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A Virtual Educational Laboratory for Tele communications Engineering

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INTRODUCTION

A fundamental requirement in professional engineering courses is the establishment of a large number of hands-on activities that allow students to practice and validate all of the analytical concepts and techniques they have learned in theoretical courses using tools and measurement systems in a laboratory. Unfortunately, fulfilling this requirement presents a number of challenges. The lack of big capacity classrooms with measuring instruments—which are often highly costly and must be constantly dispersed to create several work desks—is likely the first of these issues. Furthermore, educational labs may only be utilized during the hours specified in the semester timetable, provided they are accessible. It's also important to consider the possibility that inexperienced pupils might misuse costly equipment and cause harm. Since the mid-1990s, a group of educators at the University of Pisa's Engineering College have dedicated themselves to creating multimedia teaching activities in an effort to address the aforementioned issues and facilitate the more efficient teaching of technical courses [1]. Within the context of the Bachelor and Master Degree Programs in Telecommunications Engineering, they have developed a project to realize an educational virtual laboratory that will be utilized for professional discipline experiments [2]. The suggested teaching strategy is predicated on a collection of appropriate software interfaces known as virtual instruments (VIs), which can mimic or simulate hardware instruments. This makes it a strong and alluring substitute for traditional laboratory practice, which necessitates a significant amount of (expensive) hardware equipment. The objective Therefore, the goal of the project is to enable students to conduct experiments without the need of measuring tools, either at home or in their college laboratories. The team of teachers used National Instrument's
Lab VIEWTM
development framework [3] to implement the different software components of the virtual laboratory, utilizing its many data and signal processing functions as well as its potential for interactivity and flexibility. In actuality, LabVIEW is a software environment that is very popular for both industrial and educational applications because of its appealing features; several published papers address the latter uses. Here, we focus on a few noteworthy educational experiences in the area of information engineering disciplines that have been documented in the literature. As examples, we recall: a system for power measurement on non-standard waveforms using VIs for both signal generation and measurement [12], an audio file processing system that can load externally generated files [13], a tool for importing and processing digital logic circuit data [14], a set of VIs for acquiring and processing laboratory signals [15], and an interactive virtual laboratory for electronic and engineering education that permits both virtual simulation and real-time measurement [11].

The following instructional objectives were specifically intended to be accomplished by the educational virtual laboratory described below:

to provide a student a sense of how a complicated communication system behaves and how sensitive performance is to changes in parameters; to help a student comprehend how a complicated communication system behaves and get an understanding of how sensitive performance is to changes in parameters;

BACHELOR DEGREE IN TELECOMMUNICATIONS ENGINEERING

Course	VIs
Electrical Engineering	*Planned / Under development*
Signals and Systems	*Planned / Under development*
Electromagnetic Fields	• Transmission Line Impedance Matching Simulator • Time-Domain Transmission Line Simulator
Telecommunication Networks	*Planned / Under development*
Probability and Stochastic Processes	*Planned / Under development*
Digital Signal Processing	*Planned / Under development*

MASTER DEGREE IN TELECOMMUNICATIONS ENGINEERING

Course	VIs
Communication Systems	• AM Modulation • Angle Modulation • Coherent Detection • Costas Loop • FM-PM Modulations • PCM-DPCM-DM Toolkit
Teletraffic Engineering	*Planned / Under development*
Antennas and Propagation	• Linear and Planar Array Simulator
Statistical Signal Processing	*Planned / Under development*
Digital Communications	• BER_Eb_No • Correlation • DPSK Modulation • PAM Modulation • PSK Modulation • QAM Modulation • Viterbi Processor
Measurements on Telecommunication Equipments	• Digital Oscilloscope Agilent 54641A Emulator • Digital Transmission Analyzer HP 3784A Emulator • Measurement Instruments • Vector Network Analyzer Anritsu 37311A Emulator
Design and Simulation of Microwave Systems	• Linear and Planar Array Simulator • Transmission Line Impedance Matching Simulator • Time-Domain Transmission Line Simulator • Vector Network Analyzer Anritsu 37311A Emulator
Electromagnetic Compatibility	• Vector Network Analyzer Anritsu 37311A Emulator
Microwaves	• Linear and Planar Array Simulator • Transmission Line Impedance Matching Simulator • Time-Domain Transmission Line Simulator • Vector Network Analyzer Anritsu 37311A Emulator
Optical and Microwave Devices	• Vector Network Analyzer Anritsu 37311A Emulator
Design and Simulation of Remote Sensing Systems	*Planned / Under development*
Image Processing and Transmission	• Dual Image Analyzer • Image Analyzer
Radar Technique	*Planned / Under development*
Remote Sensing Systems	*Planned / Under development*
Design and Simulation of Telecommun. Networks	*Planned / Under development*
Optimization of Telecommunication Networks	*Planned / Under development*
Switching and Routing	*Planned / Under development*
Telematics	*Planned / Under development*
Design and Simulation of Transmission Systems	• File Transmission System • Digital Oscilloscope Agilent 54641A Emulator • Digital Transmission Analyzer HP 3784A Emulator • Measurement Instruments
Optical Communications	*Planned / Under development*
Radio Systems Engineering	• CDMA • Signature of a Microwave Radio Link
Wideband Communications	• CDMA • Coded System
Wireless Communications	• GSM Vocoder • Multipath PAM Modulation • Multipath PSK Modulation • Multipath QAM Modulation

1. to provide the student the opportunity to practice using the equipment, become proficient in its usage, and accurately interpret the measurement data;
2. 3. to enable the student to analyze real-world data in addition to waveforms created by a computer simulator. Students enrolled in the Bachelor of Telecommunications Engineering and Master of Telecommunications Engineering programs utilize the educational system described in this article, which is housed at the instructional Laboratory of Telecommunications and Applied Electromagnetics. Table 1 displays VI's availability.

THESOFTWAREENVIRONMENT

LabVIEW, a development environment from National Instruments (NI) [4], was used to assemble the software-based components of the virtual laboratory. It supports interactivity, allows for a very flexible design, and provides a wide range of signal and data processing functions (e.g., see [11–15]). These intriguing peculiarities led to the development of a virtual laboratory at the University of Pisa's Engineering College that includes several interactive software simulation tools for communication networks. These interactive programs provide the operator VIs with dials, buttons, selections, indicators, meters, graphs, and other components that accurately replicate the functionality of tools and workbenches. This makes it simple to define parameters and measure signals using (virtual) oscilloscopes, power meters, spectrum analyzers, etc. Both Windows and Mac OS X users may use the virtual laboratory's programs, which were created using LabVIEWTM. Additionally, students are given a portable, stand-alone version of the applications on CD that is implemented with LabVIEWTM Application Builder. This enables them to complete the exercises at home or in the classroom by simply installing LabVIEWTM Run-Time Engine, which is freely accessible from NI's website [4].

THEVIRTUALINSTRUMENTTO OLS

ConceptofVI-BasedExercises

The LabVIEWTM-created PC software tools known as virtual instruments (VIs) include one or more of the following features: signal production, signal processing, and signal measurement (for example, see [5] and [12]). In order to cover a wide range of applications that are relevant to students studying communication, a large collection of VIs has been created. These applications include source and channel coding, transmission systems with analog or digital modulations, antennas and microwave devices, and image processing algorithms. Figure 1 depicts the idea of such a VI-based activity. It depicts a PC running a library of VI programs (Table 2 lists all of them) and gaining access to a library of files that hold the source data that has to be processed or monitored. Additionally, VI programs provide output data files with the processing/measurement results. The Lab VIEWTM-created PC software tools nown as virtual instruments (VIs) include one or more of the following features: signal production, signal processing, and signal measurement (for example, see [5] and [12]). In order to cover a wide range of applications that are relevant to students studying communication, a large collection of VIs has been created. These include image processing algorithms, transmission systems with analog or digital modulations, source and channel coding, antennas, and microwave devices. Figure 1 depicts the idea of such a VI-based activity. It depicts a PC running a library of VI programs (Table 2 lists all of them) and gaining access to a library of files that hold the source data that has to be processed or monitored. Additionally, VI programs provide output data files with the processing/measurement results.

Generation of Vis source data files

The ability to conduct exercises using "virtual instruments" that employ "real world" data is a key component of the virtual laboratory under study. In reality, the VIs allow the PC to function much like a "physical" instrument by rocessing (previously collected) physical signals and measured data and doing (off-line) measurements. The educational systems discussed in [13–15], for example, have some of the same characteristics. The virtual lab may receive four distinct kinds of data, as shown in Fig. 2. The first kind, represented by the letter (A), are physical signals that originate from devices like cameras, microphones, sensors, and lab producers of testing signals. They are sent via normal audio/video to the PC.

Table 2.VI applications for simulating communication systems, equipment, devices, and measurement instruments

Source Coding	
	GSM vocoder
	PCM-DPCM-DM Toolkit
Modulations	
	AM Modulation
	Angle Modulation
	CDMA
	DPSK Modulation
	FM-PM Modulations
	PAM Modulation
	PSK Modulation
	QAM Modulation
Receiver Signal Processing	
	Coherent Detection
	Correlation
	Costas Loop
Error-Correcting Codes	
	Coded System
	Viterbi Processor
Transmission System Performance	
	BER_Eb_No
	File Transmission System
Multipath Radio Channels	
	Multipath PAM Modulation
	Multipath PSK Modulation
	Multipath QAM Modulation
	Signature of a Microwave Radio Link
Antennas and Microwave Devices	
	Linear and planar array simulator
	Transmission line impedance matching simulator
	Time-domain transmission line simulator
Image Processing	
	Image Analyzer
	Dual Image Analyzer
Instrumentation	
	Digital oscilloscope Agilent 54641A Emulator
	Digital transmission analyzer HP 3784A Emulator
	Measurement Instruments
	Vector Network Analyzer Anritsu 37311A Emulator

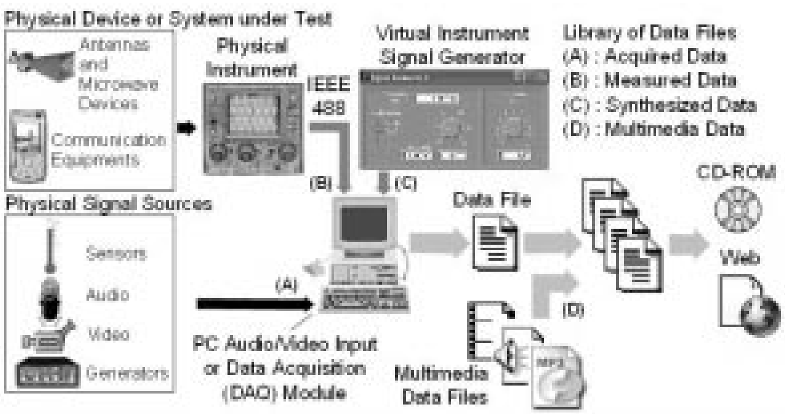


Fig.2.Generation of source data files provided to the VIs.

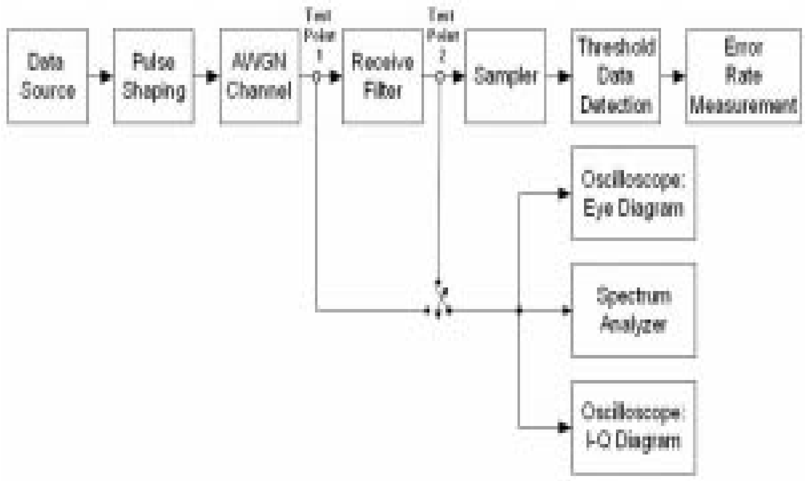
A/V) inputs, or an analog-to-digital conversion (ADC) data acquisition (DAQ) module if necessary. Measurement results from actual equipment, such a digital oscilloscope or a vector network analyzer, make up the second category of data, represented by the letter (B). A conventional IEEE 488 interface bus is used to send this data to the PC, maybe after some processing [6]. For instance, the S-parameters of any actual microwave device or antenna may be measured and sent to the PC in this manner. In the third scenario, the PC itself functions as a fully-software waveform generator and creates a discrete-time version of a signal, represented by (C), with the help of specialized VI programs. For instance, the transient along a loaded transmission line or the UMTS signal may be synthesized using the VI. Ultimately, the collected, measured, or synthesized data are added to a library of signals, which may also include multimedia files (D), and saved in a file. Students may access the data file library for later off-line processing using the

VIs, for instance, through CDs or the multimedia education group's website [1]. It should be noted that the measurements' data (i.e., type B) are really kept in instrument-dependent special format files.

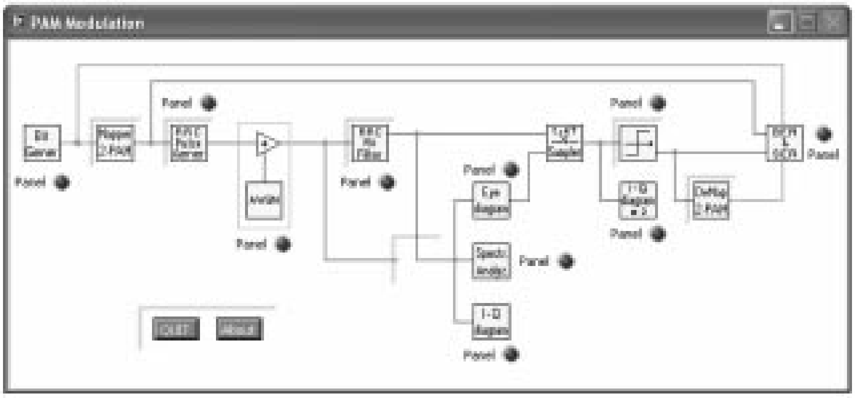
VIsforsystemsimulation

The majority of the VI library set's applications (refer to Table 2) are "test-benches" that replicate a whole transmission system, enabling simple interactive parameter adjustments and comprehensive signal monitoring features. Specifically, several of these simulator VIs were found to be very useful for teaching topics like modulated signal recognition and multipath radio propagation via simulation. Otherwise, they would need very intricate experimental configurations that go well beyond the hardware resources often found in teaching laboratories at colleges and universities. One such "test-bench" simulator, called "PAM Modulation," which has a full digital transmission system using Pulse Amplitude Modulation (PAM) [7], is briefly presented as an example. Figure 3

displays the interactive main screen of the applicable VI simulator (bottom) and a conceptual block diagram of the simulated system (top) for a configuration with a 2-PAM transmission, a Root Raised Cosine (RRC) pulse form, and a receive filter that is matched to transmit the pulses. As shown in the picture, the transmitter component of the simulator comprises a shaping filter for pulse generation, a data source generator (referred to as "Bit Gener" in the VI simulator), and a mapper that enables the selection of the modulation format between 2-, 4-, and 8-level PAM. Additive White Gaussian Noise (AWGN) is the model used to represent the channel. The receiver consists of a bit/symbol-error rate meter after a filter, sampler, threshold detector, and de-mapper module. The interactive VI panel enables the user to choose the preferred type from a variety of available alternatives for the majority of the simulator blocks, including the mapper, pulse generator, receive filter, symbol threshold detector, and de-mapper. Furthermore, a series of virtual measuring tools, such as an oscilloscope that plots the signal's "eye diagram" [7], a spectrum analyzer for frequency-domain signal analysis, and an oscilloscope in x–y mode that plots the signal's "phasor diagram" (also known as the "I–Q diagram") at certain significant (selectable) test points, provide accurate signal monitoring. Additionally, the user may access the appropriate control panel by clicking on the LED buttons labeled "Panel," which are positioned next to each block in the interactive VI diagram (Fig. 3) that represents a device or an instrument. The control panels for the eye diagram oscilloscope (top left), phasor diagram oscilloscope (top right), pulse generator (bottom left), and channel noise generator (bottom right) are shown, for instance, in Fig. 4. The panels offer the operator the impression that they are operating a genuine instrument by simulating the look of the actual instruments with all the necessary controls and indications, as shown in the figure. For example, the RRC pulse's duration and roll-off may be adjusted using the pulse generator. Additionally, the Gaussian generator adds noise to the transmitted signal by simulating a realistic transmission channel.



(a)



(b)
Fig. 3.The conceptual block diagram of the simulated system (a) and the interactive front panel of the relevant VI simulator, named‘PAM Modulation' (b).

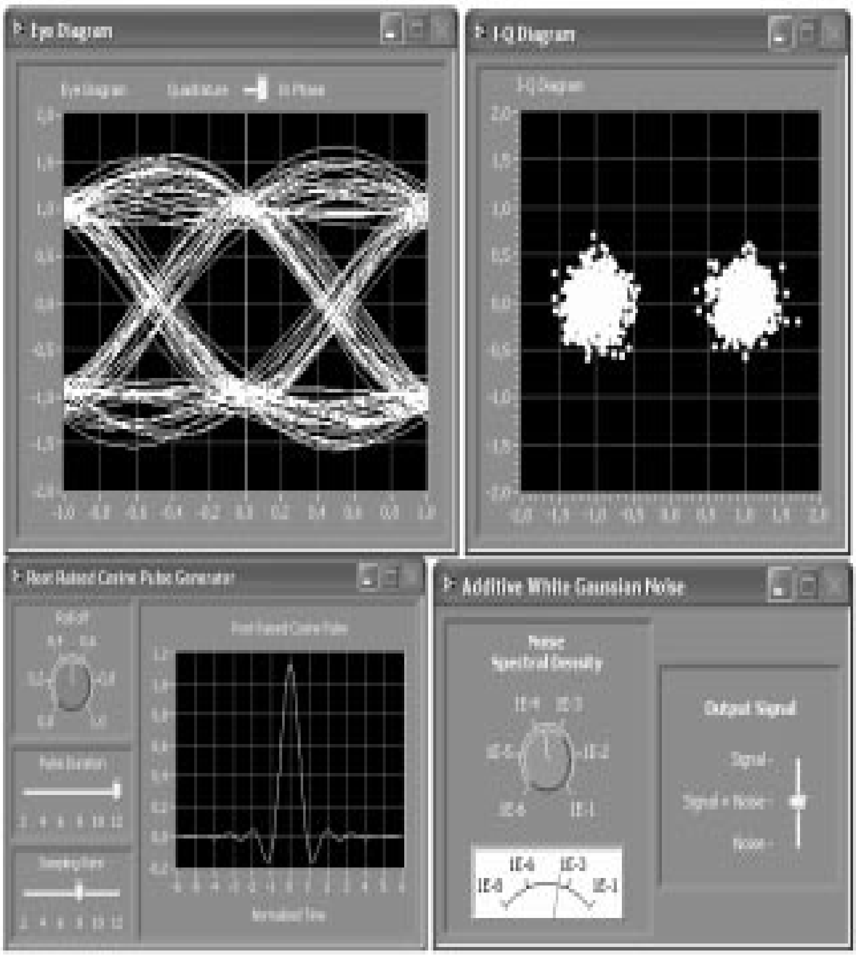


Fig.4.Frontpanelsofsomeblocksofthe‘PAMModulation':eyediagram(topleft),phasor(orI–Q)diagram(topright),pulsegenerator (bottom left) and channel noise generator (bottom right).

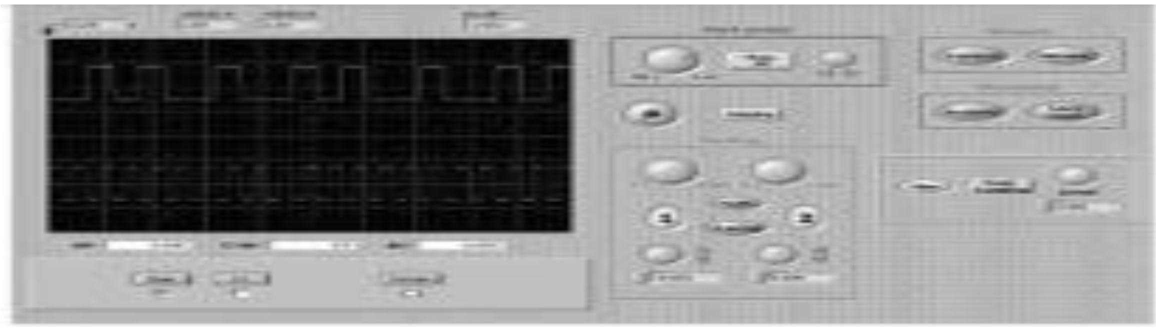


Fig.5.ThedigitaloscilloscopeAgilent54641Adisplayingtwodigital waveforms (left) and its VI panel (right).

VIs that mimic actual instruments A collection of software emulators of actual instruments was created to conduct measurements on communication equipment and microwave devices by using the extensive range of graphical capabilities offered by LabVIEWTM to create realistic VI panels. These software programs handle real-world measured data that is imported from external files obtained, and they completely mimic the look and functionality of actual equipment.as explained in the "Generation of VIs source data files"—Type (B) data files section above. The Agilent 54641A digital oscilloscope is shown in Figure 5 with the control panel of the appropriate VI application on the right and a digital waveform and its clock signal on the left. The VI software program offers several extra functions for off-line processing of the captured waveforms, including signal sum and product, FFT, and statistical analysis, in addition to the standard oscilloscope operations (such as amplitude and time scale settings, trigger controls, etc.). Additionally, the waveforms may be exported in text format after they have been processed. Figure 6 displays the control interface of the corresponding VI application (right) and the vector network analyzer (VNA) Anritsu Wiltron 37311A conducting tests on a microwave patch antenna (left). Two graphs that represent the log-magnitude and phase of the reflection coefficient of the device being tested, together with various visual display settings, are located on the left side of the VI panel. Another option is to utilize a Smith Chart representation. The panel's right side is where the VNA controls are located. The HP 3784A digital transmission analyzer (left) and the control panel of the corresponding VI application (right) are seen in Figure 7. Both the transmitter and the receiver on this analyzer are programmable to accommodate various digital signal types.

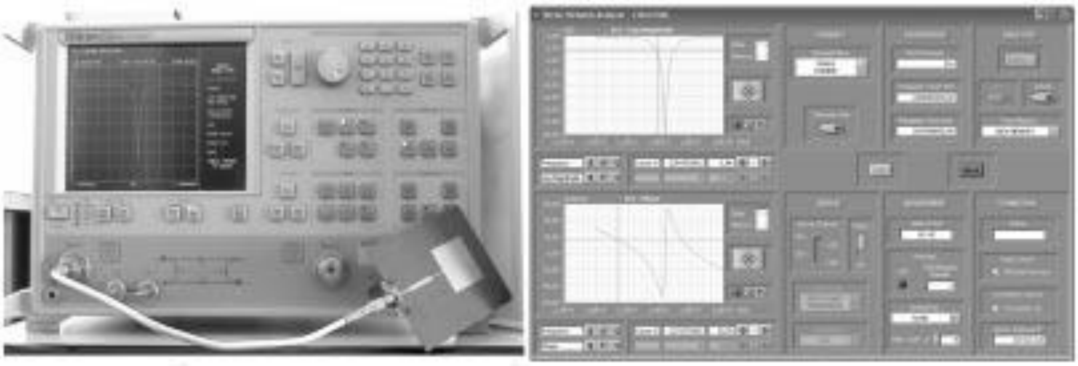


Fig.6.ThevectornetworkanalyzerAnritsuWiltron37311Aperformingmeasurementsonamicrowavepatch antenna(left),anditsVIpanel (right).

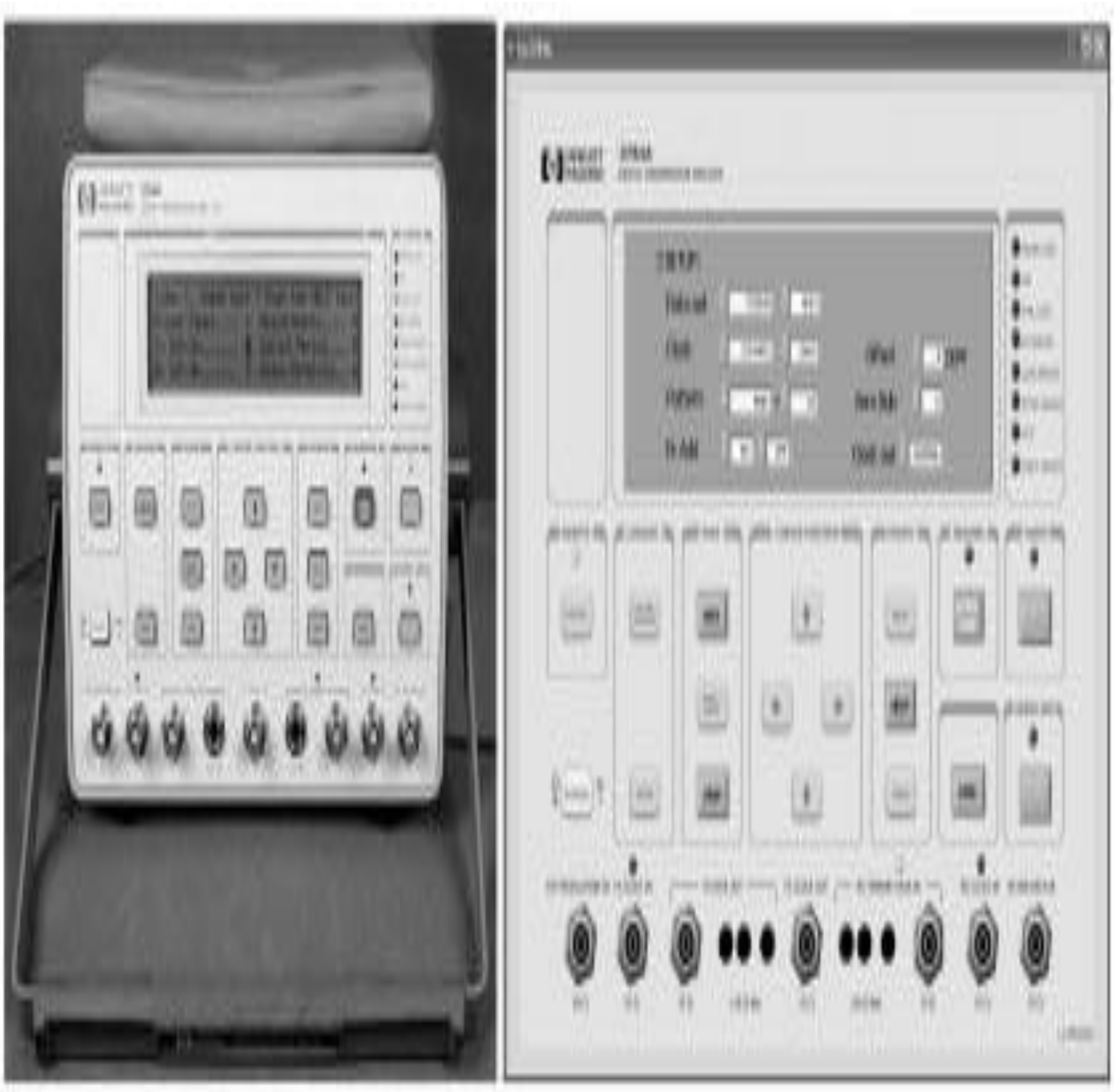
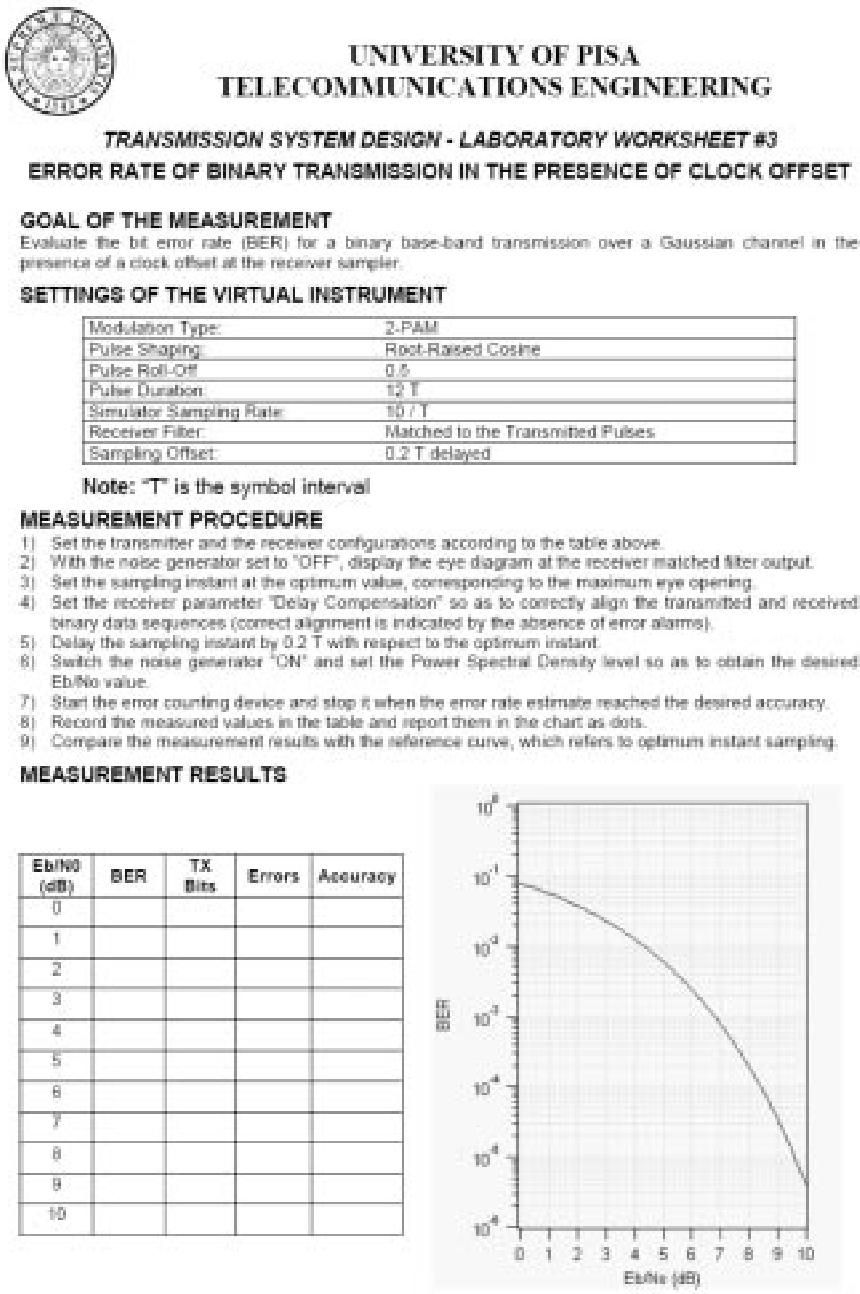


Fig.7.Thedigital transmission analyzerHP3784A (left),and itsVIpanel(right).

Moreoverbit and code error rates, errored and error-free seconds, and other statistical analysis of the received data stream are all carried out by the analyzer. The VI provides the operator with all of these metrics, which may be used for post-processing tasks like calculating outage likelihood and creating error rate charts. It's important to note that, as an extra bonus, every VI program mentioned above enables remote control of the actual instruments using a common IEEE 488 interface. This may be accomplished by establishing a direct link or a TCP/IP network between the instrument and the controlling PC [8, 16–17].

EDUCATIONAL ACTIVITIES WITH THE VIRTUAL LABORATORY

As shown below, an interactive laboratory activity that uses virtual test benches or equipment is often completed in two parts. 1. The training stage A typical laboratory exercise begins with a "Training Phase," which lasts around 30 to 40 minutes and during which the instructor shows the pupils how the virtual test-bench or instrument works. 2. The era of active learning The instructor hands out work sheets to the pupils at the conclusion of the training phase. Therefore, the pupils are asked to per



UNIVERSITY OF PISA
TELECOMMUNICATIONS ENGINEERING

TRANSMISSION SYSTEM DESIGN - LABORATORY WORKSHEET #3

ERROR RATE OF BINARY TRANSMISSION IN THE PRESENCE OF CLOCK OFFSET

GOAL OF THE MEASUREMENT

Evaluate the bit error rate (BER) for a binary base-band transmission over a Gaussian channel in the presence of a clock offset at the receiver sampler.

SETTINGS OF THE VIRTUAL INSTRUMENT

Modulation Type:	2-PAM
Pulse Shaping:	Root-Raised Cosine
Pulse Roll-Off:	0.5
Pulse Duration:	12 T
Simulator Sampling Rate:	10 / T
Receiver Filter:	Matched to the Transmitted Pulses
Sampling Offset:	0.2 T delayed

Note: "T" is the symbol interval

MEASUREMENT PROCEDURE

1) Set the transmitter and the receiver configurations according to the table above.
2) With the noise generator set to "OFF", display the eye diagram at the receiver matched filter output.
3) Set the sampling instant at the optimum value, corresponding to the maximum eye opening.
4) Set the receiver parameter "Delay Compensation" so as to correctly align the transmitted and received binary data sequences (correct alignment is indicated by the absence of error alarms).
5) Delay the sampling instant by 0.2 T with respect to the optimum instant.
6) Switch the noise generator "ON" and set the Power Spectral Density level so as to obtain the desired Eb/No value.
7) Start the error counting device and stop it when the error rate estimate reached the desired accuracy.
8) Record the measured values in the table and report them in the chart as dots.
9) Compare the measurement results with the reference curve, which refers to optimum instant sampling.

MEASUREMENT RESULTS

Eb/N0 (dB)	BER	TX Bits	Errors	Accuracy
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Fig.8.Worksheetforlaboratoryexercises.

Form measurements with the VI, exactly as they would with the actual equipment, and use the spreadsheet to record processes, instrument configurations, and measured data. A sample worksheet for the exercise based on the "PAM Modulation" application mentioned above is shown in Figure 8. The exercise's goal is to evaluate a digital transmission system's quality, measured in terms of bit-error rate (BER), when there is some impairment present (in this case, a clock offset). Following that, the students are instructed to do BER measurements using the VI panels, enter the measured data into the table worksheet, and plot the BER findings on the worksheet's blank chart. This kind of test might serve as a midterm assessment or as a component of the final exam project. Additionally, a CD with executable copies of the VIs makes it extremely simple to do laboratory exercises at home. Actually, the only program needed is the LabVIEWTM Run-Time Engine, which may be downloaded for free from NI's website.

CONCLUSIONS

In order to provide students a better grasp of communication systems, devices, and equipment, the educational virtual laboratory utilized for practical exercises in the telecommunication engineering courses mentioned above was created. Additionally, it was designed to enable measurements on both synthetic and real-world data using (virtual) instruments. The teachers discovered that the VI approach perfectly satisfies the objectives of the educational project, allowing the students to fully understand the behavior of a communication system and the operation of a measurement test-bench, which in traditional educational activities would be based on real physical equipment, even though there is no "physical" contact between the operator and the system/equipment. The configuration of the test-bed is the only important detail omitted. Fortunately, the preparation of the experimental setup often only entails connecting a few wires in the case of communication systems (see, for example, Fig. 6), so it does not pose a significant constraint. Some assessment and evaluation results from the questionnaires given to the Master's students at the conclusion of the 2003–04 and 2004–05 academic years are shown in Table 3.

Table 3Statistical data from the evaluation questionnairesabout the VI-based laboratory exercises in the ‘TransmissionSystems Design' course (population: about 60 students peracademic year)

Description	Average rating (1=worst, 4 =best)	
	2003/04	2004/05
Effectiveness of laboratory activities	3.75	3.83
Interest in laboratory activities	3.27	3.42
Overall rating of laboratory activities	3.52	3.58

VI software tools were heavily used in the teachings and lab activities of the "Transmission Systems Design" course, which was taken by degree students (about 60 students every academic year). The results show that the students' opinions on the effectiveness of VI-based instruction were overwhelmingly favorable and supportive. The primary takeaway from this study, according to the authors, is that students are very interested in lab exercises. This is particularly evident when compared to the previous educational strategy, which relied on less engaging (and thus far more dull) classroom demonstrations of single-copy instruments. Another lesson learned is that the visual interfaces of the VIs play a significant role in giving students the impression that they are working with actual equipment rather than a software tool. According to this perspective, using too many "software-oriented" elements, including dialog boxes, pop-up menus, and the like, is not the best way to create realistic instrument panels. The suggested educational system exhibits several more advantageous qualities in addition to all of the previously mentioned favorable attributes. First, it enables students who are unable to attend a classroom (for example, because of sickness or disability) to participate in experimental laboratory practice. Additionally, upgrading the experimental setups at a reasonable cost is made possible by using a VI-based laboratory. The test benches and instrument simulators may really be readily reprogrammed or re-configured to support any telecommunications standard, present or future, including IEEE 802.11 wireless networks and cellular 2G, 3G, 4G, and beyond [9–10]. In the realm of telecommunications engineering, this even makes it feasible to predict how future systems will operate.

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