VOLTERRA FILTER APPLICATION IN DS-SS RECEIVER FOR NARROWBAND INTERFERENCE SUPPRESION

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SUMMARY

The direct sequence spread spectrum (DS-SS) transmission system offers a promising solution to an overcrowded frequency spectrum amid growing demand for mobile and personal communication services. The overlay of DS-SS signals on existing narrowband users implies strong interference for DS-SS systems. In this paper, it will be shown how the application of linear and non-linear estimators in the DS-SS receivers can suppress this interference. In our consideration, Wiener filters (WF) and Volterra filters (VF) will be used as the estimators. These filters will be included between demodulator and despreading stage of a conventional receiver. Then, the received signal is passed through the estimator, which suppresses the narrowband interference prior to detection. In order to demonstrate the ability of discussed DS-SS receivers to suppress interference, a number of computer experiments will be done. The results of the experiment will show that the application of VF in DS-SS receivers can outperform the WF application or DS-SS receivers based on simple application of matched filter (MF) in a significant way.

Keywords: *spread spectrum, Volterra filter, receiver structures, interference suppression.*

1. INDRODUCTION

In the modern mobile communication systems, reusing of the frequency band already allocated to some fixed communication system is a promising opportunity. The DS-SS systems can share common spectrum with the currently operating cellular or fixed microwave system in order to achieve efficient bandwidth utilisation. In this case, the signals of coexisting users appear as narrowband interference in the spectrum of DS-SS signals. The DS-SS transmission systems can operate successfully in the presence of the strong co-channel interference if the processing gain is high enough. If the interference due to co-channel transmission is very strong or if the processing gain is limited due to bandwidth constraints, DS-SS receiver based on simple MF usually cannot provide acceptable bit-error-rate (BER). In order to solve the problem, some advanced structures of the DS-SS receivers can be applied [1].

In this paper, the DS-SS receivers based on linear and non-linear estimator will be described. In the conventional receiver structure between demodulator and despreading stage the estimator is included. The estimator provides extraction of demodulated spreaded signal from the noise. Because of signal pre-processing performed by the estimator, signal to noise ratio before signal despreading operation is higher than that of conventional receiver based on simple MF application. It can result in the improvement of BER characteristics in a significant way.

In our consideration, WF and VF will be applied as the above-mentioned estimators. In order to demonstrate the performance properties of VF and WF based DS-SS receiver, a number of computer experiments has been done. The results of the experiments, expressed as BER vs. signal to interference ratio (SIR) have shown that in the case of DS-SS receivers based on the third order VF outperforms DS-SS receivers based on MF, WF or the second order VF.

2. INPUT SIGNAL MODEL OF DS-SS RECEIVER

The signal that appears at the input of the receiver consists of three components. They are the BPSK DS-SS signal distorted by a linear transmission channel ($x(t)$), narrowband interference ($i(t)$) and additive white Gaussian noise (AWGN, $n(t)$) with power spectral density at the receiver input N_0. The AWGN level will be expressed by ratio E_b / N_0 (information signal energy per bit to noise power spectral density). All three-signal components are supposed to be independent and stationary signals. Then, the input signal to the receiver is given by

$$y(t) = x(t) + i(t) + n(t) \tag{1}$$

The BPSK DS-SS signal $s(t)$ can be modelled as

$$s(t) = U\, PNS(t)\, d(t) \cos\left(\omega_0 t\right) \tag{2}$$

where U, ω_0, $PNS(t)$ and $d(t) \in \{+1,-1\}$ represent amplitude and angular frequency of the carrier, the pseudo-noise sequence (spreading code) of chip duration T_C and transmitted information baseband signal of bit duration T, respectively. Then, BPSK DS-SS signal distorted by a linear transmission channel with an impulse response $h(t)$ is given by

$$x(t) = h(t) * s(t) \tag{3}$$

where * denotes the convolution operation.

The discrete representation of narrowband interference $i_N(n) = i(nT_S)$ is modelled by

$$i_N(n) + \sum_{k=1}^{p} a(k) i_N(n-k) = e(n) \tag{4}$$

where T_S is sampling period of $i_N(t)$ and $e(n)$ is a white Gaussian process with variance σ_e^2. A process $i_N(n) = i(nT_S)$ generated by the above model is known as the p-th order autoregressive process ($AR(p)$) [3].

3. DS-SS RECEIVER STRUCTURES

The simplest DS-SS receiver is based on MF filter application [1]. Its structure is illustrated in the Fig.1. Here, as the MF, L-tap linear FIR filter is applied. Its impulse response is equal to the spreading code $PNS(t)$. It follows from the MF theory, that a MF is optimum when a filtered signal is impaired by AWGN. However, this assumption is not valid in the case of broadband or narrowband interference or in the case of multi-user interference (e.g. CDMA communication systems). Therefore, the receiver structure based on the MF application (Fig.1) cannot be considered as optimum generally.

In order to improve the receiver performance, the modified structure of DS-SS receivers equipped by an estimator can be applied. Fig.2 shows how the estimator fits into DS-SS receiver structure. The estimator extracts demodulated spreaded signal from noise. This signal pre-processing operation can improve signal to noise ratio (SNR) before signal despreading. It can result in the improvement of BER characteristics of the receiver in a significant way. As the estimator a number of conventional or advanced digital filters can be used. In the next, WF and VF will be proposed for that purpose (e.g. [1,4,5]).

4. VOLTERRA FILTERS, WIENER FILTERS

The VFs are minimum mean-square non-linear estimators mathematical model of which is represented by a truncated discrete Volterra series [3,4]. The mathematical model of the M-th order VF memory span of which is $N = N_1 + N_2 + 1$ samples long (VF(M,N)) is given by

$$w(n) = h_0 + \sum_{i=1}^{M} \sum_{k1=-N_1}^{N2} \dots \sum_{ki=-N_1}^{N_2} h_{i,k1,\dots ki} v(n-k1)\dots v(n-ki) \tag{5}$$

In this expression $v(n)$ and $w(n)$ are the input signal and the filter response, respectively. The i-dimensional sequence $h_{i,k1,k2,\dots,ki}$ is called the Volterra kernel of the i-th order. The order M of the VF is defined by the number of the highest order of the Volterra kernel which can be found in (5). The length of the VF memory span is given by the number of the mutually different samples of the input signal, which can be applied in the VF response computation.

With regard to (5), the well-known WF(N) can be defined as the first order VF (i.e. VF(1,N)). The details concerning the design and performance properties of time-invariant and adaptive VF and WF can be found e.g. in [2,4,5].

5. EXPERIMENTAL RESULTS

In this section, a comparison of performance properties of the BPSK DS-SS receiver based on a simple MF (Fig.1.) with its modified version including estimator (Fig.2.) is presented.

In all experiments, the transmission model described in the section 2 was used. The parameters of the BPSK DS-SS signal $s(t)$ were $U = 1$ and $\omega_0 = 2\pi F_S / 4$, where F_S stands for sampling frequency. As the pseudo-noise sequence of chip duration $T_C = 4 / F_S$, the Gold sequence of the 7-th order (7 chips) was applied. The bit duration of information baseband signal was set to $T = 28 / F_S$.

The power spectral density of AWGN at the receiver input was set in such a way as $E_b / N_0 = 13\,dB$.

As the channel model, the linear time-invariant system represented by the FIR filter of the 15-th order was used. The filter passband was centralised at the carrier frequency ω_0 and its bandwidth was set to $B_{CH} = 1.2\, B_{MIN}$ where B_{MIN} is the minimum bandwidth for the BPSK DS-SS signal transmission.

In the case of the estimator based receivers (Fig.2.) time-invariant WF and VF were applied. For

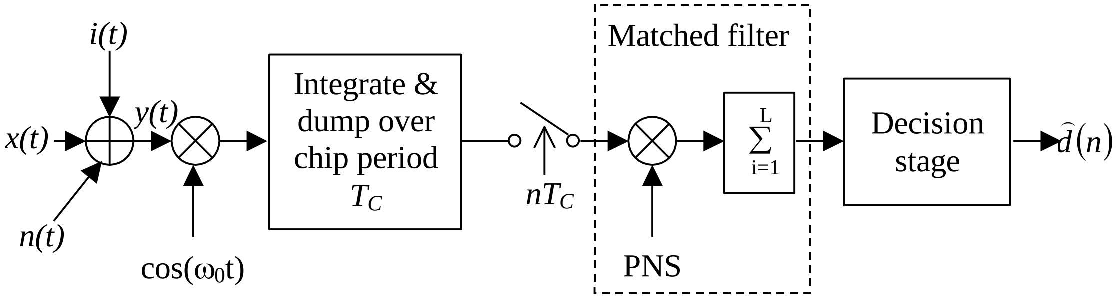

Fig.1 The DS-SS receiver structure based on simple MF

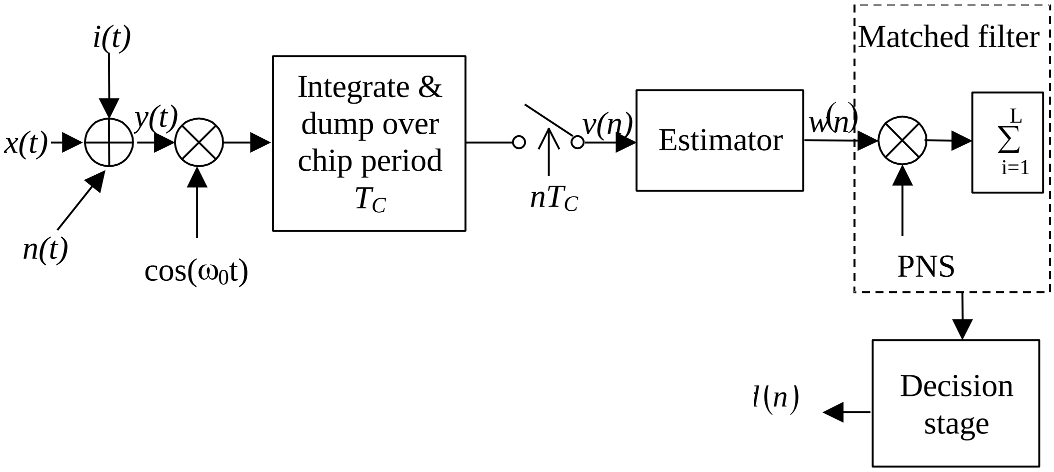

Fig.2 The DS-SS receiver structure based on estimator application

their design the methods described in [2,4,5] were used. In order to estimate the correlation and crosscorrelation functions (conventional as well as higher-order ones) necessary for the WF and VF design, the training sequence consisting of 200 information bits was transmitted before each information date sequence transmission. The original training sequence was available at the receivers for the purpose of filter design. In all experiments, perfect synchronisation of the BPSK modulator and demodulator and the DS-SS modulator and MF is assumed.

As the performance indices of the tested DS-SS receivers, the SNR at the MF input vs. SIR and BER vs. SIR were used, where SNR and SIR are defined as:

$$SNR = 20.\log \frac{E[d^2(n)]}{E\left[\left(\hat{d}(n) - d(n)\right)^2\right]} \qquad (6)$$

$$SIR = 20.\log \frac{E[s^2(t)]}{E[i^2(t)]} \qquad (7)$$

In the experiment illustrating the narrowband interference suppression, the interference $i(t) = i_N(t)$ was set to the $AR(2)$ defined by (4). The magnitudes of complex conjugate poles p_1 and p_2 of $H(z)$ were set to 0.99. The arguments of p_1 and p_2 were set to $\omega_0 + 2\pi f_1$ where $f_1 = 0.005F_s$.

For the purpose of receiver performance property evaluation, the date stream consisting of 10^6 information bits (not including training sequence) was used. The results obtained for the MF, WF(N) (N=5,7) and VF(M,N) (M=2,3 and N=1,3,5) are given in the Fig.3 and Fig.4. In the Fig.3, the signal to noise ratio at the MF input SNR versus SIR is given.

It can be seen from these figures, that for $SIR \in < -35\,dB, -2\,dB >$ the best results are provided by VF(3,3) and VF(3,5). It is caused by the fact that narrowband interference is much more stronger than signal and AWGN within this region. Thus, MF which is optimal only in case of AWGN, is outperformed by the VF(3,3) and VF(3,5). For $SIR \in < -2\,dB, 10\,dB >$ narrowband interference is becoming smaller and therefore MF provides better results than other tested receivers. The VF(3,1) possesses no memory and so its achieved results are the worst from all tested receivers.

The obtained results supports our considerations presented in the section 3 concerning the correlation between SNR and BER, too. It can be seen from the Fig. 3., that the application of VF(3,N) (N=1,3,5) can improve the level of SNR. Based on this improvement, significantly better results provided by VF(3,N) are obtained in comparison with that of the MF, WF(N) and VF(2,N).

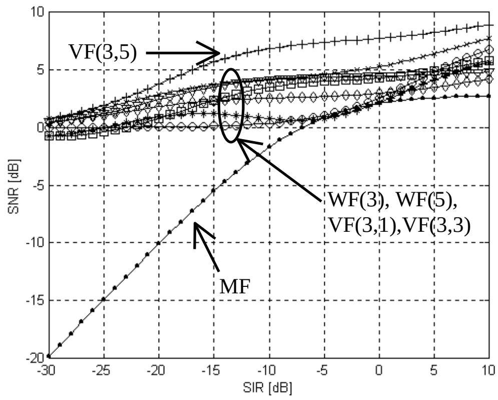

Fig.3 *SNR* vs. *SIR*

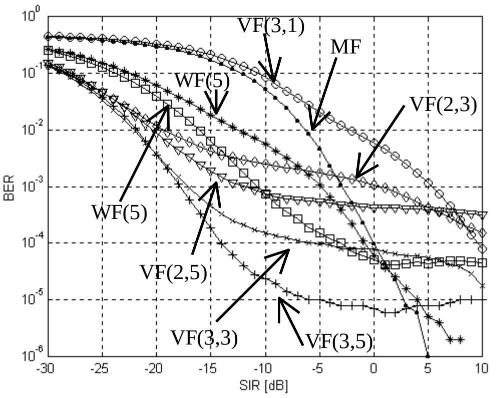

Fig.4 *BER* vs. *SIR*

6. CONCLUSION

In this paper, the BPSK DS-SS receivers based on linear and non-linear estimators have been described. The analysis of their performance properties based on computer simulations has shown that the structures of BPSK DS-SS receiver based on VF(3,N) provide the best results in the case of narrowband interference. The significant improvement of BER results provided by VF(3,N) is reached when the variance of interference is much more higher then that of information signal (e.g. $SIR < -5dB$). This improvement of BER versus SIR is reached in the cost of much more higher computational complexity of VF(3,N) in comparison with that of the MF. If variance of interference is comparable or smaller then that of information signal (e.g. $SIR > -5dB$) all tested receivers have provided approximately the same results. It follows from these facts, that BPSK DS-SS receiver based on VF(3,N) can be applied with advantage in the case of very strong narrowband co-channel interference.

It follows from the obtained results that the applications of WF(N) or VF(2,N) in the receiver structure do not provide any meaningful improvement in SNR and BER. In the case of the VF(3,N) design the sixth order correlation and crosscorrelation functions are also used. On the other hand, at the design of WF(N) and VF(2,N) only the second and the fourth order correlation and crosscorrelation functions are used. It follows from these facts that improvement SNR and BER is obtained based on information on processed signals included into the sixth order correlation and crosscorrelation functions.

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BIOGRAPHY

Dušan Kocur was born in 1961 in Košice, Slovakia. He received the Ing (MSc) and CSc (PhD) degree in radioelectronics from the Faculty of Electrical Engineering, Technical University of Košice, in 1985 and 1990. He is Associate Professor at the Department of Electronics and Multimedia Communications of his Alma Mater. His research interest are digital signal processing, especially in linear and nonlinear time-invariant and adaptive digital filters, higher order spectra, CDMA systems and psychoacoustics.

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