Understanding Digital Communication Physical Layer

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ABSTRACT

In this article a simulation environment for digital transmission systems is presented. Its application in digital transmission experimental learning is possible by allowing key parameters influence study through a graphical interface. It is possible to visualise some points of the system, modify structures and transmission parameters. Equivalent lowpass of BPSK and QPSK with limited Nyquist spectrum and non-limited spectrum (finite time impulses) are considered. Fast BER curve estimation is obtained by a semi-analytical procedure.

I. INTRODUCTION

All services provided by a digital transmission link depend on its physical layer capabilities. Those bearer capabilities have improved dramatically, allowing the actual wireless multimedia explosion. The basics of baseband and modulated digital transmission are well known but experience is needed for the engineering and study of new schemes. Full understand of 3rd generation wireless physical layer [1] requires very much that.

In this paper we review the impact in the transmission quality of some key parameters. For that we have made a simulation tool in Matlab@ [2], permitting different testing on signalling, channel and filters formatting and detection processing. The program, named *DigiLab* has a graphical interface and allows to:

- design a transmitter by selecting 5 parameters: bit rate (r_b), sequence length and type (*random*, *deBruijn*, *square wave* or *one shot bit*), pulse shape $r(t)$ and modulation (binary or quaternary PSK);
- number of points in simulation vectors;

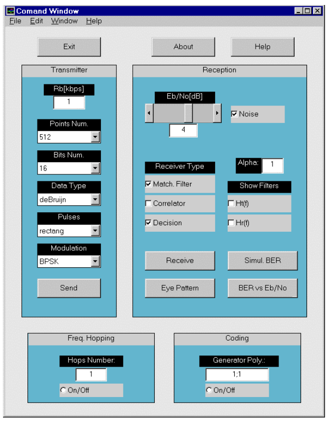

Figure 1: Command window.

- define noise power by E_b/N_0;
- set detector type: matched filter (MF) or correlation receiver (CR);
- define filters rolloff factor (α) in $H_T(f)$ and $H_R(f)$ (transmission and receiver filters),
- see filters amplitude characteristics and its composing functions for a easy understand;
- see time domain MF impulse response, $h(t)$;
- see eye patterns (YP) associated to each detection type (MF or CR). In QPSK isolated YP's are presented for I and Q components;
- compare simulation BER with theoretical value for a particular defined system;
- get fast BER curve points and compare with theoretical ones;
- make convolutional channel coding.

II. DESIGN CRITERIA

Computer simulation of bandpass transmission by its equivalent lowpass is the best option [3,4] (see Figure 2). Testbeds for future systems like Universal Mobile Telecommunications System (UMTS) use this simplification [1].

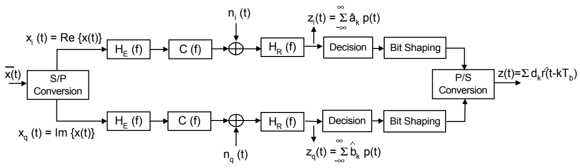

Figure 2: General lowpass scheme.

Complex numbers permit a unified channel treatment for the two stream bit flowing. Note that for BPSK particular case only half of the scheme is needed (one branch transmission).

For a total of N bits to send, $N/2$ are piped in each branch and general PAM signals are constructed, being, for the BPSK case:

$$x_i(t) = \sum_{k=1}^{N} a_k r(t - kT) \tag{1}$$

Antipodal signalling is used and so a previous bit value 0/1 to a_k=-1/1 conversion is required.

Bandpass noise, $n(t)$, is related to its lowpass equivalents, n_i and n_q, by (2) and (3):

$$n(t) = n_i \cos(2\pi f_0 t) - n_q \sin(2\pi f_0 t) \tag{2}$$

$$P_n = \langle n^2 \rangle = \langle n_i^2 \rangle = \langle n_q^2 \rangle \tag{3}$$

Pulse shapes *rect*, *cos*, *sin* and *Nyquist* one can be selected but others could easily be added in the code.

To have a very short delay time in tool operation, a semi-analytical method (SAM) is applied for BER estimation (P_b), being:

$$P_b = \frac{1}{N}\left[\sum_{i=1}^{N} Q\left(\frac{v_{th} - y_i}{\sigma_n}\right) + \sum_{i=1}^{N} Q\left(\frac{u_i - v_{th}}{\sigma_n}\right)\right] \tag{4}$$

where

N - sequence length; v_{th} - decision threshold from

$$v_{th} = \frac{1}{N}\sum_{i=1}^{N} z_i \tag{5}$$

u_i - samples above v_{th} ; y - samples below v_{th};

The SAM is based on YP aperture and supplies results in few seconds because it supposes ergodicity and has *a priori* knowledge of the channel statistical model: additive white gaussian noise (AWGN). We should have in (4) a close number of 0's and 1's and as much sets of transitions as possible. For having those properties, *deBruijn* sequences must be used when BER is wanted [3].

Although it is only presented the case of an AWGN non-dispersive channel, the study of other channels defined by a complex function $C(f)$ is also possible (except BER estimation). For those cases delay determination and compensation must occur. This is made by an f domain correlation due to:

$$x(t) * y^*(t) \leftrightarrow X(f)Y^*(f) \qquad (6)$$

To show easy code inclusion of high order blocks, convolutional coding by polynomial definition was added.

III. EXPERIMENTAL VERIFICATIONS

Different system variations can be made conducting to several experimental verifications. For example, YP's resulting from of a *square wave like* sequence deletes the constant levels of complete YP's.

The *MF* and the *CR* equivalency and their individual benefits and problems are recognised using *DigiLab*. For causality existence ($h(t)$=0 for t<0), a delay of T/2 was added in the $H_R(f)$ complex function.

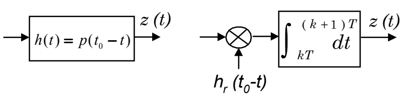

Figure 3: Matched filter and correlation receiver.

For both processes the decision is made at the optimum decision time instant t_k=kT for k=0,1,...N. In QPSK T is T_s, the symbol signalling duration.

Selecting both detection processes and inspecting kT instants, the output values for decision are seen coincident (Figure 4). That is one of the most impressive results that a user must try.

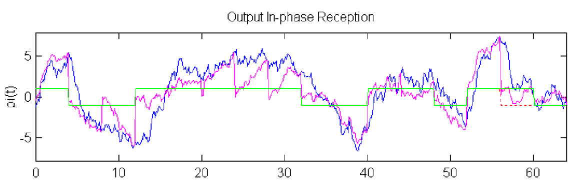

Figure 4: Detection modes equivalence at kT for *rect* pulses.

The result can be well confirmed with great amplitude noise presence. In YP's with few transmitted bits the result is also clear.

IV. NYQUIST PULSE SHAPING

Transmission with Nyquist filtering has the same performance as rectangular pulses transmission. In that case the overall frequency transfer function in *DigiLab* is always kept:

$$R(f)\cdot H_e(f)\cdot C(f)\cdot H_r(f) = P_{Nq}(f)e^{-2\pi f\frac{T}{2}} \qquad (7)$$

where

$$H_e(f)=\frac{\sqrt{P_{Nq}(f)}}{R(f)\sqrt{C(f)}}\ ;\quad H_r(f)=\frac{\sqrt{P_{Nq}(f)}}{\sqrt{C(f)}}e^{-2\pi f\frac{T}{2}} \qquad (8)$$

$$R(f)=TF\left\{\mathrm{rect}\left(\frac{t}{T}\right)\right\}=\mathrm{sinc}(fT) \qquad (9)$$

It is seen that spectrum reduction by narrowing the Nyquist chain implies a better synchronism and induces envelope fluctuations (undesired in saturated power amplifiers [5]), as seen in Figure 5.

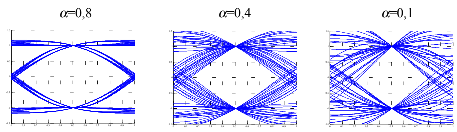

Figure 5: ISI near optimum instant by raised cosine rolloff reduction on a Nyquist chain output.

Inter symbol interference (ISI) can be zero for small α but then two problems arise: difficult filter physical realisation and strong ISI in optimum instant vicinity (Fig. 5). Fourier property of time/frequency expansion/compression is responsible for that. A 0.22 rolloff factor is being used for UMTS evaluation [1].

V. CONCLUSIONS

The paper focus aspects of a new software of digital communications signal processing.

Users interaction is only made through graphical interface and all results are achieved almost instantly.

The presented tool finds suitable application in digital transmission teaching. It was already used, with very good results, on digital communications teaching preceding an hardware BPSK extended lab demo.

The program can be used as well for new digital systems development.

REFERENCES

[1] E. Dahlman, P. Beming, J. Knutsson, F. Ovesjö, M. Persson and C. Roobol, "WCDMA - The Radio Interface for Future Mobile Multimedia Communications", *IEEE Trans.s on Vehic. Tech.*, Vol. 47, No. 4, Nov. 1998;

[2] F. Monteiro and S. Pinto, *Analysis and Efficient Simulation of Digital Modulations; Channel Coding and Frequency Hopping Spread Spectrum in Radio Communications*, Final Year Project, (in Portuguese), IST, Lisbon, Feb. 1999.

[3] M. C. Jeruchim, Philip Balaban e K. Sam Shanmugan, *Simulation of Communication Systems*, Plenum Press, 1992;

[4] J. G. Proakis, "*Digital Communications*" (3rd Edition), McGraw-Hill, 1995;

[5] John B. Anderson and Carl-Erik W. Sundberg, "Advances in Constant Envelop Coded Modulation", *IEEE Comm. Mag.*, Vol. 29, No 12, Dec. 1991.