A low-complexity PAR reduction method for WFMT System

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Abstract: - This paper discusses a simple method of Peak to Average Power Ratio (PAR) reduction developed for system with WFMT modulation. The novel Wavelet based Filtered Multi-Tone (WFMT) modulation was proposed as an alternative of the Discrete Multi-tone line code for xDSL system and represents future extending of OFDM/ DMT technologies. Because of multicarrier nature of WFMT modulation, it is well suited to carry high-speed data over a wide frequency band. As it is well known, the major drawback of the multicarrier system is the large PAR of the transmit signal, which renders a straightforward implementation costly and inefficient. In this paper, we describe a new PAR reduction technique based on an overlapping structure of a WFMT signal. We examine the WFMT PAR characteristics by SIMULINK Model of a Cable TV Broadcast System, described in [1]. The results illustrate a significant PAR reduction of the WFMT transmit signal when the proposed method is used.

Key Words: - FMT, filter-bank, Cable TV, OFDM, PAR, multicarrier.

1. Introduction

The major drawback of the multicarrier system is a large envelope fluctuation of the transmitted signal. This is usually quantified by a parameter called Peak-to-Average Power Ratio (PAR). Since most practical transmission systems are peak-power limited, designing the multicarrier system to operate in a linear region often implies operating at power levels well below the maximum power available. Therefore, the multicarrier system characterizes a low power efficiency which is especially important in applications where power sources have limited capacity. For example, the power efficiency of the WiMAX solid-state power amplifiers is less than 5% in the case of transmission of OFDM signal with PAR about 12 dB. Therefore, the multicarrier systems are not used in aerospace and satellite communications. In the WiMAX terrestrial broadcasting systems the low power efficiency of the transmitter limits the maximal distance to the serviced customer.

A number of approaches have been proposed to deal with the PAR problem in OFDM systems. These techniques include amplitude clipping [13], clipping and filtering [18], coding [13–21], tone reservation (TR) [13], tone injection (TI) [15], active constellation extension (ACE) [16], and multiple signal representation techniques such as partial transmit sequence (PTS) [13,14], selected mapping (SLM) [13,15], and interleaving [13]. These techniques achieve PAR reduction at the expense of the transmit signal power increase, bit error rate (BER) increase, data rate loss, computational complexity increase, and so on.

Theoretically, the PAR in a multicarrier system depends on a number of sub-channels and can be decreased significantly for a low number of sub-channels (N<32) [10]. Unfortunately, the OFDM system with such low number of sub-channels generates a high level of side-lobes which decreases a spectral efficiency of the communication line.

During last years, the concept of multicarrier transmission has been generalized with introduction of filter-bank multicarrier systems [1, 3]. In filter-bank based systems, the data symbols are transmitted over different sub-channels after suitable pulse shaping. In particular, the pulse shape in filter-bank system is significantly longer than the sub-channel symbol period, so, unlike OFDM the pulse waveforms of different symbols overlap in time. The number of carriers in filter-bank systems is significantly less than in OFDM system with the same bandwidth. Therefore, the filter-bank multicarrier system characterizes lower PAR than OFDM system.

A novel Wavelet based Filtered Multi-Tone Modulation (WFMT) was developed by Roman M.

Vitenberg in 2002 –2003 years [4]. A new DSP algorithm realizes a low complexly WFMT core that can be implemented in a small silicon chip. The new algorithm was published in [5], [6].

The Peak-to-Average Power Ratio Problem in WFMT system was studied in [10]. In this paper it was shown, that WFMT system with low number of sub-channels has significantly lower PAR than OFDM signal.

Most of the known methods of the PAR reduction, which were developed for OFDM, can be used in the WFMT system. In addition, a novel method of the PAR reduction can be proposed for a WFMT system. This method is based on using of an overlapped wavelet structure of the WFMT signal, and will be described below. The rest of paper is organized in the following way: Section II describes a novel WFMT modulation. In Section III a new low complexity PAR reduction method, developed especially for WFMT technology is proposed. The results of the computer simulation of the proposed PAR reduction technique will be presented in Section IV, followed by the conclusion.

2. WFMT Modulation.

The principle of a WFMT modulation was described in [4]. Figure 1 illustrates a block diagram of the WFMT transmitter.

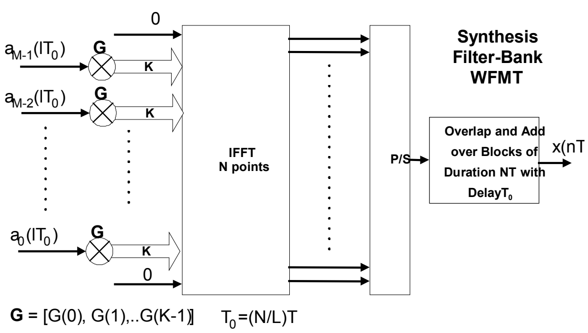

Figure 1. WFMT Transmitter

The WFMT transmitter uses an N point IFFT processor and transmits M data streams a_i each at rate $1/T_0 = L/(NT)$, where T is a sampling period and L is the number of overlapped wavelets. As shown in Fig. 1, each data stream a_i modulates a group of K inputs of IFFT core to provide the spectrum of the corresponding sub-channel wavelet. Some of the outermost data streams can be set to zero for spectral containment reasons. Finally, the spectrum components are passed through the IFFT, P/S converter. An overlap and a sum operation takes place to obtain the synthesized multicarrier signal. At the receiver side, after amplification, and A/D conversion, the received WFMT signal is processed by the analyses filter-bank that implements demodulation of the sub-channels wavelets. The analysis of the sub-channel wavelets is provided by the analysis of its frequency components by an FFT. To compensation the distortions introduced by the frequency selective fading channel authors propose to use a simple equalization scheme.

One of the significant advantages of the WFMT modulation is a very precise equalization algorithm that allows compensating the distortion of the communication channel. This algorithm includes an independent correction for each frequency component of a transmitted wavelet.

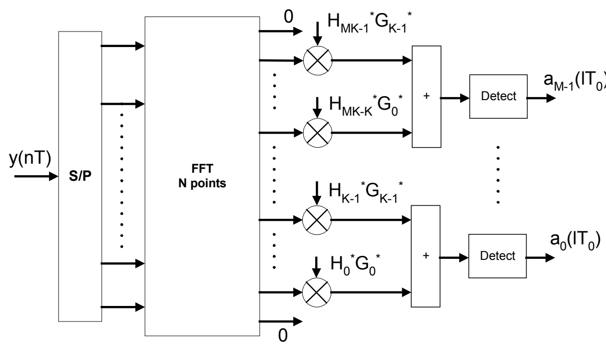

Figure 2. WFMT Receiver

Figure 2 shows a block diagram of the WFMT receiver. This device consists of a matched filter bank, whose filters are matched to the equivalent sub-channel response [6]. Instead of a well-known polyphase filter-bank, the WFMT receiver includes 1024 point FFT core that provides analysis of frequency components of received wavelets. Each received wavelet component on the output of FFT is multiplied on an equalizer coefficient H_j for compensation of distortion in the communication channel. The received information data a_i is calculated for each sub-channel by summing the weighted (G_i) wavelet components. Now we describe in detail how the overlapping of the sub-channel wavelets is takes place. A functional diagram of an Overlap and Adder Block (OAB), which produces the line WFMT code, is shown in Figure 3. This block provides an overlapping of L sequential wavelets, which come from output of IFFT core. This device comprises a shift register and adder .

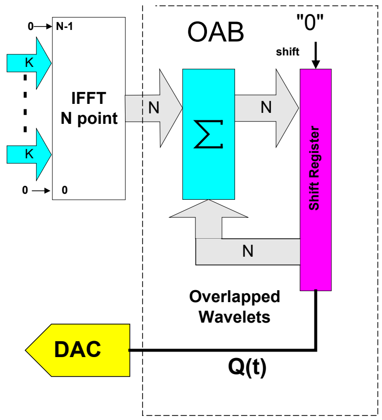

Figure 3. Overlap and Adder Block

An IFFT core generates sequence of non-overlapped wavelets **A, B, C…** , which appear with frequency $f = 1/T_0$. The current non-overlapped wavelet is added to contents of shift register SR. After this operation, the content of the shift register SR is shifted on N/L position to the right. During a shift operation, the SR input is connected to the ground and at the end of the shifting the N/L last words of FIFO are "0". The sequential data, that appears on output of the SR passes to Digital-to-Analog Converter (DAC). The DAC output signal comprises overlapped wavelets – WFMT line code. These wavelets are shifted on interval T_0 between each other and have length $\tau = LT_0$. A time diagram of the overlapping process is shown in Figure 4.

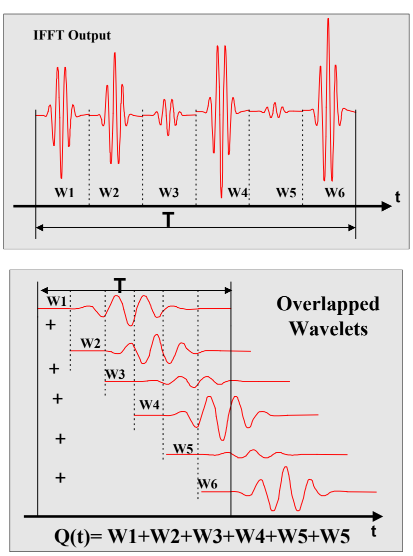

Figure 4. The overlapping process timing diagram

3. A PAR reduction method for WFMT system

Amplitude clipping is a frequently used method of PAR reduction in multicarrier system. The Idea of this method contains a non-linear limiting of peaks of the transmitted signal. Therefore, the clipping produces a special kind of noise (*clipping noise*) that generates errors in the receiver. These errors can be corrected by error correction coding of transmitted data. For this reason, in multicarrier systems the Reed-Solomon block codes and interleaving are used. Such high efficient error protection is able to correct the error packets with length up to 100~200 us. Of course, the additional signal filtering can decreases the clipping noise, but this operation requires a complex FIR filter.

The main idea of the proposed PAR reduction method is to transmit only wavelets, which do not generate high signal peak, instead of clipping of peak of a transmitted signal. The wavelets, which generate high signal peaks are not transmitted and must be regenerated in WFMT receiver by the error correction code. The overlapped structure of the WFMT signal, described above, enables to implement this idea. Figure 5 illustrates a functional diagram of an improved Overlap and Adder Block (OAB), which provides a WFMT signal with low PAR.

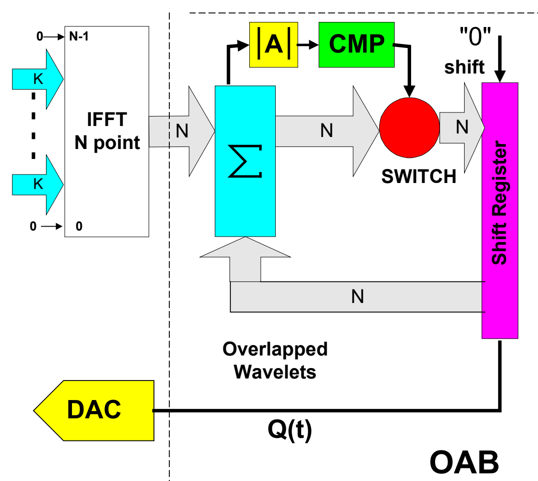

Figure 5. Overlap and Adder Block with PAR reduction

In contrast to the prototype device, which is shown in Figure 4, the new Overlap and Adder Block comprises of a Modulo-calculator |A|, a Comparator

(CMP), and a Switch (SWITCH) which connects between the output of the adder $\sum$ and the input of the shift register (SR). The Modulo-calculator |A| estimates a maximal amplitude of the signal on the output of adder $\sum$. If this maximal amplitude exceeds the predetermined reference level, then the Comparator generates a signal which closes the Switch, forbidding the change of the shift register content. As result, the amplitude of the overlapped wavelets Q(t) does not exceed the said reference level. The proposed device (Figure 5) generates an error packet each time the Switch is closed. Such an error packet has a length equal to the length of one wavelet. Therefore, the described method of the PAR reduction cannot be used in the OFDM system, where the signal symbol (frame) is significantly large than the WFMT wavelet. For example, the length of the WFMT wavelet that was developed for the Cable TV Broadcast WFMT System [9] is only 16us. The error protection in Cable TV system, mentioned above, is provided by RS(204,188) code and interleaver that is able to correct an error packet up to 200us. Of course, all the errors that were inserted by the PAR reduction schematics will be corrected in such a system.

4. The Computer Simulation of the proposed PAR reduction method

The PAR reduction method described above was tested in a Simulink model of the WFMT system. This model has been realized for study of characteristics of the Cable TV Broadcast System [5]. The system comprises of a physical interface, randomization block, forward error correction block and an interleaver in accordance with the current ITU-T J.83 standard.

The physical interface includes input and output FIFO memory blocks, each of them may store up to 512 bytes of data. The randomization block comprises a scrambler with the polynomial for Pseudo Random Binary Sequence (PRBS) Generator equal:

$$Y = 1 + X^{14} + X^{15}$$

The period of the PRBS sequence is 1503 bytes. The Forward Error Correction Block performs a systematic shortened Reed-Solomon encoding on each randomized MPEG 2 transport packet. Up to 8 erroneous bytes per transport packet can be corrected by the used RS (204,188) code. The coding process adds 16 parity bytes to the MPEG 2 transport packet.

The interleaver provides the convolution interleaving over error-protected packets with a depth of I = 12. The interleaver Frame is composed of overlapping error-protected packets and is delimited by MPEG 2 sync bytes (preserving the periodicity of 204 bytes).

The data frame structure is based on MPEG 2 Transport layer that is defined in ISO/IEC 13818-1. A coded information data is converted to a multicarrier wavelet signal that has a 6-MHz bandwidth. This signal passes through RF UP-Converter to the cable network. The integrated WFMT Transmitter performs all DSP operations which are necessary for transforming an information data in IF signal spectrum (41-47 MHz). A Down Converter transfers the received RF signal to IF frequency band 41-47 MHz. An integral WFMT receiver processes the IF signal and decodes the received information data. After de-interleaving and FEC decoding, the corrected data is converted in MPEG 2 Transport stream.

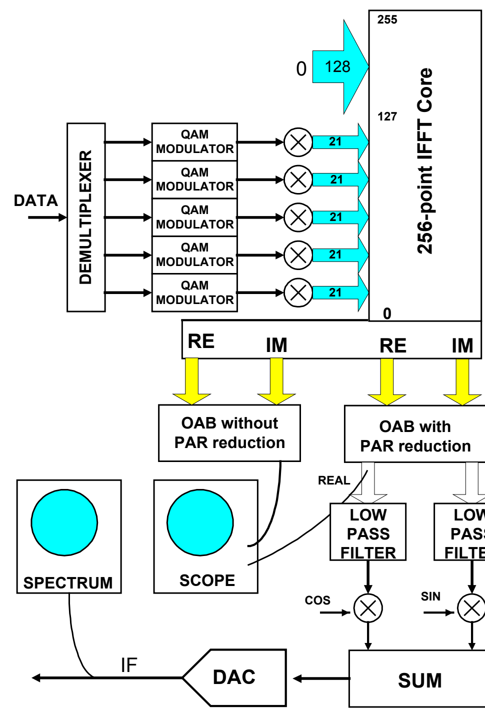

Figure 6. Simulink Model of the WFMT Transmitter

A Simulink Model of the integral WFMT Transmitter is shown on Figure 6. An error-protected and interleaved information data (DATA) comes to input of the demultiplexer, which distributes this data between five QAM-modulators, each of which serves a correspondent sub-channel of the multicarrier WFMT signal. A complex data from output of each QAM-modulator generates a set of 21 frequency components of sub-channel wavelets. All frequency components of all sub-channel wavelets are passed to 256-point IFFT core. Only N= 21*5 = 105 inputs of IFFT core are used for synthesis of WFMT signal. Other inputs of IFFT core are connected to "0". As a result, the IFFT core output signal comprises real and image components. These components are passed over low-pass filters, which are necessary for proper generation of a passband WFMT signal. A Spectral Analyzer demonstrates a Power Spectral Density (PSD) on output of the WFMT Transmitter. After a low pass filtering, real and image WFMT baseband packets are multiplied by cosine and sine of the IF carrier frequency. The SUM block provides a digital IF passband WFMT signal.

This digital IF signal comes on the input of 14-bit Digital to Analog Converter (DAC) that provides an analogy IF passband signal 41-47 MHz on the output of the WFMT Transmitter.

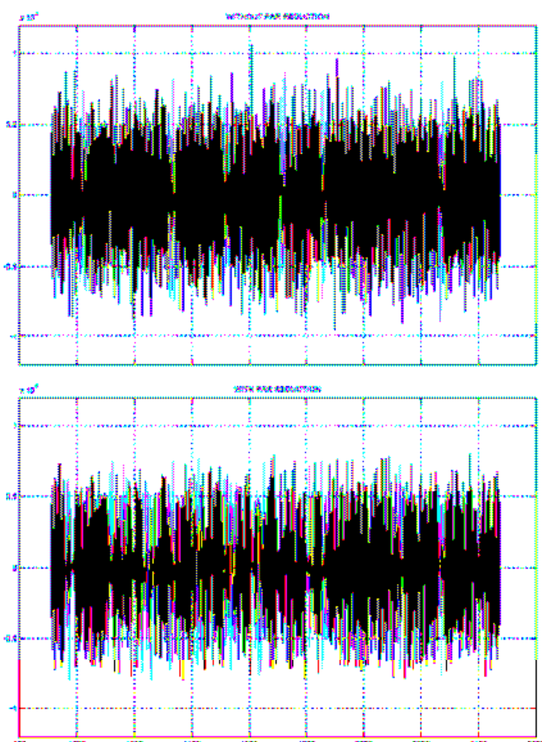

Figure 7. Top - Output signal of OAB without PAR reduction,
Bottom - Output signal of OAB with proposed PAR reduction method.

Two Overlap and ADD Blocks (OAB) are connected to an output of the IFFT core. The first OAB comprises the PAR reduction schematic (see Fig.5), the second OAB does not use a PAR reduction (see Fig. 3). The SCOPE Simulink block shows the outputs signals of both OAB devices. Because both OAB devices are connected to the same outputs of the IFFT core, we can compare the Peak-to-Average Ratio on outputs of two WFMT systems. The first of these systems does not use a special method of the PAR reduction and the second system uses the method of PAR reduction, proposed above. The output signal of OAB device with PAR reduction schematic is shown in Figure 7 (bottom). The output signal of OAB without PAR reduction schematic is shown in Figure 7 (top). As we can see the proposed method provides significant reduction of the Peak-to-Average Ratio in the WFMT system.

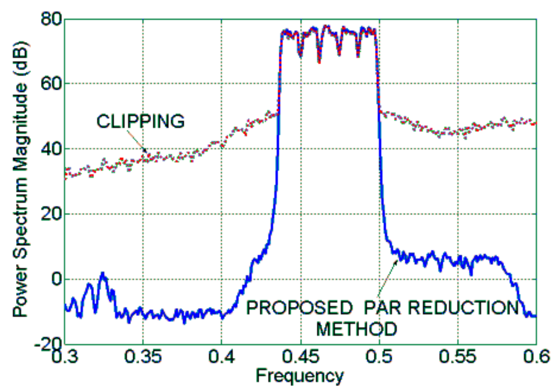

Figure 8. PSD of the WFMT Transmitter.

One of the advantages of the proposed PAR reduction method is the absence of the additional non-linear distortion and noise in the output WFMT signal. Figure 8 illustrates the Power Spectral Density (PSD) of WFMT transmitter in case of using the proposed PAR reduction method and in case of clipping of IF passband signal.

Conclusions

In this paper a novel low-complexity method of Peak-to Average Ratio reduction for WFMT system is proposed. The method uses an overlapped wavelet structure of WFMT signal and an ability of the interleaved Reed-Solomon Code to correct a long error packet. The Simulink model of WFMT system, which uses the proposed method, shows significant decrease of signal peaks. The proposed method does not insert non-linear distortion and clipping noise in the WFMT signal.

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