limitation.

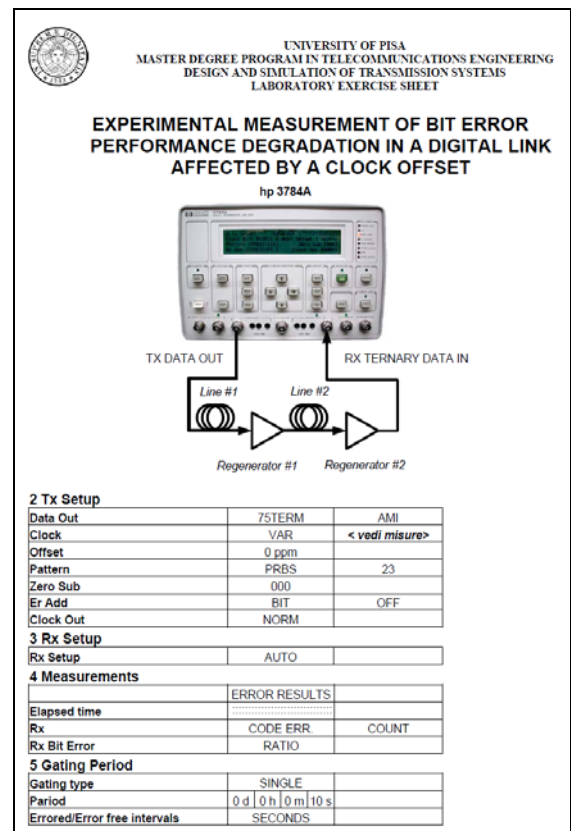


Fig. 15. A sample of a laboratory exercise sheet.

Summarizing, the proposed educational system is shown to yield the following benefits:

1. thanks to VIs, students can operate on their PCs using the same functionalities as with the real instruments for viewing and processing either synthesized or real-world data;

2. thanks to TCP/IP, remote laboratory activities with costly single-copy instruments are possible either in the college laboratories or from anywhere an Internet connection is available.

Since the academic year 2003/04, the VI software tools have been used by some courses of the Master Degree Program in Telecommunications Engineering (in particular, the "Transmission Systems Design" course massively used VI during lessons, laboratory exercises, and final examinations, too). The students gave a very positive and encouraging feedback about the effectiveness of VI-based teaching. Such an enthusiastic interest of the students in lab exercises is actually a fundamental outcome of this educational project, which results especially striking if compared with the former educational approach based on less involving (and therefore much more boring) classroom demonstrations of single-copy instruments.

From the pedagogical point of view, another important result is the acknowledgment of the capital role played by the appearance of VIs' graphic interfaces in letting the students to operate with the feel of being in front of a real equipment, instead of a software tool. This consideration suggests thus to take the maximum of care in building realistic instrument panels, avoiding too much "software-oriented" objects, such as pop-up menus, dialog boxes, and so forth.

Finally, it is worthwhile to remark that the use of VI simulators allows a low-cost upgrade of the experimental set-ups. As a matter of fact, the test-benches and the instruments simulators can be easily re-configured, or re-programmed, so as to support any telecommunication standard, both current and forthcoming, such as cellular Third- or Fourth-Generation (3G/4G) systems and beyond (e.g., LTE), or IEEE 802.11x and IEEE 802.16x families of wireless networks.

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