Self Intersymbol Interference Reduction in Chirp Spread Spectrum Communication Systems

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Abstract

In this paper we proposed new method for self intersymbol interference reduction in chirp spread spectrum (SS) systems. Method is based on the design of compression filters with low sidelobes and preserved main lobe width.

1. INTRODUCTION

Digital radio communications in heavily distorted indoor environment are limited by the communication channel characteristics. Due to the very reflective and shadowing environment, depending on building type, radio signal propagates over multiple paths. Multipath propagation leads to signal distortions in time (delay spread), frequency (Doppler spread) and space (angle spread) domain. In addition, electromagnetic emissions from other devices and radio spectrum users introduce interference in communication channel. Spread-spectrum signals in these conditions have substantial inherent advantages.

The spread-spectrum technique is especially well suited to provide a reliable data transmission in an multipath environment. The key operations in spread-spectrum systems are spreading in the transmitter and despreading (compression) in the receiver. Techniques of frequency hopping and direct-sequence require complicated circuits for compression code synchronization. Using chirp modulation for binary data communications first proposed in [1], synchronization circuits are eliminated [2].

Chirp modulation has been considered for many applications: radar, sonar, data transmission in high-frequency (HF) band, multiple-access spread-spectrum communications [3,4], wireless local area networks (WLAN) communications [5-9].

In [2-9] low cost chirp spread-spectrum system is proposed for combating the multipath distortions in an industrial and office surroundings. Proposed chirp SS systems are limited due to self intersymbol interference which appears because of consecutive symbols and its time sidelobes overlapping. In this paper procedure for self ISI reduction in chirp SS systems is proposed.

In chapter 2 the fundamentals of chirp SS communications system are given. In chapter 3 self ISI problem is described and new way for its reducing is proposed. Results are given in chapter 4.

2. CHIRP SPREAD-SPECTRUM SYSTEMS

In radar systems signal has to spread over a time as long as it is possible, so it gains more energy for given peak power, but in the other hand, it has to have as wider bandwidth as it can to achieve better resolution. Therefore, it is necessary to have large time (T) and bandwidth (B) product. These requirements can be fulfilled by introduction of intrapulse frequency or phase modulation, i.e. waveforms which, for a given pulse duration (T), have bandwidth wider than \( B = 1/T \) \( (TB > 1) \). So, the extensive radar range can be achieved with a low radiated peak power without a loss of bandwidth and resolution. First applied method for spectrum spreading in radars was linear chirp intrapulse modulation. This technique is later proposed for applications in communication [1].

![Fig. 1 Chirp SS communication transceiver](image-url)

In [2,5-9] is proposed technique with overlapping of consecutive chirp signals in time.

SAW delay line, chirp generator, is stimulated with impulse burst from information source (Fig. 1). At the output, sum of time delayed chirp signals is produced. In the receiver, matched chirp compression filter for signal detection is applied. Spectral components are summed at the compression filter output and signal energy distributed in the interval \( T \) is compressed to pulse interval \( 1/B \).

Information bit interval \( T_i \) has to be greater or equal to...
pulse interval, i.e. $T_i \geq (1/B)$. Date rate, therefore, is limited by compressed pulse interval, and not by chirp signal duration $T$.

Complex linear chirp envelope is given by
\[
\mu(t) = e^{j\pi t^2} \text{ for } |t| < \frac{T}{2},
\] (1)

and envelope of matched filter response is
\[
g(\tau) = \sqrt{TB} \frac{\sin \left( \frac{TB \tau(1 - |\tau|/T)}{\pi B \tau} \right)}{\pi B} \text{ for } |\tau| \leq T. \tag{2}
\]

In the expression (2) envelope shape is $\sin(x)/x$ with sidelobe level of -13.26 dB.

3. SELF ISI REDUCTION

The sidelobes of one pulse spread into adjacent symbol intervals so as to interfere with detection process. Even in the absence of noise result of an unsatisfactory filtering process is appearance of the ISI. Self ISI in chirp spread spectrum communications causes system performance degradation (higher error rates).

A usual method of reducing the sidelobes is to apply amplitude weighting of the chirp filter (or input chirp signal). However, the mainlobe of the compression filter’s response (output pulse) becomes wider by window utilization. Let the $w$ index of output pulse width, so $w=1$ for chirp filter and $w>1$ for weighted chirp compression filter. Information bit interval has to be $T_i \geq w/B$. Thus, maximal achievable data rate is decreased $w$ times. Square-root weighting by Hamming window of the filter transfer function magnitude reduces sidelobes of compressed pulse to –42.8 dB. Thus, mainlobe becomes wider 1.47 times at the 3 dB from the peak ($w=1,47$).

Problem of self intersymbol interference in chirp SS systems is comparable to the problem of self clutter in SS radar systems. In this paper we proposed algorithm for compression filter design with suppressed sidelobes and preserved mainlobe width. On the basis of minimax modification of the closed form of the LS (Least Square) [10, 12] and ECF modifications of minimax algorithms [11] procedure for maximal sidelobe reduction of compression filter is developed. As minimax criterion weighed square error is used:

\[
\varepsilon = e^T R e,
\] (3)

where matrix $R=\text{diag}(r)$, and $r$ is the weighting vector,

\[
r_n = r_{n-1} \cdot e_{n-1}.
\] (4)

Solution which provides estimated filter coefficients $\hat{x}$, and minimizing error $e_n$ is given in the form

\[
\hat{x}_n = \left( S^T R_{n-1} S \right)^{-1} S^T R_{n-1} d,
\] (5)

where signal matrix $S$ has a Toeplitz structure and $d$ is a preferred filter response. Previous expression performs basic formulation of the iterative reweighted LS algorithm (IRLS). During the iterative procedure the vector $r_n$ is modified through multiplication with error vector (4). Estimation error at the end of the $n$-th iteration is evaluated as

\[
e_n = \zeta - \left| X_{n-1} \right|.
\] (6)

where $X_{n-1}$ is the normalized filter’s response in the $(n-1)$-th iteration, and $\zeta$ is the error window defined as rectangular window at position where the mainlobe is placed. The widths of both the error window and mainlobe are the same. Iterative design procedure take care of output pulse width.

4. RESULTS

To illustrate efficiency of the proposed method compression filter for chirp with slope $k=64$ and $T=1$ is designed.

Compression filter response to one input chirp signal can be seen in Fig. 2. Chirp compression filter response is shown at the same picture by the curve a) (dashed line) and by the curve b) (solid line) IRLS compression filter response with reduced sidelobes.

![Fig. 2](image)

Fig. 2 Comparison of a) a matched chirp compression and b) IRLS compression filter responses for one input pulse.

If the bit sequence is carried at the receiver input, sidelobes will be summed at the decision moment and a probability of false detection will increase. This effect is more emphasized for higher date rates.

Figures 3 and 4 show compression filters responses when at the input of chirp SS system comes following bit sequence ‘1011011’. It is assumed that there are no signal distortions in communication channel. Designed IRLS compression filter response is shown by the curve b) (solid line), chirp compression filter is shown by the curve a) (doted line) and Hamming weighted chirp compression filter by the curve c) (dashed line). Information bit interval $T_i$ is $2/B$ and $1.5/B$ at the figures 3 and 4 respectively.
It can be noted that Hamming window and IRLS filter application achieve much lower sidelobes. However, with IRLS compression filter mainlobe width stays unaffected.

![Fig. 3 Comparison of a) a matched chirp b) IRLS and c) Hamming weighted chirp compression filter responses for input bit sequence ‘101101’ and $T_i=2/B$.](image)

![Fig. 4 Comparison of a) a matched chirp b) IRLS and c) Hamming weighted chirp compression filter responses for input bit sequence ‘101101’ and $T_i=1.5/B$.](image)

5. CONCLUSION

Robustness and significant immunity to the strong multipath distortion effects as well as a low cost and power consumption make the chirp spread-spectrum systems attractive for commercial use. The achievable data rate is limited by the chirp signal duration, by the mainlobe width when chirp signal is overlapping, and by ISI produced due to high sidelobes level. Sidelobes suppression is successful when an amplitude weighting of chirp filter impulse response or its transfer function is applied, but mainlobe becomes wider. Maximal data rate, in this way, is additionally decreased.

Presented technique gives compression filter output with unchanged mainlobe width and reduced sidelobe (self ISI) level.

REFERENCES


