Proceedings of the

XVIII CONFERENCE on DESIGN of CIRCUITS and INTEGRATED SYSTEMS

dcis 2003

ORGANIZED BY THE COMPUTER
ARCHITECTURE AND NETWORKS GROUP
UNIVERSITY OF CASTILLA-LA MANCHA - SPAIN

CIUDAD REAL (SPAIN)
NOVEMBER 19-21,2003

www.dcis.org

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Computer Architecture and Networks

UCLM
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Binary Data PLD Based Conformation.
Application to DSSS Wireless Optical Links.

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Abstract—A digital filter scheme for digital binary data based in a LUT is presented in this paper. The performance of several conformation families as Sinusoidal, Gaussian and Raised Cosine is compared. The conformation scheme is applied to a DSSS wireless optical communication system. Also the advantages of using DSSS in the wireless optical channel are discussed.

Index Terms— Conformation, DSSS, spread spectrum, Wireless Optical Systems, Gaussian Filter, Raised Cosine Filter

I. INTRODUCTION

Wireless optical communications between portable devices, and wireless optical in-house communications in general, have been intensively studied in the last decade [1-3]. They introduce some advantages as low cost, reduced dimensions, or improved confidentiality when compared with radio-frequency (RF) communications. They also do not require legal procedures for frequency assignment and are not affected by EM noise sources (which is particularly important when dealing with domestic appliances). On the other hand they lack of some disadvantages, especially when using a diffuse optical channel. It presents several noise and interference sources (thermal noise, incandescence and fluorescent lamps....) and suffers a severe bandwidth penalty due to multipath propagation because of multiple reflections with walls, furniture etc. Spread-spectrum (DS-SS) techniques [4-7] are widely used because their narrowband interference rejection capability, (especially when it is non-correlated with the spread signal [5]). Most of the interferences produced by illumination or by another IR communication systems (remote controls, Ad-hoc IR networks, ...) can be modeled as this kind of narrowband interference. SS also reduce the effect of multipath propagation. Another interesting possibility introduced by using SS signals is the Code Division Multiple Access (CDMA) capability. As in the indoor IR channels the working area is very reduced, most of the received signals have approximately the same power, avoiding the near-far problem [4]. In this work we study the use of conformation techniques over a diffuse wireless optical baseband, intensity-modulated Direct-Sequence Spread-Spectrum (DSSS) prototype, suitable for local-area network transmissions o in-house networks. We have tested with low bit rates but conclusions can be extended to any other system up to 10 Mb/s. The use of conformation techniques reduces the complexity of both emitter and receiver as it reduces the bandwidth requirements and the co-channel interference without a significant loss of performances. The conformation scheme presented here is simple, cheap and has good performance, but only suitable for binary digital signals. It is easy to change the system frequency and the conformation family. It only needs a LUT, a DAC and simple logic to synthesize the filter behavior. For binary digital signals is not necessary to implement expensive DSP based filters, neither large area integrated filter. The LUT scheme here presented gives a good solution in this particular case.

This paper is organized as follows: in section 1 some guidelines about the use of SS techniques over indoor optical channels are given. Conformation techniques with extensive simulation results are explained in section 2, while its circuit implementation is given in section 3. Experimental results of the operation of a DSSS optical prototype are shown in section 4. Then, some conclusions and application scenarios are presented.

II. SPREAD SPECTRUM FOR THE IR INDOOR CHANNEL

As is well known, Spread Spectrum techniques offer the possibility of avoiding the intersymbol interference induced by multipath propagation (such as in the IR indoor channel), but having on the other hand higher complexities in the symbol-time recovery stage of the receiver. Wireless infrared direct-sequence spread spectrum is based on multiplying a narrowband data signal with a baud rate R, by a broadband spreading sequence with baud rate (often known as *chip rate*) R_{ss} And then is intensity-modulated (driving a LED or Laser diode). As the spreading sequence is coded following a pseudo-noise algorithm, only the receiver synchronized to that code would obtain the original narrowband signal. For another receiver using a non-synchronized replica of the code, or a different sequence, the signal delivered to the decision stage will be almost white or colored noise. As the power of the original data signal is also spread throughout the coded-signal bandwidth, the power spectral density (PSD) of the coded signal will become far below that of the data signal (and even below the environmental PSD of noise). This ensures that the interference levels induced by a DSSS emitter are lower than

for a non-spread system. The ratio between the baud rate and the chip rate is known as *process gain G_p* and defines how much the PSD of the signal is reduced (and, in the same way, how much the data bandwidth is spread). The larger the G_p, the more robust the communication will become against interferences (as those produced by illumination or infrared remote controls) or multipath propagation (reduced as the receiver only tracks one replica of the received signal, corresponding to the maximum cross-correlation between received signal and local replica of the code). Other multi-propagated replicas of the emitted signal will have delayed replicas of the code, their correlation values will be lower and will be rejected (figure 1). The effect of external narrowband interference is reduced because the incoming signal is also multiplied by the spread code, so G_p divides the interference level delivered to the decision stage. As the DSSS receiver only is "tuned" to one code, we can establish several simultaneous communications using the same bandwidth without collision by using different codes for each link. The use of this kind of multiple access strategy (known as Code Division Multiple Access or CDMA) is well known in other fields of application such as cellular telephony, and offers interesting possibilities in the indoor infrared channel. It avoids the use of complex protocols as CSMA/CA or CSMA/CD, that are not well-suited to this channel as they need to test the presence or absence of a carrier (and it is not easy in a carrier less system as IR).

III. CONFORMATION TECHNIQUES

We call conformation to a modification of the signal waveform, which pursues to reduce both bandwidth and power consumption. The conformation processes presented in this paper are based in those used on well-known modulation schemes, as could be FQPSK [8] or GMSK [9] and are only suitable for two level digital signals. It consists in the substitution of the transitions between the transmission level of 1's and 0's by smoothed slopes. In this paper, a sinusoidal function or the output of ideal Gaussian or Raised Cosine filter are studied but other conformation families are possible. These waveforms have well-known characteristics that produce high bandwidth reduction and very low distortion with non-linear amplification (allowing lower power-consumption).

Conformation is based in the fact that, given a filter, with finite h[n] there is a finite number of input sequences that if we know the output of the ideal filter to these sequences, we are able to synthesize the filter behaviour to any input sequence. In order to be able to synthesize a filter output, as Gaussian or Raised Cosine, some previous steps are necessary.

● Choose a filter family, filter parameters and approximation, when the impulse response is not finite and must be truncate in order to implement it.

● Take samples from the ideal filter output to different input signals. When pulse dispersion occurs, output depends on more than one input pulse. Samples are quantified and store in a memory (LUT).

● With this memory, a D/A converter, some logic to implement a time basis for memory addressing and an antialiassing filter it is possible to synthesize the filter output.

This work considers the possibility of applying pulse conformation to direct sequence spread-spectrum signals. Modifications on the pulse shape do not require changes on the acquisition or tracking stages of the DSSS receiver, because the cross-correlation between the conformed signal and the non-conformed local-generated code replica is almost similar to the self-correlation of two non-conformed sequences. We shall test three main alternatives: sinusoidal, Gaussian filtering and Raised Cosine filtering.

3.1. Sinusoidal conformation

It consists in the substitution of the abrupt transitions between the transmission level of 1's and 0's by smother curves. Filtering is performed through an IJF digital filter [10] which follows the equation 1, (for the 0-to-1 transition, the 1-to-0 transition is accomplished by its complementary):

$$p(t) = \begin{cases} 0.5 \cdot \left[1 + \cos\left(\dfrac{\pi t}{T_s} \right) \right] & |t| \le T_s \\ 0 & |t| > T_s \end{cases} \tag{1}$$

The comparison between the spectral power density of the conformed and not conformed signals is shown in figure 1. It can be seen that main lobule of the transmitted signal is identical to the non-conformed spread-spectrum case.
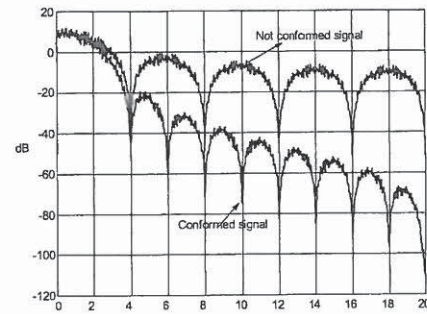

Figure 1: Conformation effect in SPD.

3.2. Gaussian conformation

As in the sinusoidal case, gaussian conformation consists on smoothing the transitions slope [9]. The gaussian filter corresponds with a impulse response (2):

$$p(t) = \frac{1}{\sqrt{2\pi} \cdot \sigma T} \cdot \exp\left(\frac{-t^2}{2\sigma^2 T^2} \right) \tag{2}$$

$$\sigma = \frac{\sqrt{Ln(2)}}{2 \cdot \pi \cdot BT}$$

Where BT is the shaping parameter of the filter, it takes values from 0 to 1, but for our purposes, BT=0.5 is a good compromise between bandwidth reduction and the

maintenance of the BER performances of the transceiver. In figure 3 the time and frequency response signal waveform is presented.

3.3 Raised Cosine Filtering

$$Xrc(f) = \begin{cases} T & \left(0 \leq |f| \leq \dfrac{1-R}{2T}\right) \\ \dfrac{T}{2}\left\{1+\cos\left[f|-\dfrac{1-R}{2T}\ ]\right\} & \left(\dfrac{1-R}{2T} \leq |f| \leq \dfrac{1+R}{2T}\right) \\ 0 & \left(|f| > \dfrac{1+R}{2T}\right) \end{cases}$$

Raised cosine filter family has no finite impulse response, so h[n] must be truncated in order to implement it. Frequency response is more alike to ideal response as h[n] is longer truncated. It means no changes in conformation scheme but a longer LUT is needed. Also delay time is present and the effect of several bits must be considered in order to give the output signal.

For the purpose of compare the performances of both sinusoidal and Gaussian conformation techniques, a DSSS system with a spreading code frequency of 7.5 MHz, and data signal of 125 kHz has been simulated. Thus, the resulting processing gain G_p is 64. We have compared the BER against a medium-band interference (5 MHz) for both techniques and for the non-conformed signal and assuming perfect synchronization. It results that there are no significant differences between both techniques.

Another important consideration is the effect of modifying the waveform over the cross-correlation value on the receiver. DSSS receivers are based on a Tracking-and-acquisition process which requires high cross-correlation values when operating the synchronized code replica at the receiver with the received signal. For a MLS (Maximum Length Code) code with a chip period T_c, we shall assume $R_{xy}(0)$ normalized to 1 for square signals. For a sinusoidal-filtered received signal and a square code replica, the maximum value of R_{xy} is (3):

$$R_{xy}\left(\frac{T_c}{2}\right) = \frac{(\pi + 2) \cdot L + 2 - \pi}{2 \cdot \pi \cdot L} \tag{3}$$

We can observe that the difference between maximum values for large values of L is less than 1 dB. For $t \neq 0.5 \cdot T_c$ the value of $R_{xy}(t)$ tends to be equal to $-1/L$ for both conformed o non conformed signals, but the slope is smoother in the conformed case, resulting in a widening of the cross-correlation function ($3 \cdot T_c$ instead of $2 \cdot T_c$). In figure 2 both cross-correlation results (square with square and square with gaussian-conformed signals) are compared.
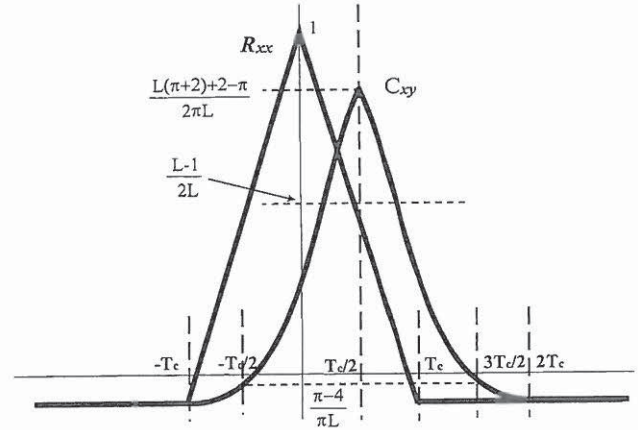

Figure 2. Self-correlation of two non-conformed sequences (R_{xx}) and cross-correlation of a sinusoidal-conformed and a non-conformed sequence

IV. SYSTEM IMPLEMENTATION.

In this section, we describe the implementation of a prototype to test the performances of different conformations over an optical DSSS real system. The chip rate is 7.5 MHz while the bit rate is 125 KHz. These give us a process gain of 64 (18 dB). DSSS system is based on an ALTERA EPLD 7128SLC84. As DAC we have used an INTERSIL HI1171 and after the DAC, an active-resistive filter [11]. The optical transceiver uses a laser diode SHARP LTO27 with 5 mW of output power, and a HAMAMATSU C5351-03 APD module as receiver. For the conformation stage, (figure 3) we have selected a full-digital, look-up table based implementation. It is necessary previously, to know the output curves of the conformation filters in order to quantify and store them in look-up tables. For example with a gaussian BT=0.5 conformation and four samples per bit, the quantified samples are:

Analogical samples	Quantified levels	Codified levels
1	255	11111111
0.8080	231	11100111
0	128	10000000
-0.8186	23	00010111
-1	0	00000000

The conformed signal generation consists in a selection of the corresponding memory address in order to perform a digital-to-analog conversion of the samples to obtain the output curve from the look-up table values.
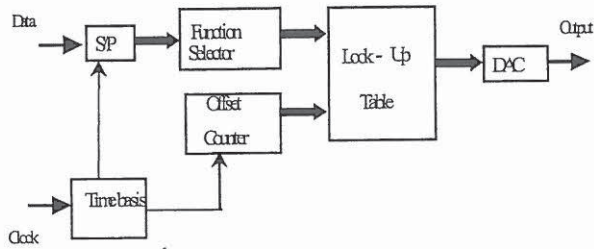
Figure 3: Conformation scheme

This digital implementation allows the use of the same circuit to perform conformation for any frequency (or any desired output waveform) of the input sequence. We only have to change the system clock of the conformation circuit in order to accept the new sequence rate, or the samples in the look-up tables for changing the waveforms. The length of the shift register (S/P) and the size of the memory depend on the pulse dispersion and family of curves (sinusoidal, Gaussian, Raised Cosine). After the DAC an antialiassing filter is necessary. In this prototype an active-resistive filter is used. This filter uses no Capacitors or inductors. In order to change the cut-off frequency or the Gain, the resistor values must be changed [11], [12]. Burn-Brown OPA4650 is used for the anti-aliasing filter. General block-diagram of the transceiver can be seen in figure 4
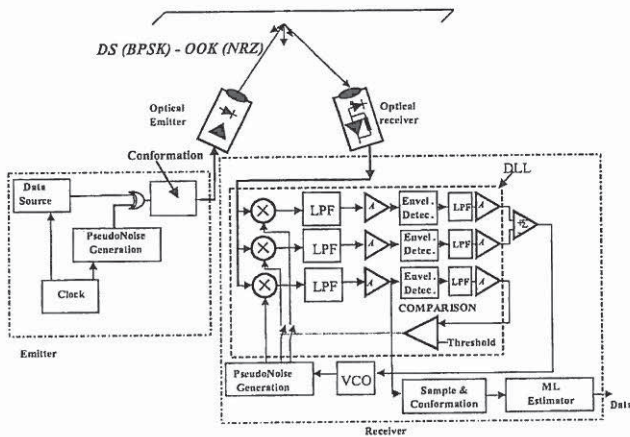

Figure 4: Block Diagram of the WIR-DSSS system

Transmission module is the modem simplest block, as it is an entirely digital circuit, except DAC converter. It consists of : a code generator block ; a conformation stage, implemented with the schemes before explained ; and an output amplifier. All digital circuits are integrated in a programmable logic device (ALTERA EPLD 7128SLC84).

The signal reception system has to perform synchronization and data recovery processes. The receiver is make up of analog and digital circuits: digital part consists of a code generator circuit – implemented in a EPLD device, just like that used in transmission . This code generator is part of a

Sliding Series Correlator (SSC) and a Delay Locked Loop [6], the selected scheme for synchronization in the prototype. Analog elements carry out signal amplification and correlation process needed in the detection procedure.

V. MEASUREMENTS AND RESULTS.
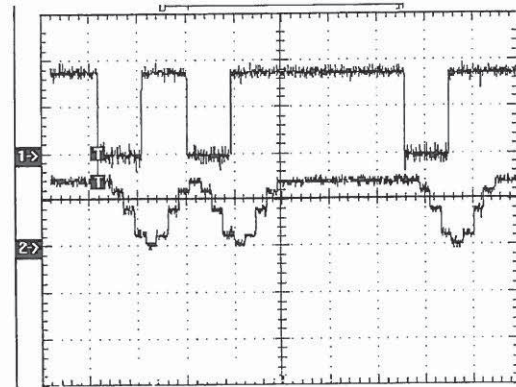
In Figure 5 we can see the output of the DAC:

Figure 5: DAC Output

The anti-aliasing filter make the curves smother as is shown in Figure 6
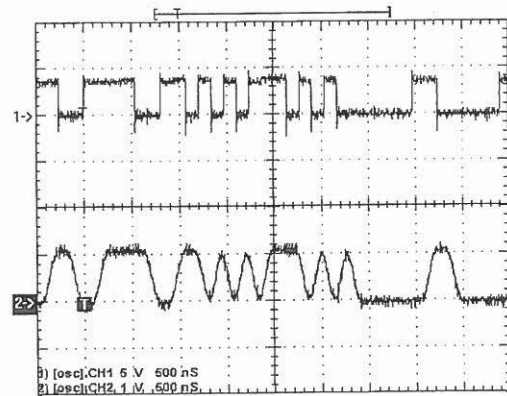

Figure 6: Anti-aliasing Filter Output

In figure 7 the sideband lobe reduction in the DSSS signal is presented. For example, for the gaussian filter compromise solution (with B·T=0.5) this reduction is about 30 dB. This results in a much lower co-channel interference (when maintaining the separation between channels).
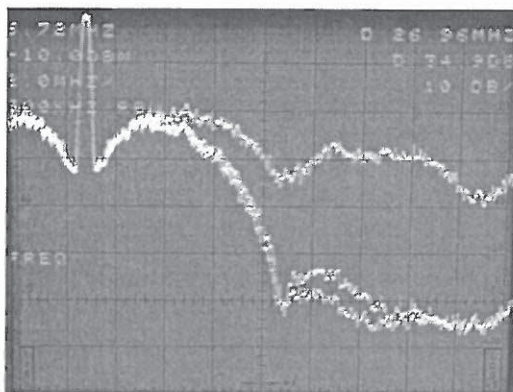
Figure 7: Effect of conformation in lobes attenuation.

The eye diagram of the received DSSS signal with sinusoidal conformation is shown in figure 8.
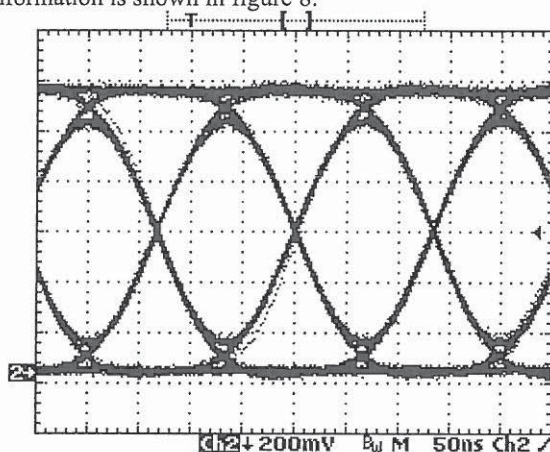

Figure 8. Received eye diagram for sinusoidal conformation

VI. CONCLUSIONS

In this work, we have seen that the use of conformation techniques for DSSS systems introduces some advantages, as a lower bandwidth and power consumption. On the other hand, conformation requires more complex circuits. These modules have to be incorporated in the transmission devices, but not in the receivers, which do not require further modification to work. For implementing the conformation process, we are using full-digital PLD based circuits, avoiding the use of analog filters or expensive digital signal processors. They only need a logical decision circuit, a memory-based look-up table and a digital to analog converter. All these structures can be easily implemented at working baud rates (about 1-2 Mb/s).

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