

# Distance Learning in Communications Signal Processing using MATLAB Web Server

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## ABSTRACT

*This paper describes the development process and some latest results and experiences related to the development of a distance learning package dealing with fundamental aspects of communications signal processing. The idea is to provide students with compact lecture notes type text materials explaining the basic theory, combined and accompanied with interactive demonstrations and exercises implemented using MATLAB. In order to avoid the need for local MATLAB licenses, the so called web server concept provided by Mathworks is utilized. This allows the students to effectively use MATLAB over the Internet in the form of various demos and exercises, with user-defined freely selectable parameters. The work reported here is part of the larger European Union (EU) funded Invocom project.*

## 1. INTRODUCTION

During the last ten to fifteen years or so, major advances in digital signal processing (DSP), both at the algorithm as well as the implementation levels, have revolutionized the world of communications. As a result, also the needs for education and training in the DSP and communications area have increased dramatically. On the other hand, the advances in multimedia technologies enable alternative learning procedures in addition to the traditional person-to-person type techniques. In fact, various distance learning approaches based on delivering and receiving information through the Internet play a significant role in many top-level universities and educational institutes as well as numerous ICT companies worldwide, see, e.g., the short review in [1]. Several aspects and variants of using multimedia techniques in the signal processing education are discussed, e.g., in [1]-[4].

One fundamental motivation behind the work reported in this paper is the ability to provide interactive demonstrations and exercises, such that these are (i) accessible to everyone through the public Internet and (ii) can be used

with minimum amount of licenced software, i.e., using just a web-browser in practice. By interactivity we mean that users are really able to freely choose the crucial demonstration parameters, not only to browse through some pre-determined set of fixed examples. This is one crucial enhancement compared to many other Internet based educational materials currently available.

This paper is organized as follows: In Section 2, the Invocom project is described which forms the general framework for this work. Then in Section 3, we describe the basic tools and techniques used to create the interactive material, as well as the latest results. In Section 4, we discuss the continuation and further work, which basically concludes the paper.

## 2. INVOCOM PROJECT

The work described in this paper is carried out within the EU-funded Invocom (Internet-based vocational training of communication students, engineers, and technicians) project [5], which has partners from several technical universities and companies around the Europe (see Section 5 and/or the project website [5] for more detailed information). The idea in general is to produce high-quality distance learning material with interactive demos and simulation experiments in the broad field of communications technologies. This includes, e.g., the following areas (links to the available materials can be found from the project website [5]):

- *Basic DSP*: Discrete-time signals and systems, filter design techniques, deterministic and random signals, spectral analysis, basics of adaptive and multirate signal processing.
- *Communications Signal Processing*: Bandpass and complex signal and system concepts, sampling and multirate processing of bandpass signals, non-idealities in analog signal processing and A/D interfaces, basic receiver architectures, system calculation principles.
- *Modulation and Detection Techniques*: Modulation and demodulation, detection and channel equalisation, symbol timing and carrier frequency and phase

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recovery, coded modulation and error control codes, Viterbi decoding.

- *Multimedia:* Digital image processing, compression and coding, non-linear filters and filtering, video and audio coding and signal processing.
- *Optical Communications:* Propagation and attenuation in optical fibres, fibre dispersion and bandwidth, components for fibre communications, optical amplification and processing, system level design aspects.
- *Network and Protocol Level Aspects:* Medium access control protocols and wireless systems, signaling in telecommunications networks, asynchronous transfer mode networks, multirate traffic and multiservice networks, TCP IP protocols, quality of service.

The above list really shows just a general snapshot of the most relevant topics covered. The authors of this paper are responsible for the communications signal processing area, thus the rest of the paper focuses on those issues. Current material (the short-course entitled “Bandpass and Complex Signal and System Concepts”) [6] is available online at <http://www.cs.tut.fi/tlt/invocom/>.

### 3. TOOLS, TECHNIQUES AND RESULTS

In general, the educational material consists of compact lectures in the form of text and figures, explaining the basic theory of the selected topic(s). The lecture material is written in HTML and accessible through public Internet [6] using any of the standard web browsers. The lectures are accompanied with interactive simulation experiments and exercises, showing some illustrative examples of the covered topics with various user-selectable parameters.

Considering the implementation of the simulation experiments, MATLAB [7] is in general a commonly used tool in the design and analysis of digital signal processing systems. This is mostly due to its powerful numeric computation capabilities, highly sophisticated visualization tools, and high number of easy-to-use dedicated signal processing tools provided in various toolboxes. For these reasons, we also selected MATLAB to be our basic tool in building most of the demonstrations and simulation examples. In order to make the whole material as easily accessible as possible, we decided to use the web server concept provided by Mathworks [8]. This is illustrated in Fig. 1. Here the actual MATLAB software, the web server, and the server daemon all run on a single PC. Currently, this PC is a 2.53 GHz Pentium 4 with 512 MB of memory. In general, the user-determined parameters of a particular simulation setup are delivered to Matlab over the Internet, and after the actual calculations, the results (graphics etc.) are returned to the end user. In this way, the users don’t need to have MATLAB locally installed or to basically know anything about MATLAB programming.

The graphical representation and configuration of the simulation experiments is implemented using HTML

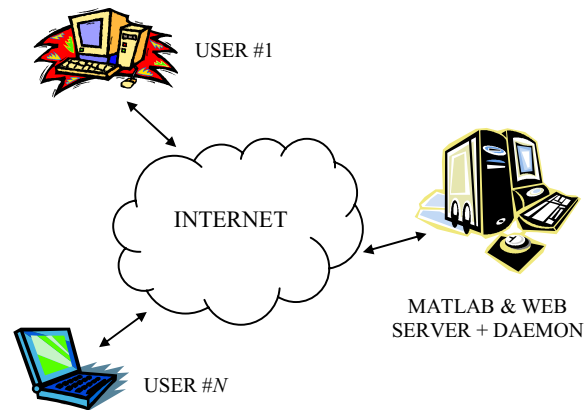


Fig. 1. The MATLAB web server concept.

forms. So also in this sense, the material development is really straight-forward and does not require any special programming skills. This makes the whole web server concept easily accessible also from the material authors’ point of view. An example block-diagram is given in Fig. 2 for a basic I/Q modulation experiment. Here a digitally modulated complex baseband waveform is quadrature modulated to a carrier frequency. The user can choose the input signal type out of a list of common digital modulations, and can freely choose the carrier frequency, sampling frequency, oversampling factor (number of samples per symbol), and the pulse-shape rolloff factor. By pressing the “submit” button, these values are delivered to the server and imported to MATLAB for the actual generation of signals and the related signal processing. After this, the generated signals are illustrated both in time and frequency domains using MATLAB’s visualization tools. To the end user, these graphics are “returned” in terms of a separate HTML view with JPEG images. By changing the modulation format and/or the other simulation parameters, users can easily explore the fundamental features of I/Q modulated signals from both the time domain waveform as well as spectral content point of view. In addition to stating a typical example case with default parameter values, there are example problems and exercises where material users need to determine proper parameter values for specific system scenarios. Another example experiment is depicted in Fig. 3 which deals with analytic signals and Hilbert transformers. The corresponding input and output spectra with the default parameter values returned to the user are presented in Fig. 4.

According to the experiences so far, the web server concept is really useful and beneficial from both the material developers’ and users’ point of views. Most of the authors of the courses and demonstrations in communications and signal processing area are likely to be familiar with MATLAB programming, and, e.g., all the old codes and scripts are basically directly applicable. The end user, on the other hand, doesn’t necessarily need to know anything about MATLAB being still able to study and run the demos as efficiently as anyone. Of course, if so decided by the material author(s), the actual MATLAB

scripts behind the simulations can be easily distributed to the end users over the Internet. Another important factor in this context is the system response time. According to the observations so far, the current system is easily able to support one to five simultaneous users without any notable difference with the current processing power and memory. Naturally this depends on the complexity of the simulations and experiments as well as on the capacity of the network (at least to some extent).

#### 4. DISCUSSION AND CONCLUSIONS

Currently, the second short-course “Sampling and Multirate Processing of Bandpass Signals” [6] is under preparation. Since the experiences with the MATLAB web server have been so positive, this tool is also applied in this course as well as in the coming ones “Non-Idealities in Analog Signal Processing and A/D Interface”, “Basic Receiver Architectures”, and “System Calculation Principles”. In addition, also Macromedia Flash [9] (Flash MX 2004 Educational v7.0) is planned to be used, e.g., in demonstrating aliasing effects in multirate filtering, but most of the demos and example simulations will anyway be implemented using MATLAB due to its versatility.

The authors of the material [6] are also responsible, e.g., for the course entitled “Receiver Architectures and Signal Processing” lectured every other year at Tampere University of Technology, Tampere, Finland, under the course identifying number 83080 [10]. The distance learning material is planned to be used as a supplementary material when the course is lectured next time during fall 2004. In addition, parts of the materials are likely to be used in other courses as well.

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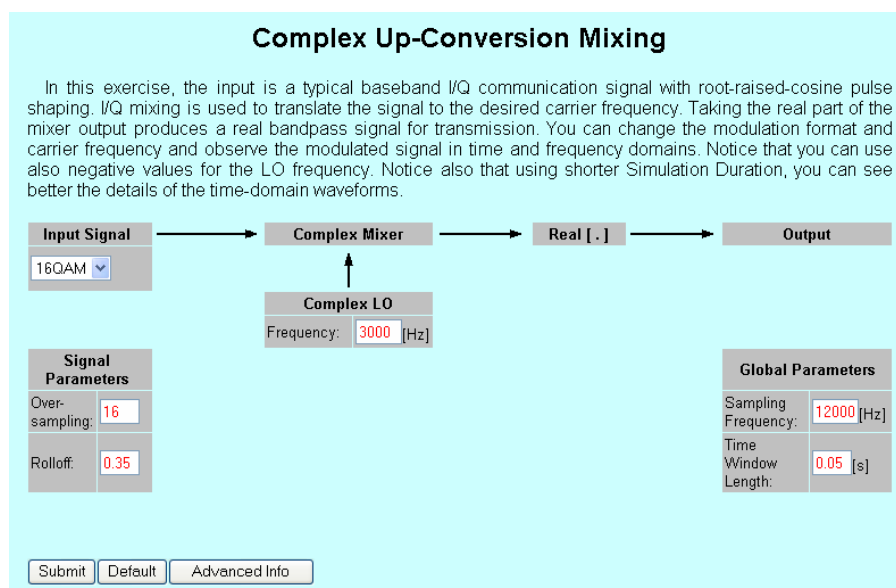
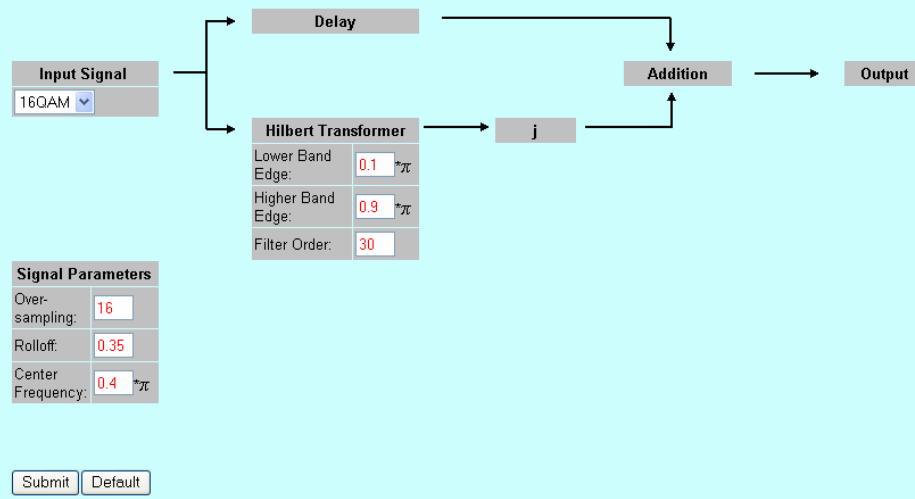


Fig. 2. An example screen shot of the I/Q modulation experiment graphical user interface [6].

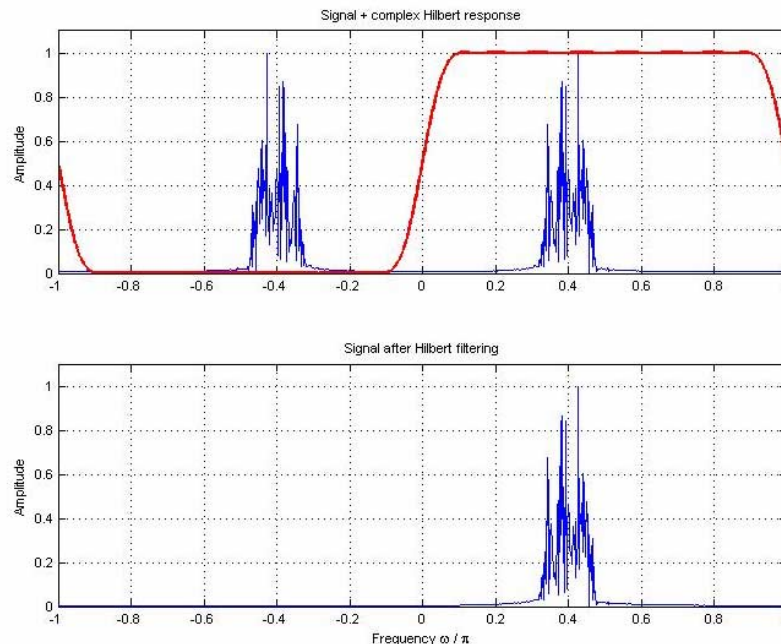
## Analytic Signals

In this experiment, we illustrate the use of Hilbert transformers to reject negative frequencies while passing the positive ones. The signal flow diagram for these experiments is given below. The input is a linearly modulated communication signal and the output is the corresponding complex signal after Hilbert based filtering.

The parameters in this setup are the band edges within which to approximate the Hilbert response (an allpass filter with 90 degree phase shift) as well as the filter order (defined here as the length of the filter - 1). Again use an **even order** in carrying out the Hilbert design such that the needed delay in the upper branch of the structure is an integer. The parameters of the input signal are its center frequency, the rolloff of the pulse shaping filter, as well as oversampling factor telling how many samples per one data symbol are used in the simulation. All the frequencies (the lower band and higher band edges as well as the signal center frequency) are given as a fraction of pi where pi refers to half the sampling frequency.



**Fig. 3.** A simple demonstration of Hilbert transformers and their connection to analytic signals [6].



**Fig. 4.** The output graphics (input and output spectra) returned to the user in the Hilbert transformer demonstration described in Fig. 3 with the default parameter values [6].