Int. J. Engng Ed. Vol. 16, No. 6, pp. 553–559, 2000
Printed in Great Britain.

0949-149X/91 $3.00+0.00

A New Digital Communications Course Enhanced by PC-Based Design Projects*

K. M. S. SOYJAUDAH and M. I. JAHMEERBACUS
Department of Electrical and Electronic Engineering, Faculty of Engineering, University of Mauritius.
E-mail: eeass@uom.ac.mu

Typical undergraduate study programs in digital communication systems (DCS) include a wide range of lecture topics that cover all stages of the system from information source to information sink. However, common practical programs in DCS are aimed more towards helping students to understand theoretical material, rather than providing them with the necessary design experience. In this paper we describe a new approach for giving students hands-on experience in the design of specific parts of a communication system through PC-based projects. The implementation of such a scheme in the existing curriculum is shown to be readily feasible, and its benefits to engineering education are also demonstrated.

INTRODUCTION

MANY electrical engineering curricula are constantly being upgraded so as to reflect the importance of digital communications in an increasing range of applications. As such, typical undergraduate courses in communication engineering include extensive coverage of topics like data formatting, source and channel coding, encryption and modulation techniques. However, students should not only master the different schemes at each stage of signal transformation, but more importantly, they should be given the necessary foundation in designing working systems later as engineers. Fulfilment of the later objective remains a major educational challenge since the setting up of comprehensive design-oriented practical programs in digital communications may be financially prohibitive for many institutions. Quite often, students are placed on short industrial attachment so that they may gain design experience. However the perceived jump from an academic to an industrial environment does not always guarantee that students will acquire the necessary confidence and understand the goals of the communication systems designer.

With the aim of enhancing the design component in the digital communication systems modules, a combined theory, design and simulation course has been introduced in our curriculum. The benefits of using computer-aided learning in many fields of electrical engineering are well-established [1, 2]. In the proposed study program, students are given a broad base in digital communications over one semester, and then assigned PC-based design projects on specific parts of a communication system over the following semester. The projects are devised so that students can fully explore the possible implementation alternatives, as well as understand how to achieve the best trade-offs for a given scheme. Apart from considerably improving their understanding and interest in the subject, this new course has also developed interpersonal skills and teamwork [3, 4] within the class, qualities which are essential in making engineers effective in industry. Moreover, most of the projects require commonly available computer facilities and can be readily implemented in typical undergraduate programs.

DIGITAL COMMUNICATION MODULES

The digital communication modules are covered in two semesters during the final year of a four-year B.Eng. (Hons.) course. As a pre-requisite to the modules, students are expected to be already familiar with Fourier transforms, convolution, random processes, analogue communication systems and programming with C. In fact these topics are thoroughly covered during the first and second years of the degree program. The approach we have adopted is to provide students with a broad picture of the complete communication system by tracing through the main stages from the information source to the information sink, as shown in Fig. 1.

First semester DCS module

The main topics [5] covered in a 45-hour DCS module over the first semester are outlined as follows:

- *Message formatting:* character coding, sampling, quantisation, PCM.
- *Source coding:* Huffman coding, arithmetic coding, run length coding.
- *Error control coding:* linear block codes [6, 7], cyclic codes and convolutional codes.

* Accepted 12 December 1999.

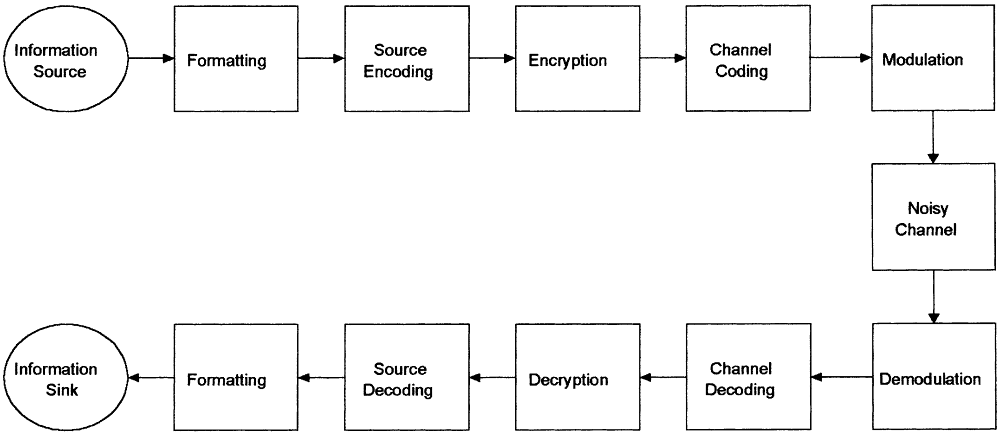

Fig. 1. Functional block diagram of a digital communication system.

- *Digital modulation techniques:* PSK, FSK, ASK and APK, higher order QAM techniques, signal constellation and decision boundary, trade-off between coding and modulation.
- *Data encryption techniques:* data encryption standards, stream encryption techniques, public key cryptosystems.

Second semester module

The second semester DCS module is also of 45 hours duration, with the following topics:

- *Communication links analysis:* link budget analysis, noise figure, noise temperature and system temperature, sample link analysis.
- *Terrestrial microwave digital radio system:* design guidelines, system parameters and reliability objectives.
- *Digital satellite communication systems:* satellite system configuration, transponders, bandwidth and power limitations, power amplifiers, multiple access techniques.
- *Optical fibre communication systems:* optical transmitters and receivers, coherent optical communication.

DESIGN PROJECTS

By the beginning of the second semester, students are divided into a set of teams of four to five students and each group is assigned a PC-based design and implementation project, based on the material they have studied in the previous semester. A class is typically forty to fifty students and the groups are formed so that they exhibit a fair degree of diversity in terms of student academic performance and personality type. The projects are selected so that they have more or less the same level of complexity and can be completed within fifteen weeks. An academic supervisor is responsible for guiding and monitoring each team during the course of the project. Each student spends an average of four hours weekly on the project, out of which at least two hours are reserved for software design. The computer projects laboratory currently hosts over fifty PCs, each being equipped with the standard Windows applications and Turbo C++ compiler. The laboratory also remains accessible to students outside lecture hours and they are given a tentative schedule, as shown in Table 1, to help them plan, organise and complete their project within a fifteen-week period.

A sample list of projects and brief description is given below.

Project #1: Design and implementation of convolutional codecs using hard and soft decision Viterbi, decoding, and study of their performance in Gaussian channels

- *Objectives*: It is required to simulate convolutional codecs (i) with hard decision Viterbi decoding and (ii) with soft decision (using quantisation) maximum likelihood decoding.
- *Methodology:* Implementation of a pseudo-random sequence generator, convolutional encoding of the bit sequence using a rate 1/2 convolutional encoder, generation and addition of additive white Gaussian noise (AGWN) to the encoded bits, decoding of the corrupted information successively using hard decision and soft decision Viterbi decoding. Evaluation of the bit error rate (BER)

Table 1. Recommended time schedule for design project

Week	Activities
1–3	Perform literature survey Investigate possible solutions and finalise implementation method
4–7	Software design Start report writing
8–13	Software implementation and testing
14–15	Complete final report and prepare PowerPoint presentation

- *Results:* To be presented in terms of plots of BER against signal-to-noise ratio per bit (SNR/bit).

Project #2: Comparative study of convolutional codecs using Viterbi, Stack and Fano decoding

- *Objectives*: To simulate convolutional codecs with three types of decoding, namely Viterbi, Stack and Fano decoding and compare their performances.
- *Methodology:* Implementation of a pseudorandom sequence generator, convolutional encoding of the bit sequence using a rate 1/2 convolutional encoder, generation and addition of additive white Gaussian noise (AGWN) to the encoded bits, decoding of the corrupted information using successively Viterbi, Stack and Fano algorithms. Evaluation of the bit error rate (BER).
- *Results:* To be presented in terms of plots of BER against signal-to-noise ratio per bit (SNR/bit).

Project #3: Design and implementation of linear block codes and evaluation of their performances in AWGN channels employing trellis decoding

- *Objectives:* To simulate and compare the performances of linear block codes using trellis decoding in AGWN channels.
- *Methodology*: Programs to generate a pseudorandom sequence, to encode the bits using the corresponding block code, to generate and add AWGN to the encoded bits, to perform soft decision trellis decoding on the corrupted information, and to compute the BER for each SNR/Bit.
- *Results*: Illustrate the performance of these block codes using graphs of BER against SNR/bit.

Project #4: Design and implementation of Huffman data compression encoder/decoder in a AWGN channel

- *Objectives:* To investigate the compression of a data file using Huffman compression/decompression technique (i) in the absence of AWGN and (ii) in the presence of AWGN.
- *Methodology:* To write programs for (i) scanning a data file (ii) evaluating the probability of occurrence of each symbol in the file, (iii) construction of the Huffman tree, (iv) generation of a code table and compression of the data file, (v) reconstruction of the Huffman tree, (vi) decompression of the file and evaluation of the percentage compression of the algorithm for different file sizes. The effect of adding AWGN to the compressed bits on the BER for different SNR/bit should also be studied.
- *Results:* The following graphs need to be shown: (1) percentage compression vs. file size and (2) BER vs. SNR/bit

Project #5: Design and implementation of trellis coded modulation codecs employing convolutional codes and MPSK modulation

- *Objectives:* To design and implement TCM codecs employing convolutional codes and MPSK modulation and to evaluate and compare their performances in AWGN channel.
- *Methodology:* Software implementation of a pseudorandom sequence generator, a combined convolutional encoder and an MPSK modulator, generation and addition of AWGN to the MPSK symbols, combined decoding/demodulation of the received data using trellis decoding. The CCM codes are to be compared with the corresponding uncoded case and the effect of increasing order of modulation on the block codes should also be investigated.
- *Results:* Plot of BER against SNR/bit for the various MPSK schemes used.

Project #6: Design and implementation of block coded modulation (BCM) schemes using linear block codes and MPSK modulation

- *Objectives:* To design a block coded modulation scheme using block codes and MPSK modulation and to evaluate their performances in AWGN channels.
- *Methodology:* Software implementation of a pseudorandom sequence generator, a linear block code encoder, an MPSK modulator, generation and addition of AWGN to the MPSK symbols, combined decoding/demodulation of the received data using trellis decoding. The BCM codes should be compared with the corresponding uncoded case and the effect of increasing order of modulation on the block codes should also be investigated.
- *Results:* Plot of BER against SNR/bit for the various MPSK schemes used.

Project #7: Software design and implementation of self-synchronous stream ciphers and convolutional codecs

- *Objectives:* To design and implement self-synchronous stream ciphers and convolutional codecs.
- *Methodology:* Programs to generate a pseudorandom sequence generator, encrypting the bit sequence using self-synchronous ciphers, convolutional encoding of the encrypted bits using a constraint length 6 rate 1/2 convolutional encoder, generation and addition of AWGN to the channel encoded bits, decoding the received bits using a Viterbi decoder and decryption of the channel decoded bits.
- *Results:* Graphical representation of (a) degradation vs. BER and (b) BER vs. SNR/bit curves for (i) uncoded bits with encryption and (ii) coded bits using (2,1,6) convolutional encoder with encryption.

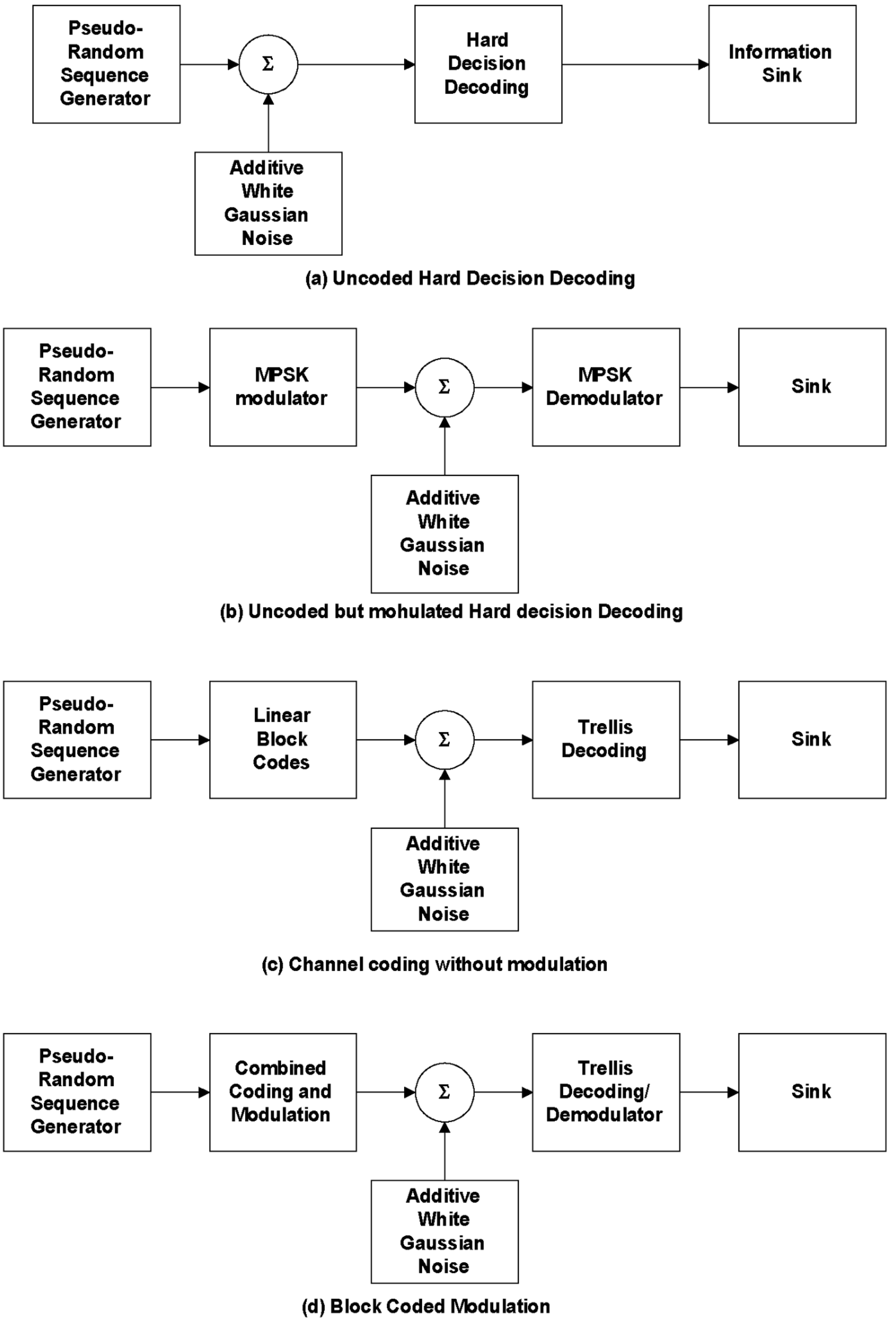

Fig. 2. Block diagrams of systems to be implemented for Project #6.

Project #8: Design and implementation of a secure data transmission scheme employing DES and RSA algorithms

- *Objectives:* To design and implement a secure data transmission scheme by combining the advantages of the DES and the RSA algorithms.
- *Methodology:* To scan a text file and encrypt it by combining the advantages of the data encryption standard (DES) and the Rivest-Shamir-Alderman (RSA) schemes in such a way that transmission of the DES key is not required. The encrypted file is then transmitted. At the receiver it is required to decrypt the crypted file using the reverse operations.
- *Results:* To display a small text file to be encrypted, the encrypted file and the decrypted file.

DETAILED PROJECT DESCRIPTION

In order to illustrate the educational benefits derived from this method we shall describe Project #6 in greater detail.

The aim of this project is to enable students to have hands-on experience on:

- the effects of channel noise and its effects on data transmission;

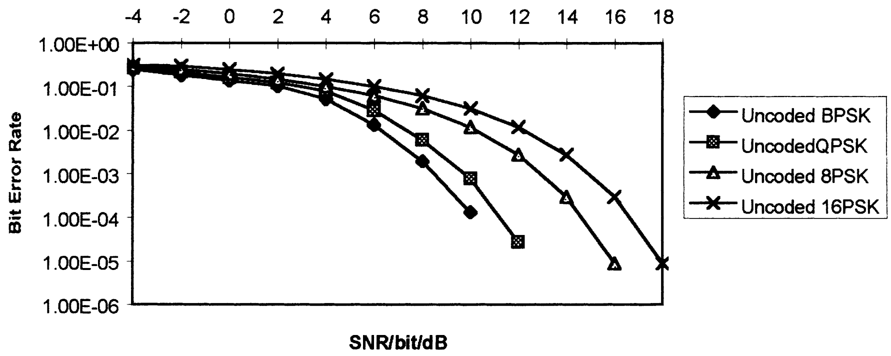

Fig. 3. Performance of uncoded MPSK modulation in AWGN channel.

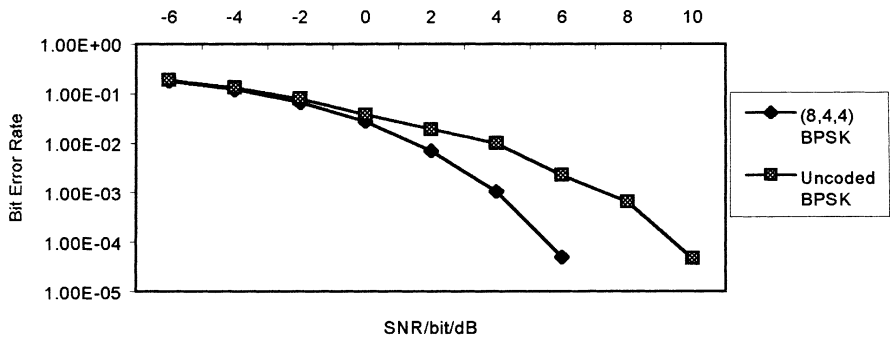

Fig. 4. Performance of coded and uncoded BPSK.

- the effect of modulating the uncoded data in a noisy channel;
- the correction of errors caused by noise by adding controlled amount of redundancy through the use of linear block codes;
- the effect of combining a linear block code with MPSK modulation in a noisy channel;
- the trade-off between coding and modulation.

The project is divided into four parts:

1. The generation of AWGN and evaluation of its effect on the performance during data transmission using hard decision decoding.
2. Study the performance degradation produced by modulation of the uncoded data in a noisy channel using MPSK modulation.
3. Study of the performance improvement produced by employing a linear block channel code during data transmission in a noisy channel.
4. Study of the effect of combining MPSK modulation with a linear block code in the noisy channel.

The four schemes to be implemented are illustrated in Fig. 2. Students are expected to write programs in C to implement a pseudo random sequence generator, a Gaussian noise generator, a hard decision decoder, linear block code encoders and decoders, MPSK modulators and demodulators. The performances of the different schemes in terms of plots of BER against SNR/bit should also be presented graphically.

In working through the projects students understand the need for reducing errors when transmitting data through a noisy channel through the use of channel codes. They can clearly follow the performance degradation produced by employing higher order modulation in channel coded data. The performance degradation produced by combining MPSK modulation with channel coding as compared to employing channel coding alone also become obvious. Moreover students clearly understand the trade-off between performance, modulation and bandwidth.

DISCUSSIONS OF RESULTS

The results, Figs 3 to 6, of the project are illustrated in terms of graphs of bit error rate against signal-to-noise ratio per bit.

From all the graphs it is seen that as the amount of channel noise becomes negligible the BER falls to zero. In Figs 3 and 6 it is shown that as the order of the modulation increases the performances deteriorate both in cases of uncoded MPSK as well as for the block coded modulated system. The effect of employing linear block codes is shown in Fig. 4, which compares the performance of coded BPSK employing the (8,4,4) linear block code with uncoded BPSK. The superior performance of the coded BPSK over the corresponding uncoded case can be clearly seen. In Fig. 5 the effect of combining linear block code with QPSK is shown. Here

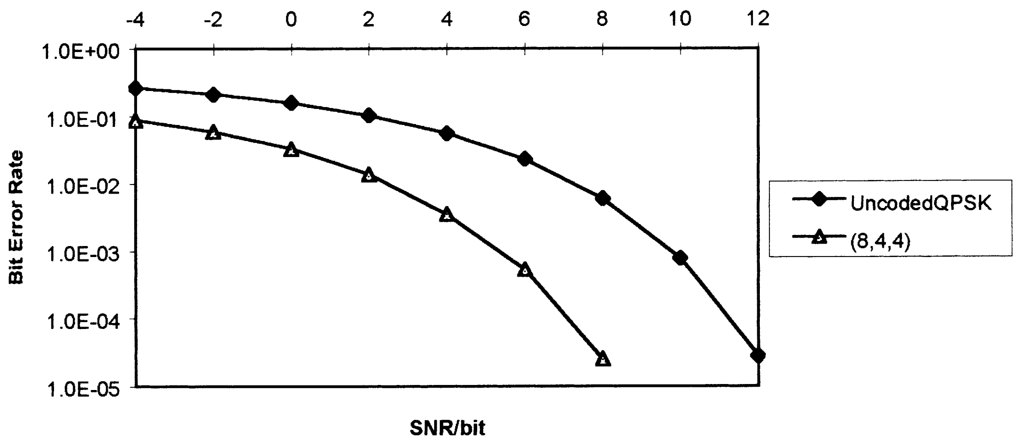

Fig. 5. Performance of the (8,4,4) linear block code employing QPSK modulation.

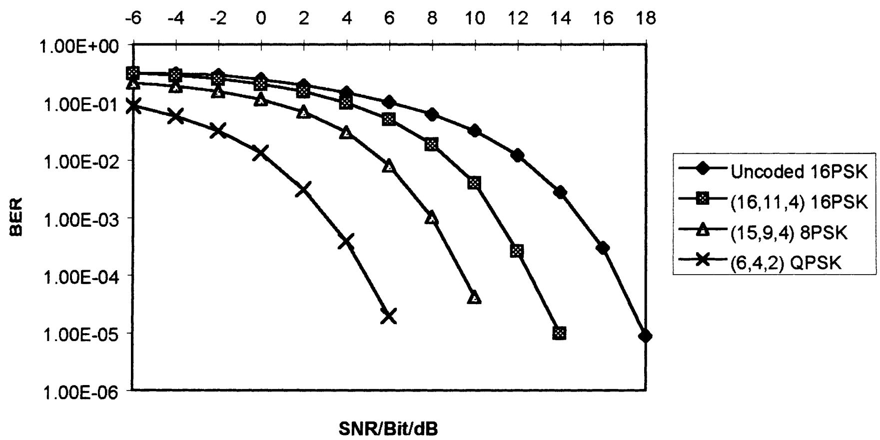

Fig. 6. Comparison of the performances of linear block codes and MPSK modulation with increasing M.

also the performance of the combined coding and modulation scheme surpasses that of the uncoded QPSK case. The trade-off between coding and modulation is also made clear. Thus students can see that, as the order of modulation increases the information transmission rate within the same bandwidth increases, but at the expense of deterioration in the BER.

The group projects culminate with the submission of a report and an oral presentation, where each team is required to demonstrate the performance of its implemented system. A report typically:

- describes the problem at hand and the objectives;
- compares the possible solutions to the given problem and justifies the choice of the proposed solution;
- presents the detailed design, implementation and testing procedures;
- compares results obtained against theory and provides recommendation for further work so as to improve the system.

Each oral presentation and demonstration lasts for fifteen minutes (plus five minutes question time) and the time allocated is equally shared among team members as far as possible. Thus, the whole class is exposed to the achievements in the various projects. Since it is important to have almost equal contribution of each team member to complete a design project in time, students realise the importance and effectiveness of teamwork. They also learn to share responsibilities, establish realistic deadlines and improve their interpersonal skills. There is near unanimity among students that the projects considerably improve their understanding of their theoretical material and their problem-solving skills.

CONCLUSIONS

This paper has described a new approach for presenting the design and simulation of digital communication systems in a communication engineering course. Such a scheme enables students to design specific parts of a communication system on a fully software-based platform. For each project, a wide range of implementation alternatives is explored by students, so that, in the process, they understand the relative merits of each scheme. At the same time they have a much better insight of how the various stages of a communication system are linked to one another. This would not have been possible if they were provided with ready-made experimental modules, which would merely enable them to observe the performance of existing set-ups.

REFERENCES

1. J. Kocijan, J. O'Reilly, W. E. Leithead, An integrated undergraduate teaching laboratory approach to multivariable control, *IEEE Trans. Educ.*, **40,** 4 (Nov. 1997).
2. K. Chau, A software tool for learning the dynamic behavior of power electronic circuits, *IEEE Trans. Educ.*, **39,** 3 (Nov. 1996).
3. C. Bhurtun, M. I. Jahmeerbacus, F. Coowar, Training programme to develop engineering skills for electrical engineering undergraduates, *4th World Conf. Engineering Education*, Minnesota, USA, 15–20 Oct. 1995.
4. J. D. Bronzino, et al., Design and teamwork: a must for freshmen, *IEEE Trans. Educ.*, **37,** 2 (May 1994).
5. B. Sklar, *Digital Communications: Fundamentals and Applications*, Prentice-Hall, New Jersey (1988).
6. H. Honary, G. Markarian and P. Farrell, Generalised array codes and their trellis structure, *Electron. Lett.*, **29,** 6 (1993) pp. 541–542.
7. B. Honary, G. Markarian and M. Darnell, Low-complexity trellis decoding of linear block codes, *IEE Proc. Commun.*, **142,** 4 (1995) pp. 201–209.

Sunjiv Soyjaudah received his B.Sc. (Hons.) degree in physics from Queen Mary College, University of London in 1982, his M.Sc. degree in digital electronics from King's College, University of London in 1991 and his Ph.D. degree from University of Mauritius in 1998. He is a chartered engineer and a member of the Institute of Electrical and Electronics Engineers (IEEE) and an associate member of the Institute of Electrical Engineers (IEE). He is presently a senior lecturer in the Department of Electrical and Electronic Engineering of the University of Mauritius. His interests are communication theory and engineering education.

Iqbal Jahmeerbacus received his B.Tech. (Hons.) degree in electrical and electronic engineering from the University of Mauritius, and his M.Sc. degree in real-time power electronics and control systems from the University of Bradford, UK. He is a member of the Institute of Electrical and Electronics Engineers (IEEE). He is presently a lecturer in the Department of Electrical and Electronic Engineering of the University of Mauritius and is also working on his Ph.D. in the fields of power electronics and control. His interests include control engineering, communication theory and engineering education.