Teaching Basis Signal Processing to Mechanical Engineering Students

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Abstract

Engineering education reform often involves some dramatic changes in the curriculum as well as new teaching time constraints. This paper presents an original approach to this double challenge:

1. How to teach ″*Introduction to Signal Processing*″ to students enrolled in ″Mechanical Engineering″ studies at a bachelor level.
2. What can you do in a one semester course consisting of only 45 minutes a week for both lecturing and laboratory work?

Since both student motivation [1] and involvement are key factors to successfully convey important new theoretical concepts, it was decided to work with them on practical situations in order to progressively answer the following question: ″What extra benefit can *Signal Processing (SP)* bring to typical *Mechanical Engineering* Applications? ″.

1. Introduction

Recently, the availability of powerful digital signal processing tools (both "off-line" and ″real-time″) prompted resurgence in popularity of theoretical work (e.g. Time-Frequency Analysis, Discrete Fourier Transform, Hilbert Transform,…) made decades ago. Thus, the past ten years has seen a considerable growth in SP (analog and digital) applications. However, SP has most often been considered as a purely ″Telecommunication Technology" topic. Likewise, the teaching staff active in so called ″old″ engineering fields (e.g. Power Engineering, Control Theory) has often vigorously opposed any curriculum changes favoring SP. As mentioned earlier [1], SP and now digital signal processing (DSP) has often been seen as a threat. Nevertheless, thanks to the persistence of *″Signal Processing Believers″*, this situation has now evolved and many professors active in engineering related fields are now realizing what benefits DSP can bring to their particular field of expertise. This has implied drastic changes to many engineering curricula with the unavoidable stringent time constraints. Consequently, original and motivating teaching techniques had to be considered and somehow *″experimented″* in order to meet these new challenges.

The SP education experience of the author, with both students and practicing engineers, directed to teaching methodology and objectives described in the next two sections. Then, a step-by-step procedure is given followed by the topics proposed by group of students. In the next section, two selected projects examples are presented along with the basic signal processing analysis and some of the significant results obtained. Finally, in the last two sections, course assessment suggestions are given followed by concluding comments.

2. *Teaching objectives:*

- Demonstrate what SP can do in typical ″Mechanical Engineering Applications″ in taking advantage of *"Files made-out of Real Signals".*
- Show them that currently available hardware and software, if adequately chosen, are not very difficult to use for doing basic analysis.
- Develop an attitude of quickly ″looking for help from someone working in SP″.

3. *Teaching methodology:*

- To initiate motivation, ask the students to define small SP projects related to their particular field of interest and/or studies (by group of 2).
- Show what SP can do in typical ″Mechanical Engineering Applications″ by applying simple concepts in the context of their projects.
- Use modern hardware and software that are inherently *″user friendly″* (i.e. very short learning-curve) to do the basis data acquisition and analysis.
- Develop a positive attitude toward SP by demonstrating that this can dramatically enhance many mechanical processes.
- Find a way to test the student understanding of the most important concepts applied to real situations.

4. *Procedure:*

4.1. Project Selection

The students (by group of two) select a mechanical process or system which will be the focus of their project.

4.2. Project Description

Each group describes its project with a few written lines and try to define some realistic objectives.

4.3. Lecture #1

Basic Theoretical Introduction on ″Signal Acquisition″ including:

Guidelines to choosing the right sampling frequency, input signal dynamic range issues, AC/DC coupling, A-to-D converter number of bits (saturation – quantization noise…..), total number of samples (i.e. total run time).

4.4. Field Data Acquisition

The professor goes to every particular experiment location with each group to do ***"Data Acquisition"*** with a ″Pico ADC212″ and a ″Laptop″. A first series of experiments are made in order to determine the optimum parameters to do data acquisition. Then, using the PicoLog option, several files are made of the electrical signals representing at least one parameter of the student selected mechanical process or system.

4.5. Lecture #2

Basic Theoretical Introduction on ″Signal Processing″ including:

Classification of signal type (i.e. periodic vs. non-periodic signal, noise vs. signal….), basic signal analysis and filtering (FFT, noise removal, DC component removal, abnormalities….) and key features extractions (envelop, time decay constant, non-linearities, instantaneous frequency.….).

A particular emphasis is placed upon the following statements [3]:

″***Computer simulations***, *when properly applied, provide a great deal of insight into a problem of interest, but they are* ***no substitute for tests with real-life data.*** *It is therefore not surprising that many algorithms fail to survive the ″test of time″.*

Without question, mathematics is a powerful tool that gives an algorithm both elegance and general applicability. By the same token, however, an ***algorithm that ignores physical reality*** *may end up being of* ***limited*** *or* ***no practical use****.*

Signal processing is at its best when it successfully combines the unique ability of mathematics to generalize with both the insight and ***prior information*** gained from the underlying ***physics of the problem at hand***″.

4.6. Preliminary Files Analysis

Back to the SP laboratory, each group visualises the files representing their experiments with a user friendly *"Signal Processing Software"* (SystemView by Elanix).

4.7. Basic Signal Processing

Then, they run pre-prepared programs which to basic signal analysis and/or meaningful data extraction or display (e.g. spectrum, resonance frequencies, signal envelop, instantaneous frequency, file segments comparison….).

4.8. Exam Preparation

Finally, each group of students is asked to prepare three transparencies for their project. These transparencies will be made available to be freely used by every body for the duration of the exam. Thus, discussions and collaboration between the groups are strongly encouraged while preparing the transparencies for the exam.

4.9. Oral Exam (30 minutes)

Description of the student's project (with pre-prepared transparencies) - highlights of important issues - Q and A.
Description of another randomly chosen project (with pre-prepared transparencies) - highlights of important issues - Q and A.

5. *Topics chosen by the students (7 groups):*

- Cellular phone (buzzer and/or music classification and identification)
- Combustion engine (cylinder pressure vs. time)
- Milling Machine (cutting forces during milling operation, acceleration on the bearings of the spindle)
- Electric Fan (switch-on, switch-off detection, random signal vs. random noise, periodic signal vs. random signal)
- Guitar (timber spectrum content, single string frequency stability and decay time)
- Single Degree of Freedom Discrete System: a) Rotation (free and forced oscillation frequencies, non-linearities)
- Single Degree of Freedom Discrete System: b) Translation (free and forced oscillation frequencies)

6. *Selected Project Examples (basic analysis)*

Procedures: 1) Data Acquisition (PicoLog)
2) Digital Signal Processing (SystemView)

Data Acquisition: The data acquisition system used is called ″Pico ADC212″ (www.picotech.com). Its main specifications and set-up are the followings (PicoLog option):

2 channels, 12 bits A-to-D, maximum number of samples: 131036

131036 samples at 20 ns → ≈ 2.6 ms (total run-time)	sampling rate:	50 MHz
40 ns → ≈ 5.2 ms		25 MHz
1280 ns → ≈ 168 ms		≈ 780 kHz
……………………		
……………………		
164 µs → ≈ 21 s		≈ 6 kHz
328 µs → ≈ 42 s		≈ 3 kHz
655 µs → ≈ 85 s		≈ 1.5 kHz

Input Range: ±50mV, ±100mV …±20V, coupling: AC-DC, Trigger: Channel, Slope, Level

Note: In most cases, a trade-off must be made between "sampling rate" and ″total run-time″!

Digital Signal Processing: Due to the limited time available for this course, files for each project are prepared in advance by the professor and individually explained to the groups

Example #1 Single Degree of Freedom Discrete System: b) Translation

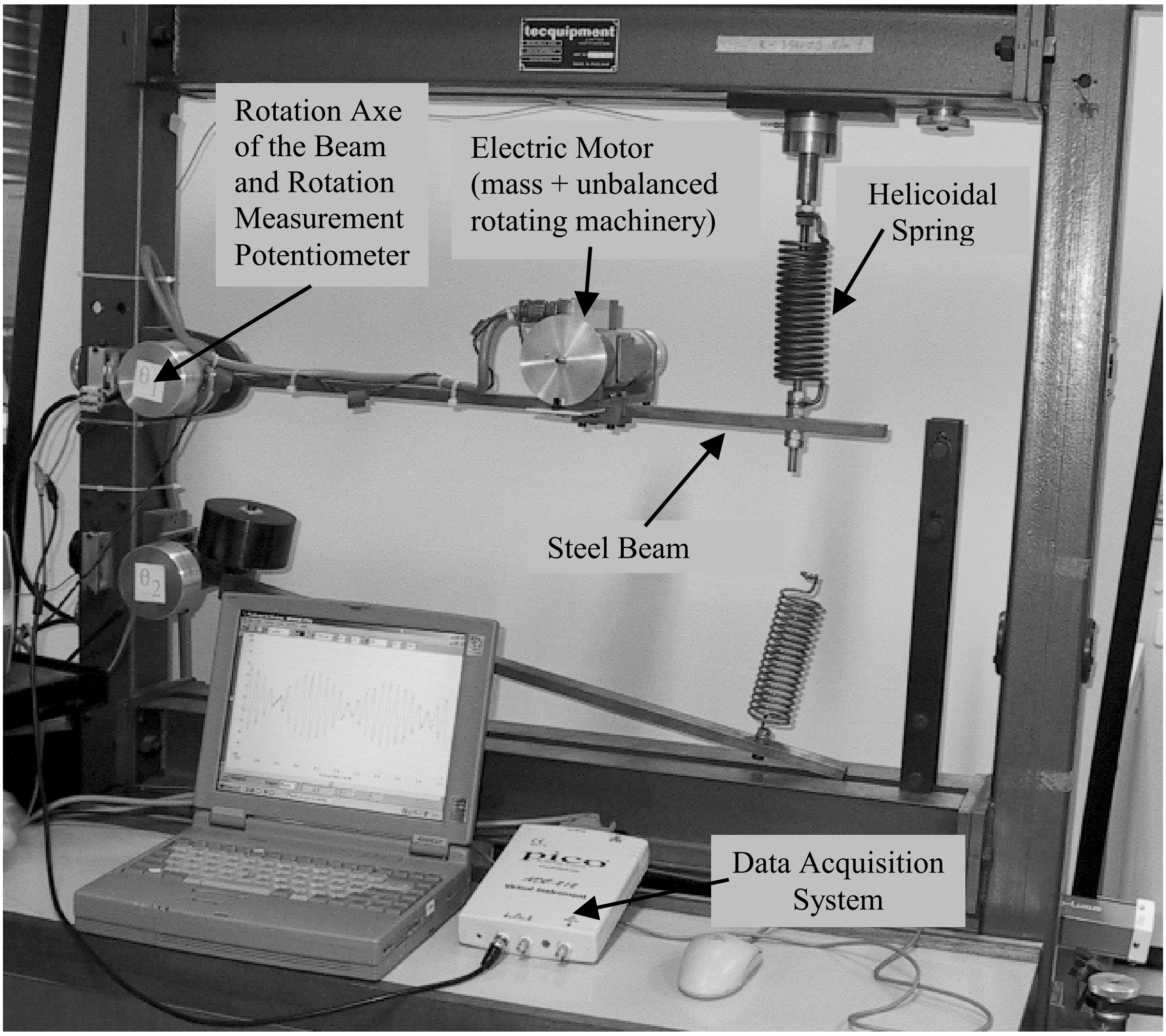

Fig. 1 Laboratory Set-Up

Part 1 Free Vibration Response Measurement (short pulse response function)

Objectives: free oscillation frequency and damping parameter

PicoLog: Sampling rate: ≈ 1.5 kHz, Number of samples: 120000 → total run time: ≈ 79 s

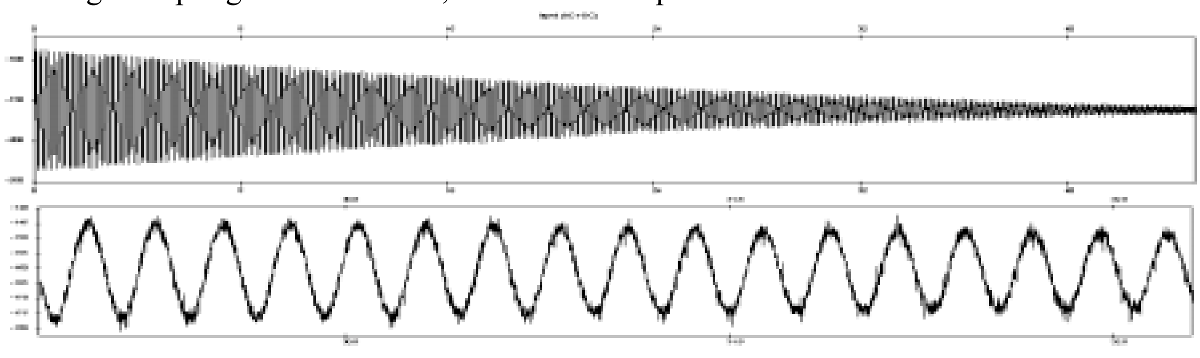

Fig. 2: Digitized Potentiometer Signal, top: 0 → 45 s, bottom: 30 → 33 s

FFT on band-pass filtered potentiometer signal (free oscillation frequency): 5.69 Hz

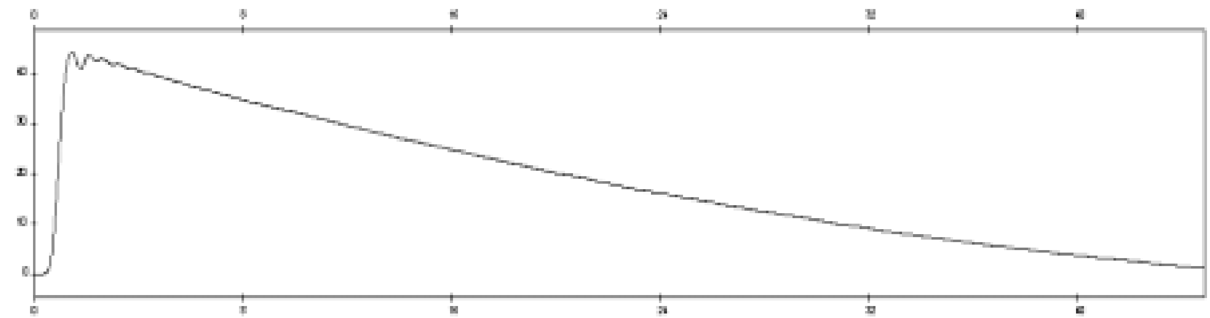

Fig. 3: Exponentially Decaying Envelop (DSP) → $\tau \approx 25$ s

Part 2: Harmonic Excitation Vibration Measurement (unbalanced rotating machinery)

Objectives: transient and stationary responses (free and forced oscillation discrimination)

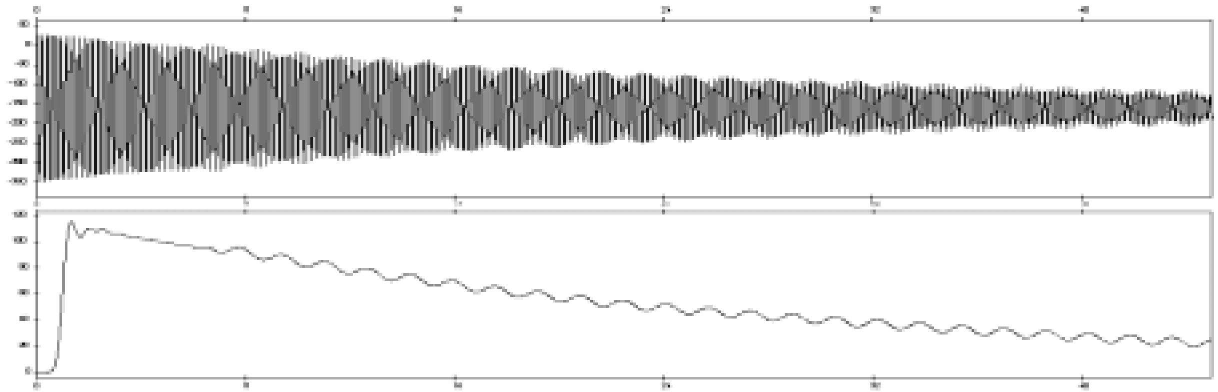

Fig. 4: Top: Digitized Pre-filtered signal, Bottom: Envelop (0 → 45 s)

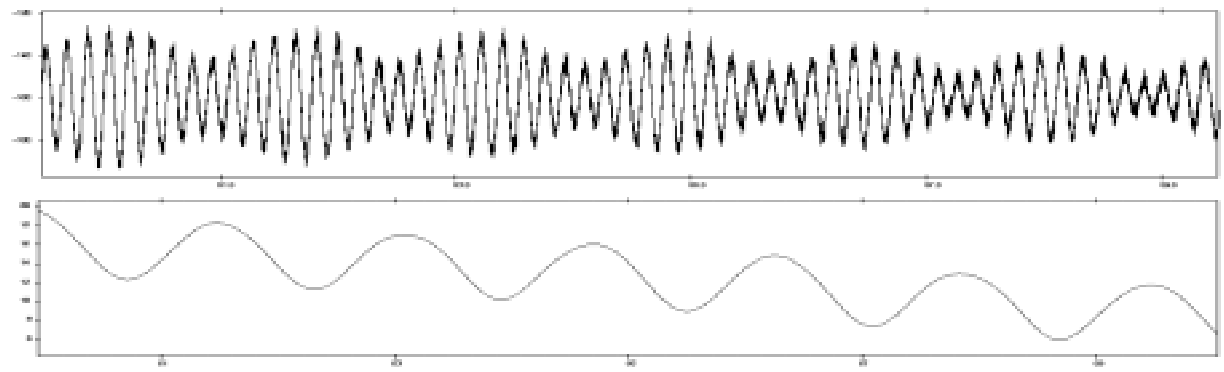

Fig. 5: Top: Digitized Pre-filtered signal, Bottom: Envelop (50 → 60 s)

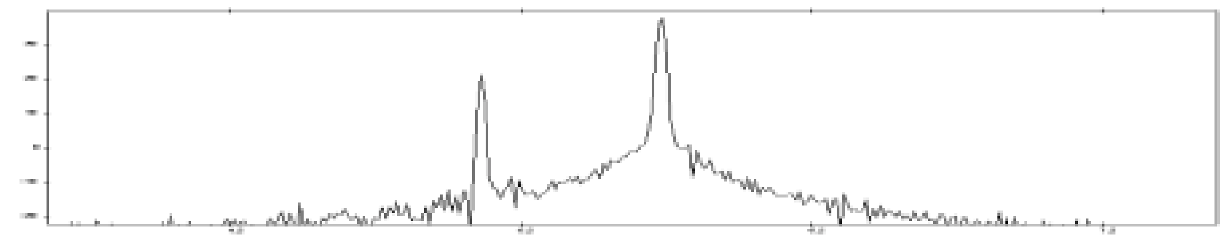

Fig. 6: Row Signal Power Spectrum (dB) with *"Hanning"* window
→ 5.06 Hz (periodic excitation), 5.67 Hz (free oscillation)

Lesson: ***"Time-Domain"*** and ***"Frequency-Domain"*** must be simultaneously considered in most analysis of processes.

Example #2   Combustion engine (cylinder pressure vs. time)

An electric signal coming from a sensor measuring the pressure of the engine compression chamber is recorded while the engine is accelerated step-by-step.

PicoLog: Sampling rate: ≈ 1,5 kHz, Number of samples: 120000 → total run time: ≈ 79 s

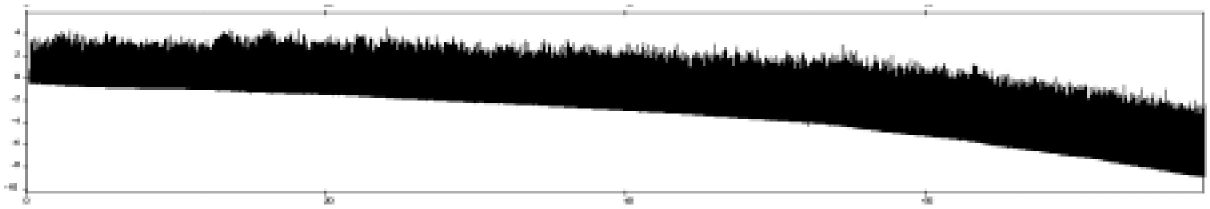

Fig. 7:   Digitized Pre-Amplified Sensor Signal   (0 → 79 s)

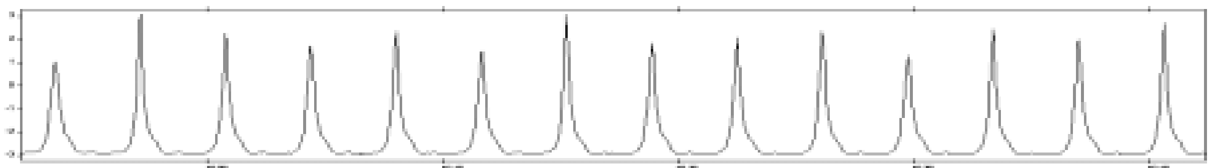

Fig.8:   Zoom of the Digitized Pre-Amplified Sensor Signal   (40 → 40.5 s)

Signal Processing Objectives: 1) Remove the DC component (blocks: 3, 4, 5 and 7).
2) Estimate the frequency of the ″pulses″ vs. time.

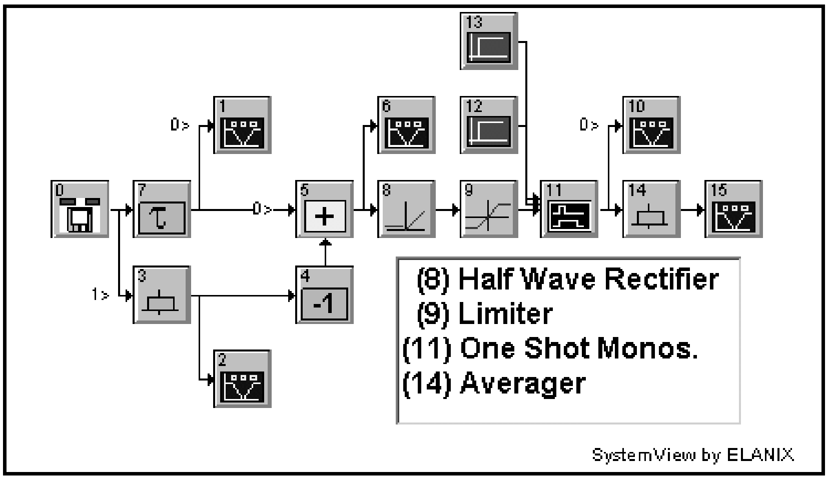

Fig. 9:   Digital Signal Processing Block Diagram (token 0: Digitized Sensor Data)

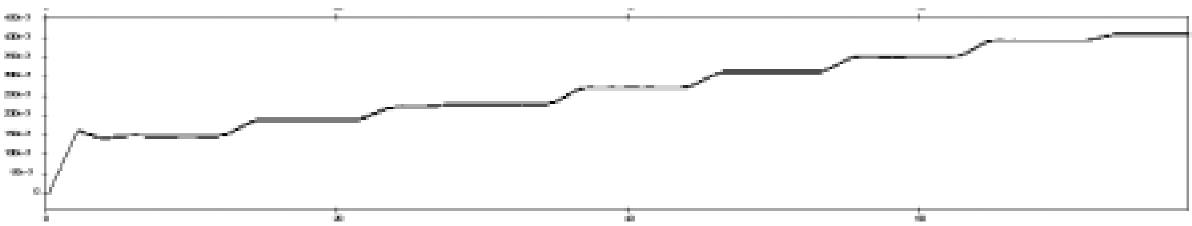

Fig.10:   Computed cylinder pressure versus time   (0 → 79 s)

Comments: This example demonstrates very clearly the power of DSP. It is envisaged to go one step further with the addition of a block programmable real-time DSP kit (″INFINITY Technology Kit″, Speedy-33, TMS320C33 based DSP board and VAB Software from Hyperception, Inc).

7. Course Assessment: In order to constrain the students to get partially involved in the other group projects, it was decided to test them orally (30 minutes) according to the following guiding principles:

- The student describes his project (with the transparencies prepared in advanced) and highlights the most important issues.
- Q and A on the student project
- The student describes another group project randomly chosen by the professor (with the transparencies prepared in advanced) and highlights the most important issues.
- Q and A

The most important point of the oral exam is to check every student has a clear understanding of the most important issues and of the potential of SP techniques as applied to mechanical engineering related problems.

Since ″understanding″ and not ″memorization″ is the issue, each group of students is asked to prepare three transparencies for their project. These transparencies will be made available to be freely use by every body during the course of the exam. Thus, discussions and collaboration between the groups are strongly encouraged while preparing the transparencies for the exam.

8. Conclusions

After running a first time the course according to the proposed scheme, we can conclude that this teaching methodology met most of the objectives. Globally, the student feedback was very good. This course initiated some real motivations by concretely showing the potentialities of SP in *″Mechanical Engineering Processes″*. The most obvious improvement to bring to this course is the addition of one or two progress reports whose purpose is to constrain the students to work on a more regular basis!

It goes without saying that the extreme time constraint is a serious limiting factor for the instructor who is compelled to compromise between the teaching of DSP fundamentals and working on ″Real Signals″. An interesting comment came at the very end of the course: ″Why don’t we have so little of that? ″. This can be taken as a compliment as well as an encouragement to carry on the effort along the proposed scheme.

9. Bibliography

[1] James H. McClellan, Ronald W. Schafer, and Mark A. Yoder, ″A Changing Role for DSP Education″, *IEEE Signal Processing Magazine,* pp. 16-18, May 1998

[2] L. Richard Carley, Pradeep Khosla, and Robert Unetich, ″Teaching “Introduction to Electrical and Computer Engineering” in Context”, *Proceedings of the IEEE,* pp. 8-22, Vol. 88, January 2000

[3] Simon Haykin, ″Signal Processing: Where Physics and Mathematics Meet″, *IEEE Signal Processing Magazine,* pp. 6-7, Vol. 18, July 2001

10. Biography

JEAN-PAUL SANDOZ is professor of Electronics and Signal Processing at EIAJ-HES/SO (Western Switzerland University of Applied Sciences). He focuses on ″Hilbert Transform″ real-time digital applications. He gave several ″Analog/Digital Signal Processing″ short courses with hands-on laboratories to engineers from world leading industries of Switzerland and a two week course at UNHAS-Poli, Ujung Pandang, Indonesia.