

A Virtual Educational Laboratory for Telecommunications Engineering*

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We present a virtual educational laboratory that allows the simulation of communication systems, equipment, devices, and measuring instruments, developed by using the software environment LabVIEW™ from National Instruments. The system, which fulfills the need for a flexible and low-cost educational tool for laboratory practice, is being used in the Laboratory of Telecommunications and Applied Electromagnetics of the Engineering College of the University of Pisa, Italy.

Keywords: Communication engineering education; e-learning; virtual laboratories

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 inexpert 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-1990s, devoted itself to the development of multimedia teaching activities [1]. They have developed a project for realizing 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]. The proposed educational approach is based on a set of suitable software interfaces, named virtual instruments (VIs), which are able to simulate/emulate hardware instruments, and represents a viable and very attractive alternative to conventional laboratory practice, which requires a large amount of (costly) hardware equipment. The aim

of the project is thus to allow the students to perform experiments, either in their college labs or at home, without the need for measurement 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 that is also very popular for both industrial and educational applications, and there are a many published papers dealing with the latter applications. Restricting our attention to some significant educational experiences in the field of information engineering disciplines found in the literature, we recall here, as examples: an interactive virtual laboratory for electronic, and engineering education, which allows both virtual simulation and real-time measurement [11], a system for power measurement on non-standard waveforms using VIs for both signal generation and measurement [12], an audio file processing system capable of loading externally generated files [13], a tool for importing and processing digital logic circuit data [14], and a set of VIs for acquiring and processing laboratory signals [15].

This paper, presents a LabVIEW™-based virtual laboratory that has been realized, which includes a large variety of interactive applications to emulate telecommunication systems and to simulate the different functions of measurement set-up. The educational virtual laboratory presented below was conceived 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;

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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 paper is hosted in the educational Laboratory of Telecommunications and Applied Electromagnetics and is used by the students attending the Bachelor and Master Degree Programs in Telecommunications Engineering. Table 1 shows the availability of VI

Table 1. Courses of the Bachelor Degree (top) and the Master Degree (bottom) at the Engineering College of the University of Pisa, Italy, which have educational applications (VIs) available, or planned

BACHELOR DEGREE IN TELECOMMUNICATIONS ENGINEERING	
Course	VIs
Electrical Engineering	<i>Planned / Under development</i>
Signals and Systems	<i>Planned / Under development</i>
Electromagnetic Fields	<ul style="list-style-type: none"> • Transmission Line Impedance Matching Simulator • Time-Domain Transmission Line Simulator
Telecommunication Networks	<i>Planned / Under development</i>
Probability and Stochastic Processes	<i>Planned / Under development</i>
Digital Signal Processing	<i>Planned / Under development</i>
MASTER DEGREE IN TELECOMMUNICATIONS ENGINEERING	
Course	VIs
Communication Systems	<ul style="list-style-type: none"> • AM Modulation • Angle Modulation • Coherent Detection • Costas Loop • FM-PM Modulations • PCM-DPCM-DM Toolkit
Teletraffic Engineering	<i>Planned / Under development</i>
Antennas and Propagation	• Linear and Planar Array Simulator
Statistical Signal Processing	<i>Planned / Under development</i>
Digital Communications	<ul style="list-style-type: none"> • BER, Eb, No • Correlation • DPSK Modulation • PAM Modulation • PSK Modulation • QAM Modulation • Viterbi Processor
Measurements on Telecommunication Equipments	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<i>Planned / Under development</i>
Image Processing and Transmission	<ul style="list-style-type: none"> • Dual Image Analyzer • Image Analyzer
Radar Technique	<i>Planned / Under development</i>
Remote Sensing Systems	<i>Planned / Under development</i>
Design and Simulation of Telecomm. Networks	<i>Planned / Under development</i>
Optimization of Telecommunication Networks	<i>Planned / Under development</i>
Switching and Routing	<i>Planned / Under development</i>
Telematics	<i>Planned / Under development</i>
Design and Simulation of Transmission Systems	<ul style="list-style-type: none"> • File Transmission System • Digital Oscilloscope Agilent 54641A Emulator • Digital Transmission Analyzer HP 3784A Emulator • Measurement Instruments
Optical Communications	<i>Planned / Under development</i>
Radio Systems Engineering	<ul style="list-style-type: none"> • CDMA • Signature of a Microwave Radio Link
Wideband Communications	<ul style="list-style-type: none"> • CDMA • Coded System
Wireless Communications	<ul style="list-style-type: none"> • GSM Vocoder • Multipath PAM Modulation • Multipath PSK Modulation • Multipath QAM Modulation

educational applications for both degree courses. As one can see, many courses already have VI applications available, and many other VIs are planned or are under development.

THE SOFTWARE ENVIRONMENT

The software-based components of the virtual laboratory were assembled using LabVIEW, a development environment from National Instruments (NI) [4], which allows a very flexible design, supports interactivity, and makes available a wide range of signal and data processing functions (e.g., see [11–15]). Thanks to these appealing peculiarities, a virtual laboratory that encompasses many interactive applications for software simulation of communication systems was developed at the Engineering College of the University of Pisa. These interactive applications reproduce the functionality of equipment and workbenches with a high degree of fidelity, giving the operator VIs with dials, buttons, selectors, indicators, meters, graphs and so on. This allows easy parameter setting and signal measurement with (virtual) oscilloscopes, spectrum analyzers, power meters, etc. The applications of the virtual laboratory were written with LabVIEW™ and are available for both Windows and Mac OS X systems. Moreover, a portable stand-alone version of the applications on CD, implemented with LabVIEW™ Application Builder, is also distributed to students, allowing them to do the exercises in the classroom or at home, simply by installing LabVIEW™ Run-Time Engine, which is freely available from NI's Website [4].

THE VIRTUAL INSTRUMENT TOOLS

Concept of VI-Based Exercises

The virtual instruments (VIs) are PC software tools, made using LabVIEW™, featuring one, or more, of the following functions: signal generation, signal processing, and signal measurement (e.g., see [5] and [12]). A broad set of VIs has been developed in order to encompass a variety of applications that are of interest to telecommunica-

tion students, including source and channel coding, transmission systems, with either analog or digital modulations, antennas and microwave devices, and image processing algorithms. The concept of such a VI-based exercise is illustrated in Fig. 1. It shows a PC equipped with a library of VI applications (the complete list is given in Table 2), accessing a library of files containing the source data to be processed/measured. VI applications also provide output data files containing the results of the processing/measurement.

Generation of VIs source data files

A fundamental feature of the virtual laboratory under analysis is that it allows one to perform exercises using 'virtual instruments' that use 'real world' data. Actually, the VIs enable the PC to act very like a 'physical' instrument performing (off-line) measurements and processing (previously acquired) physical signals and measured data. Somewhat similar features can be found, for instance, in the educational systems described in [13–15]. As can be seen from Fig. 2, four different types of data can be given to the virtual lab. The first type, denoted (A), are physical signals which come from sources such as sensors, microphones, cameras, or lab generators of testing signals. They are sent to the PC through standard audio/video

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

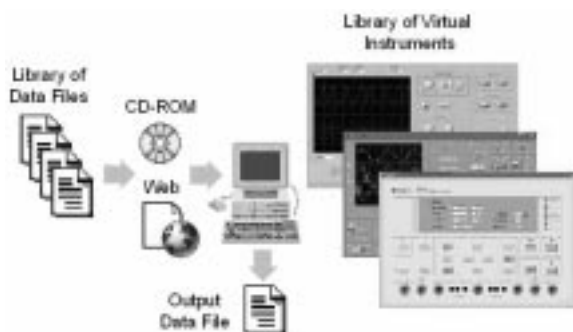


Fig. 1. The concept of a VI-based exercise.

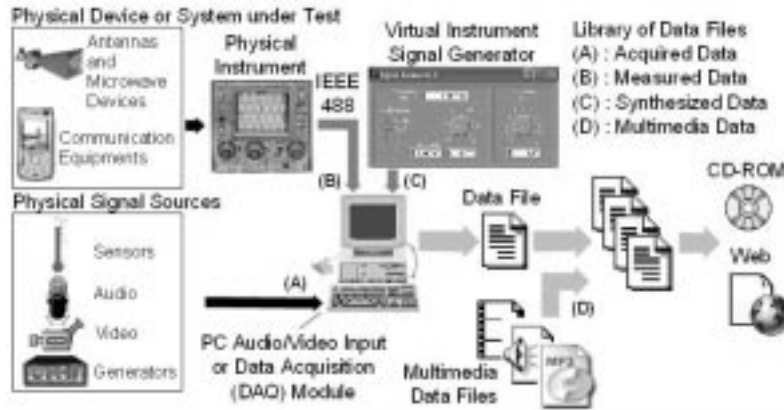


Fig. 2. Generation of source data files provided to the VIs.

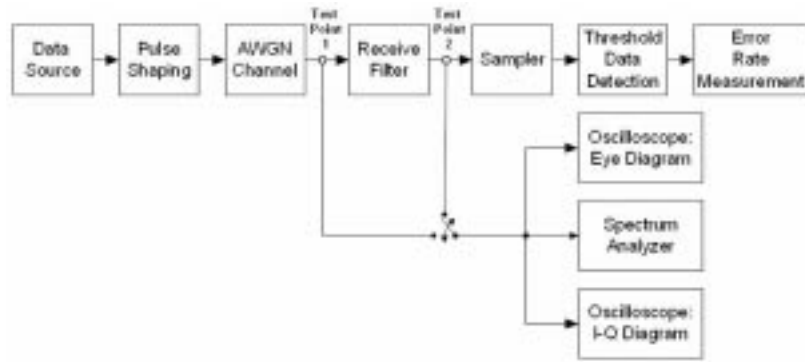
(A/V) inputs, or, if required, a data acquisition (DAQ) module with analog-to-digital conversion (ADC). The second type of data, denoted (B), is measurement results from real instruments, such as a digital oscilloscope or a vector network analyzer. These data are, maybe after some processing, sent to the PC via a standard IEEE 488 interface bus [6]. In this way, for example, the S-parameters of any real microwave device or antenna can be measured and passed to the PC. In the third case, thanks to dedicated VI applications, the PC itself acts as a fully-software waveform generator and synthesizes a discrete-time version of some type of signal, denoted (C). For example, the VI can be used to synthesize the UMTS signal or the transient along a loaded transmission line. In any case, the acquired, measured, or synthesized data are eventually stored in a file and added to a library of signals that can also include multimedia files (D). The data file library is made available, for example, via CDs or the Website of the multimedia education group [1], to the students for subsequent off-line processing through the VIs. Notice that the data acquired by measurements (i.e., type B) are actually stored in special format files that are instrument-dependent.

VIs for system simulation

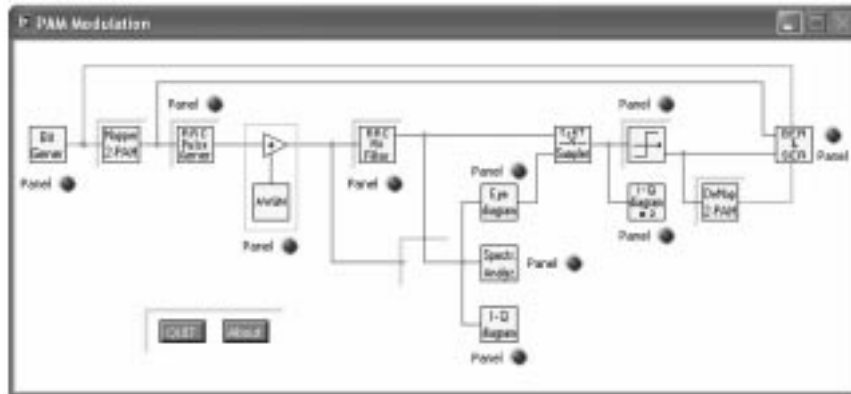
Most of the applications available in the VI library set (see Table 2) are 'test-benches' that simulate a complete transmission system, allowing easy interactive parameter settings and detailed signal monitoring capabilities. In particular, some such simulator VIs were found to be especially effective for the teaching, through simulation, of some concepts, such as multipath radio propagation and modulated signal detection. These would otherwise require very complex experimental set-ups, well beyond the hardware resources commonly available in college and university teaching labs.

To give an example, a brief description of one such 'test-bench' simulator, namely 'PAM Modulation', that features a complete digital transmission system employing Pulse Amplitude Modulation (PAM) [7], is described. Figure 3

shows a conceptual block diagram of the simulated system (top) and the interactive main panel of the relevant VI simulator (bottom) for a configuration with a 2-PAM transmission, Root Raised Cosine (RRC) pulse shape and receive filter matched to transmit the pulses. As can be seen from the figure, the transmitter section of the simulator includes a data source generator ('Bit Gener' in the VI simulator) followed by a mapper, which allows the modulation format to be selected from 2-, 4-, and 8-level PAM, and a shaping filter for pulse generation. The channel is modeled as Additive White Gaussian Noise (AWGN). The receiver is made of a filter, a sampler, a threshold detector, and a de-mapper module, followed by a bit/symbol-error rate meter. For most of the simulator blocks (such as the mapper, the pulse generator, the receive filter, the symbol threshold detector, and the de-mapper) the interactive VI panel allows one to select the desired type from different available options. In addition, a set of virtual measuring instruments, including an oscilloscope that plots the 'eye diagram' of the signal [7], a spectrum analyzer for frequency-domain signal analysis, and an oscilloscope operating in x - y mode, which plots the 'phasor diagram' (or ' I - Q diagram') of the signal symbol constellation [7], yields accurate signal monitoring at some significant (selectable) test points. Furthermore, by clicking on the LED buttons labeled 'Panel', which are placed next to each block representing a device or an instrument in the interactive VI diagram (Fig. 3), the user can open the relevant control panel. For example, Fig. 4 shows the control panels of the eye diagram oscilloscope (top left), the phasor diagram oscilloscope (top right), the pulse generator (bottom left) and the channel noise generator (bottom right). As shown in the figure, the panels reproduce the appearance of the real instruments with all the relevant controls and indicators, and give the operator the feeling that they are using a physical instrument. For instance, the pulse generator allows one to set the roll-off of the RRC pulse and its duration. Also, the Gaussian generator simulates a realistic transmission channel, which adds noise to the transmitted signal and



(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).

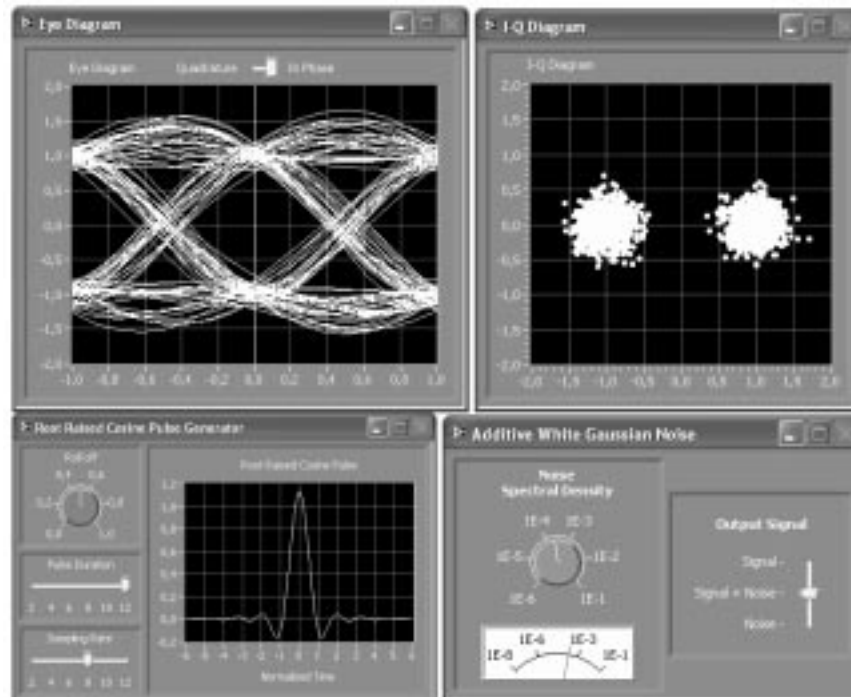


Fig. 4. Front panels of some blocks of the 'PAM Modulation': eye diagram (top left), phasor (or $I-Q$) diagram (top right), pulse generator (bottom left) and channel noise generator (bottom right).

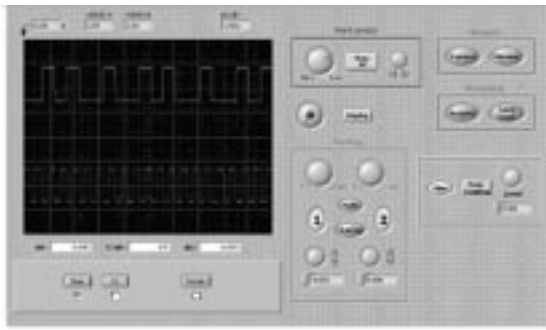


Fig. 5. The digital oscilloscope Agilent 54641A displaying two digital waveforms (left) and its VI panel (right).

allows one to set the operating Signal-to-Noise power Ratio (SNR).

VIs emulating real world instruments

The wide range of graphical tools available from LabVIEW™ to build realistic VI panels was exploited to develop a set of software emulators of real instruments to perform measurements on communication equipment and microwave devices. Such software tools fully emulate the appearance and the functionalities of physical instruments, and process real world measured data, which are loaded from external files acquired

as described in the section above ('Generation of VIs source data files'—Type (B) data files).

Figure 5 shows the digital oscilloscope Agilent 54641A displaying a digital waveform and its clock signal (left), and the control panel of the relevant VI application (right). Besides the customary oscilloscope functionalities (e.g., amplitude and time scale settings, trigger controls, etc.), the VI software application has many additional features for off-line processing of the acquired waveforms, such as signal sum and product, FFT and statistical analysis. Furthermore, after being processed, the waveforms can be exported in text format.

Figure 6 shows the vector network analyzer (VNA) Anritsu Wiltron 37311A performing measurements on a microwave patch antenna (left), and the control panel of the relevant VI application (right). The panel of the VI is divided into two main parts: on the left are two graphs showing the log-magnitude and the phase of the reflection coefficient of the device under test and some graphic display controls. As an alternative, a Smith Chart representation can also be used. VNA controls are placed on the right side of the panel.

Figure 7 shows the digital transmission analyzer HP 3784A (left) and the control panel of the relevant VI application (right). This analyzer features both a transmitter and a receiver, which can be configured for several digital signal formats.

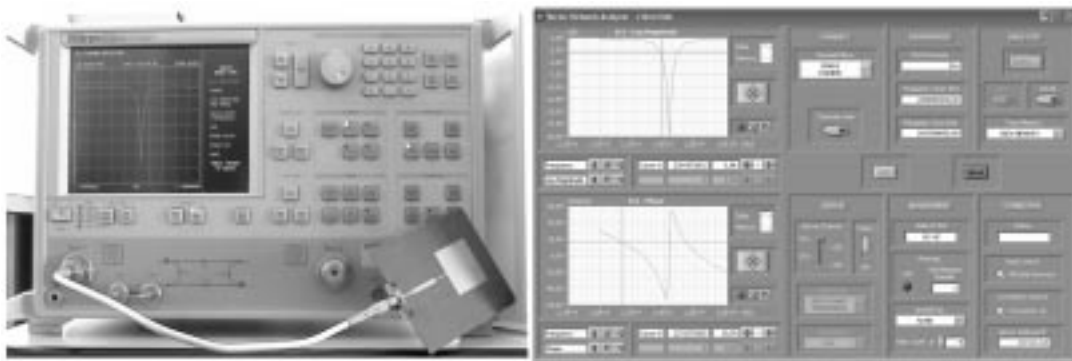


Fig. 6. The vector network analyzer Anritsu Wiltron 37311A performing measurements on a microwave patch antenna (left), and its VI panel (right).



Fig. 7. The digital transmission analyzer HP 3784A (left), and its VI panel (right).

Moreover, the analyzer performs a great deal of statistical analysis of the received data stream, such as bit and code error rates, errored and error-free seconds, and so on. All of these measurements are conveyed to the operator through the VI and can be used for post-processing, such as plotting error rate charts, evaluating outage probability, etc.

It is worth remarking that, as an added-value feature, all of the VI applications described above also allow the remote-control of the physical instruments via a standard IEEE 488 bus. This can be done by connecting the controlling PC to the instrument either through a direct connection or through a TCP/IP network [8, 16–17].

EDUCATIONAL ACTIVITIES WITH THE VIRTUAL LABORATORY

An interactive laboratory exercise involving the use of virtual test-benches or instruments is usually carried out in two steps, as described below.

1. *Training phase* A typical laboratory exercise starts with a 'Training Phase', lasting about 30–40 minutes, wherein the teacher demonstrates the functioning of the virtual test-bench or instrument to the students.
2. *Active learning phase* At the end of the Training Phase, the teacher gives the students worksheets. The students are thus requested 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 E_b/N_0 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

E_b/N_0 (dB)	BER	Tx Bits	Errors	Accuracy
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

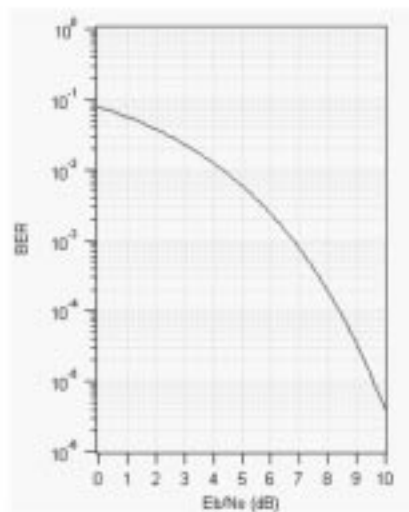


Fig. 8. Worksheet for laboratory exercises.

form measurements using the VI, just as if they were using the real equipment, and to report procedures, instrument set-ups and measured data on the worksheet. Figure 8 shows a sample worksheet of the exercise based on the 'PAM Modulation' application described above; the exercise is aimed at assessing the quality of a digital transmission system, expressed in terms of bit-error rate (BER), in the presence of some impairment (a clock offset, in this particular case). The students are then asked to use the VI panels to perform BER measurements, to fill in the table worksheet with the measured data and to plot the BER results on the blank chart on the worksheet.

This kind of test can be used as a mid-term evaluation or can represent a part of the final examination project. In addition, laboratory practice can also be very easily carried out at home using a CD with executable versions of the VIs. In fact, the only software requirement is the installation of the LabVIEW™ Run-Time Engine, freely downloadable from NI's Website.

CONCLUSIONS

The educational virtual laboratory used for experimental exercises in telecommunication engineering courses outlined above was designed to provide students with an understanding of communication systems, equipment, and devices. It was also intended to allow the use of (virtual) instrumentation for measurements on both synthetic and real world data.

Despite the lack of 'physical' contact between the operator and the system/equipment, the teachers found that the VI approach perfectly fulfils the goals of the educational project, allowing the students to fully understand the operation of a measurement test-bench and the behavior of a communication system, which in conventional educational activities would be based on real physical equipment. The only significant aspect that is left out is the arrangement of the test-bed. Fortunately, in the case of communication systems, the preparation of the experimental set-up usually only consists of connecting some cables (see, for instance Fig. 6) and therefore it does not represent a severe limitation. Table 3 presents some assessment/evaluation data obtained from the questionnaires distributed at the end of the academic years 2003/04 and 2004/05 to the Master

Table 3 Statistical data from the evaluation questionnaires about the VI-based laboratory exercises in the 'Transmission Systems Design' course (population: about 60 students per academic 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

Degree students (about 60 students per academic year) who attended the 'Transmission Systems Design' course, which massively used VI software tools during lessons and laboratory exercises. As one can see from the ratings, the students gave very positive and encouraging feedback about the effectiveness of VI-based teaching. The main lesson that the authors learnt from this research is that the students' have an enthusiastic interest in lab exercises, a result which is especially striking if one compares it with the former educational approach based on less involving (and therefore much more boring) classroom demonstrations of single-copy instruments. Another lesson learnt is the major role played by the appearance of the VIs' graphic interfaces, in that the students work with the feeling that they are in front of real equipment, instead of a software tool. This consideration suggests that in order to take the maximum care in building realistic instrument panels, one should avoid too many 'software-oriented' objects, such as pop-up menus, dialog boxes, and so forth. In addition to all the positive properties described above, the proposed educational system reveals many other beneficial features. First, it allows experimental laboratory practice to be carried out by students who can not attend a classroom (for instance due to illness or disability). Also, the use of a VI-based laboratory allows low-cost upgrades of the experimental set-ups. In 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 in the future, such as cellular 2G, 3G, 4G and beyond, or the IEEE 802.11 family of wireless networks [9–10]. In this way, it even becomes possible to foresee the performance of future systems in the field of telecommunications engineering.

REFERENCES

1. Website of the Multimedia Education and e-Learning Activities Group, at the University of Pisa: <http://www.tlc.ing.unipi.it/e-learning>
2. Website of the Telecommunication Engineering at the University of Pisa: <http://www.tlc.ing.unipi.it>
3. LabVIEW User Manual, National Instruments, (2005).
4. Website of National Instruments: <http://www.ni.com>

5. A. Ferrero and V. Piuri, A simulation tool for virtual laboratory experiments in a WWW environment, *IEEE Trans. Instrum. Meas.*, **48**(3), 1999, pp. 741–746.
6. Website of the IEEE 488 Standard: http://standards.ieee.org/reading/ieee/std_public/description/im/488.1-1987_desc.html
7. R. E. Ziemer and R. L. Peterson, *Introduction to Digital Communication*, 2nd edn, Prentice Hall, Upper Saddle River, (2001).
8. F. Giannetti, P. Nepa, M. Michelini, G. Manara and A. N. D'Andrea, An educational laboratory for telecommunications engineering based on TCP/IP remote instrument control, *IADAT International Conference on Education e-2005*, Biarritz, (2005), pp. 180–184.
9. R. Berezdivin, R. Breinig and R. T. Raytheon, Next-generation wireless communications concepts and technologies, *IEEE Communications Magazine*, **40**(2), 2002, pp. 108–116.
10. S. Y. Hui, K. H. Yeung, Challenges in the Migration to 4G Mobile Systems, *IEEE Communications Magazine*, **41**(12), 2003, pp. 4–59.
11. Zhou Yi, Jiang Jian-Jun and Fan Shao-Chun, A LabVIEW-based interactive virtual laboratory for electronic and engineering education, *Int. J. Eng. Educ.*, **21**(1), 2005, pp. 94–102.
12. Jack Denton and Elaine Cooney, Power measurements: simulations and measurement, *Int. J. Eng. Educ.*, **21**(1), 2005, pp. 6–32.
13. Dale H. Litwhiler, Listening to PSpice simulations with LabVIEW, *Int. J. Eng. Educ.*, **21**(1), 2005, pp. 19–25.
14. Jay R. Porter and Sanjay Tumati, Using simulation tools to verify laboratory measurements, *Int. J. Eng. Educ.*, **21**(1), 2005, pp. 11–18.
15. Dale H. Litwhiler, More meaningful PSpice simulations via LabVIEW, *Int. J. Eng. Educ.*, **21**(1), 2005, pp. 3–10.
16. Jim Henry and Charles Knight, Modern engineering laboratories at a distance, *Int. J. Eng. Educ.*, **19**(3), 2003, pp. 403–408.
17. Ingvar Gustavsson, A remote access laboratory for electrical circuit experiments, *Int. J. Eng. Educ.*, **19**(3), 2003, pp. 409–419.

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