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A Novel OFDM PAPR Reduction Scheme Based on Selected Mapping

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Abstract: In this study, a novel effective PAPR reduction scheme for OFDM system based on conventional selected mapping technique has been proposed and presented. The proposed PAPR scheme combines two well known PAPR reduction techniques: Conventional Selected Mapping (SLM) and Repeating Clipping and Filtering (RCF). The objective is to enhance the overall OFDM PAPR redaction factor (PRF) and to achieve approximately the same Bit Error Rate (BER) as the original OFDM system. A convolutional code has been selected for the proposed OFDM transceiver as channel coding for error correction and PAPR reduction purpose. The proposed PAPR scheme is referred to as Convolutional Selected Mapping Repeating Clipping and Filtering scheme “CSLM_RCF”. A detailed analysis and performance evaluation of the proposed PAPR scheme are presented. Simulation results show that the proposed PAPR scheme has been achieved a significant PRF as compared to either SLM or RCF alone. In addition, the overall BER of OFDM transceiver has been evaluated for different standard channel models (Additive White Gaussian Noise/Rayleigh Fading) with and without the proposed PAPR scheme. The results show that the proposed PAPR technique has been almost achieved the same BER in case of different channel models. Therefore, the proposed CSLM_RCF scheme presented in this study is practically feasible solution of OFDM PAPR problem with insignificant additional processing time.

Key words: PAPR in OFDM, PAPR reduction techniques, selected mapping, repeating clipping and filter

INTRODUCTION

One of the main problems of OFDM transceiver occurring in time domain is high signal peak-to-average power ratio (PAPR) (Han and Lee, 2005; Shumei *et al*., 2007). This leads to non-linear distortion occurred at the output of power amplifier. Many methods have been developed in order to mitigate this main drawback. This includes: Golay and Reed-Muller coding (Jones *et al*., 1994; Davis and Jedwab, 1997), Selected Mapping (SLM) (Han and Lee, 2004; Bauml *et al*., 1996), Partial Transmit Sequence (PTS) (Cimini and Sollenberger, 2000; Tian *et al*., 2009) and filtering and clipping (Armstrong, 2002; Wang *et al*., 2008; Li and Cimini, 1998). All of these above techniques can be classified into two main categories: Linear and nonlinear. PAPR techniques which lead to increase the computational complexity of OFDM system are belonging to linear methods. On the other hand, higher BER of OFDM system is obtained with nonlinear methods. In fact, a compromise between complexity and the BER should be considered in selecting the PAPR scheme. Therefore, less complexity and adequate BER of OFDM system is the only measure for a good PAPR technique.

In this study, a novel approach combining nonlinear and the linear methods along with convolutional code has been proposed and presented. This includes selective mapping and repeating clipping and filter techniques. The proposed PAPR technique is denoted by Convolutional Selected Mapping Repeating Clipping and filtering “CSLM_ RCF”. The main objective is to reduce the Peak-to-average Power Ratio (PAPR) and to maintain an acceptable BER at OFDM receiver. The proposed scheme has been achieved a significant reduction in PAPR. In addition, acceptable BER level has been obtained at receiver as compared to the original OFDM system (without PAPR module). The presented study is organized among the following five main sections. The first section describes in details the PAPR problem in OFDM system. The basic concept of Clipping and Filtering is presented in second section. Conventional SLM algorithm is introduced in third section. Simulation results of the proposed PAPR technique are investigated and presented in the fourth section. Performance evaluation and analysis of OFDM system with and without the proposed CSLM_RCF technique are also presented in the same section. Finally, the presented study is concluded in the last section.

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OFDM SYSTEM WITH PAPR PROBLEM

In contrast to the single carrier, OFDM technology summed up a number of sub carriers modulated by group of data symbol. Therefore, transmitted signal may have a relatively large peak power which leads to high PAPR. The PAPR can be defined as follows (Ochiai and Imai, 2001):

$$PAPR = 10\,Log_{10}\left(\frac{MAX\{|x_n|^2\}}{E\{|x_n|^2\}}\right) \qquad (1)$$

where, x_n is time domain data symbol obtained via IFFT given as follows:

$$x_n = \frac{1}{N}\sum_{k=0}^{N-1} x_k \exp\left(nk\frac{2\pi}{N}\right) \qquad (2)$$

where, N denotes the total number of sub-carriers

x_k denotes the frequency domain data symbol obtained at source output and to modulate sub-carrier number k. $x_k = \{1, -1\}$ in case of BPSK modulation and $x_k = \{1, -1, -j\}$ in case of QPSK modulation

In OFDM system, N sub-carriers are summed with phase shifts as given in Eq. 2 in order to maintain the orthogonality in frequency domain. In this case, the signal peak power is N times greater than the mean power (in the worst case) which can be described as follows:

$$(PAPR)_{max} = 10\log_{10}(N) \qquad (3)$$

For example, if the number of sub-channels varies between 64 and 256, upper limit of the $(PAPR)_{max}$ value in OFDM system varies between 18.0 and 24.0 dB. The normalized complex base band symbols of OFDM are given by:

$$x(t) = \frac{1}{\sqrt{N}}\sum_{n=0}^{N-1} x_n e^{(jn\Delta ft)} \qquad (4)$$

Where:

x_n : Denotes the modulated symbols of the n^{th} sub-carrier
Δf : Denotes is frequency spacing between successive sub- carriers

According to the Central limit theorem, as long as the number of sub-carriers N Large enough, you can determine the real and imaginary parts of x(t). In this case, they follow Gaussian distribution with zero Mean and 0.5 variance (real and imaginary separately parts half of the entire signal). The Cumulative Distribution Function (CCDF) has been used to evaluate the PAPR of OFDM symbols. In general, a complementary equation of CCDF is given by:

$$P\{PAPR > z\} = 1 - P\{PAPR \le z\} = 1 - (1 - e^{-z})N \qquad (5)$$

where, z represents a specific threshold power to evaluate the PAPR in OFDM.

CLIPPING AND FILTERIN TECHNIQUE

In OFDM symbol, item contains high peak (exceeding a certain threshold) will be applied to clipping and Filtering processes (CF) as illustrated in Fig. 1. In the Clipping part, when amplitude exceeds a certain threshold, the amplitude is hard-clipped while the phase is saved (Leung *et al*., 2002; Qing and Hongsheng, 2008).

In Fig. 1, vector A = [A_0, ..., A_{N-}] obtained after oversampling stage is first transformed using an oversize inverse fast Fourier transformation. For an oversampling factor denoted by IF, A_1 is extended by adding N(IF-1) zeros in the middle of the vector. This results in a trigonometric interpolation of the signal time domain signal {I_i, 01 i≤N(IF-1)-1}. The interpolated signal is then clipped. In this study, hard-limiting is applied to the amplitude of the complex vector I_i. However, any other form of nonlinearity could be used. The clipping ratio CR is defined as the ratio of the clipping level value to the root mean square value of the unclipped signal. The clipping is followed by filtering to reduce out-of band power. The filter consists of two FFT operations. The forward FFT transforms the clipped signal back into the discrete frequency domain resulting in vector C_1. The in-band discrete frequency components of [$C_{0,i,\ldots\ldots}$, $C_{N/2-1,i,}$ C_{NI1}-N/$_{2+1,i,\ldots}$ $C_{NI1-1,i}$] are passed unchanged to the inputs of the second IFFT while the out-of-band components [C_1(N/(2+1, I.....)) C_1(NI1 =N/(2,i))] are nulled. In systems where some band-edge subcarriers are unused the components corresponding to these are also nulled. The resulting filter is a time-dependent filter which passes in-band and rejects out-of-band discrete-frequency components. This means that it causes no distortion to the in-band OFDM signal. Since the filter operates on a

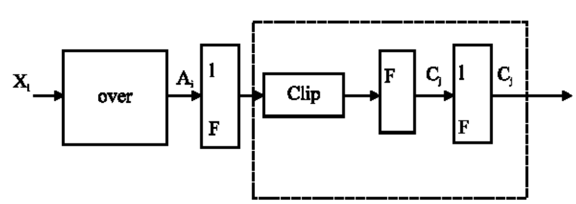

Fig. 1: Repeating clipping and filtering technique

symbol-by-symbol basis, it causes no Inter-symbol interference. Clipping method sets a clipping threshold, when the amplitude of the signals over the threshold, then cut the high peak power. According to the system acquirement, the following function has been used to calculate the clipping ratio. PAPR0 = $10Log_{10}$[CR], where, PAPR0 is the threshold value and CR is the clipping ratio.

PROPOSED PAPR REDUCTION METHOD

The Block diagram of conventional SLM is shown in Fig. 2 with basic principles described as follows: First of all, this method is used for minimization of peak to average transmit power of multi-carrier transmission system with selected mapping. A complete set of candidate signal is generated signifying the same information in selected mapping and then concerning the favorable signal with the lowest PAPR to be transmitted. In more details, OFDM data block X is multiplied element by element with complex exponent sequence $B(U) = [b_{u,0}, b_{u,1}, \ldots\ldots, b_{u,N-1}]^T$, u = 1, 2, ..., U, where, U is the number of exponents sequences randomly selected with range [0, 2π]. Multiplication result denoted by $X^{(U)} = [X_{u,0}, X_{u,1}, \ldots, X_{(u,N-1)}]^T$ where; $X_{u,m} = Xm.b_{u,m}$, m = 0, 1, ….., N-1 is given in Eq. 6 called phase rotated OFDM data blocks. All U phases used in SLM operation should be known at both transmitting and receiving end:

$$x^u(t) = \frac{1}{\sqrt{N}} \sum_{M=0}^{N-1} x_M b_{u,m} ej2\pi_e j2\pi f_m t \quad (6)$$

where, PAPR is calculated for U phase rotated OFDM data blocks using Eq. 4 and 6. Among the phase rotated OFDM data blocks, one with the lowest PAPR is selected and transmitted. The information about the selected phase sequence should be transmitted to the receiver as side information. At the receiver, reverse operation should be performed to recover the unmodified OFDM data block. SLM technique needs U IDFT operations for each OFDM data block and the number of required side information bits is $Log_2(U)$. The phase sequences are selected in a way such that the phase rotated OFDM data blocks are 'sufficiently' different. In the ordinary SLM technique, there is no restriction on the construction of the phase sequences.

In the proposed OFDM system, a convolutional code with selected mapping technique (SLM) and RCF (Repeating Clipping and Filtering) has been used as shown in Fig. 3. The main idea of the proposed PAPR method (CSLM_RCF) is to use three main signal processing steps to reduce the PAPR value while acceptable BER performance is maintained at receiver. Stages of OFDM transceiver with the proposed (CSLM_RCF) is illustrated in Fig. 4.

SIMULATION RESULTS AND DISCUSSION

A Matlab code has been developed to simulate a complete OFDM transceiver. The main simulation parameters of OFDM system have been assumed as follows. The selected FFT point is 64 (i.e., 64-subcarriers), modulation technique is QPSK, the cyclic prefix is 16-symbols and convolutional code with rate 1/3. Communication channel environment has been assumed to be AWGN and Rayleigh channel models. The fading channel parameters assuming maximal equalizer ratio are as follows. The number of multipath is three and fading type is frequency selective with Doppler shift equal to 20 Hz. In addition, other practical parameters are oversampling factor IF = 2, number of iterations n = 4 and clipping ratio CR = 4. The number of sequence phases for selected mapping technique U is assumed to be equal 2^n (n = 1, 2, 3 and 4). The overall performance of OFDM system has been evaluated and investigated with and without the proposed PAPR scheme (CSLM_RCF). The simulation results are presented in ascending order from Fig. 5-6. Figure 5a-c presents the performance of SLM, RCF and proposed PAPR (CSLM_RCF), respectively. First, Fig. 5a illustrates CCDF versus PAPR of SLM technique for different phase number U as compared to

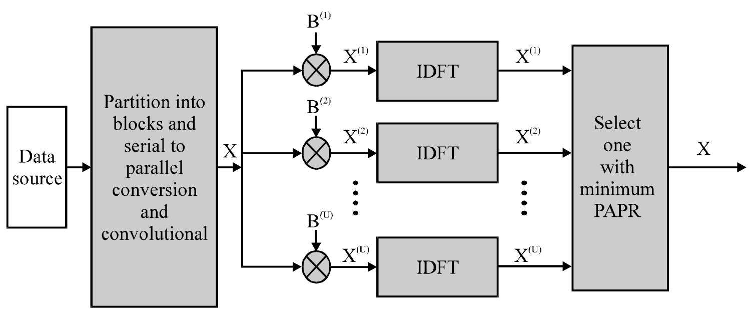

Fig. 2: Conventional SLM principle

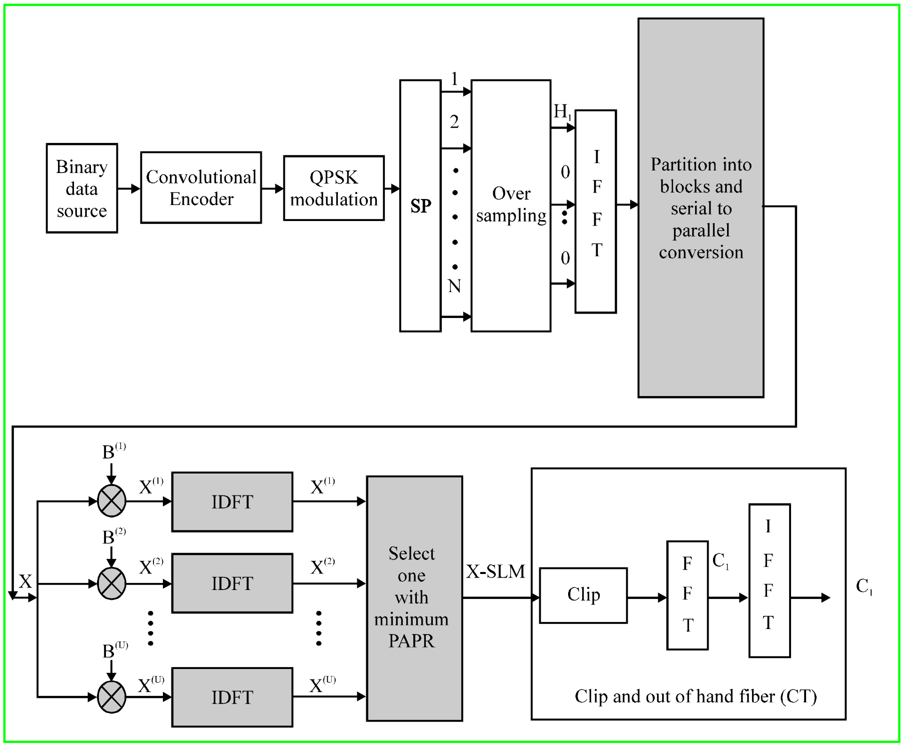

Fig. 3: Proposed PAPR block diagram (CSLM-RCF)

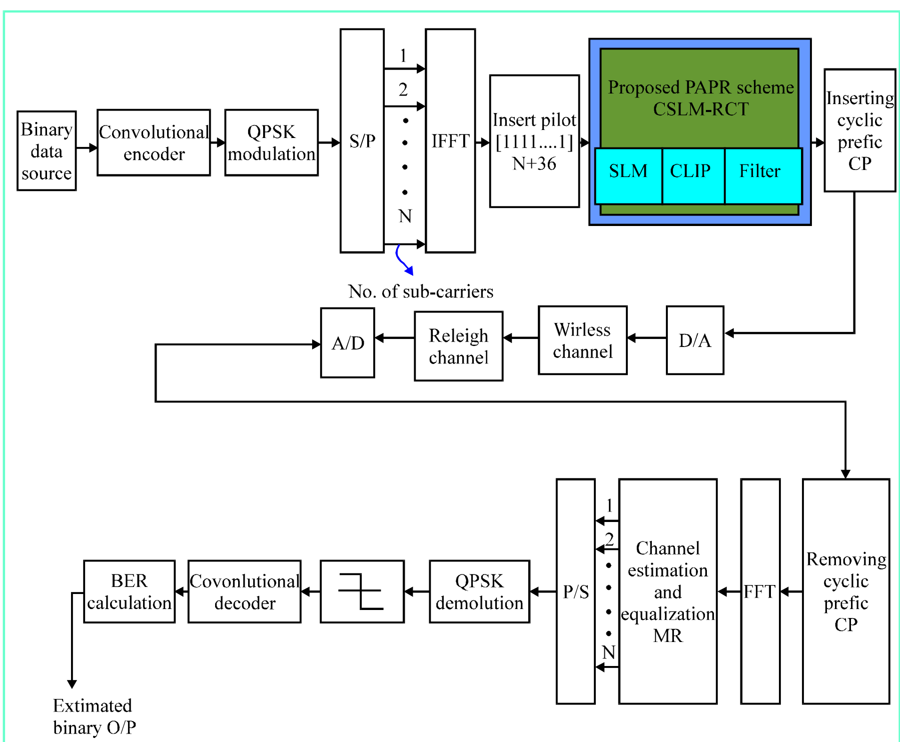

Fig. 4: Proposed PAPR technique (CSLM-RCF) for OFDM transceiver system

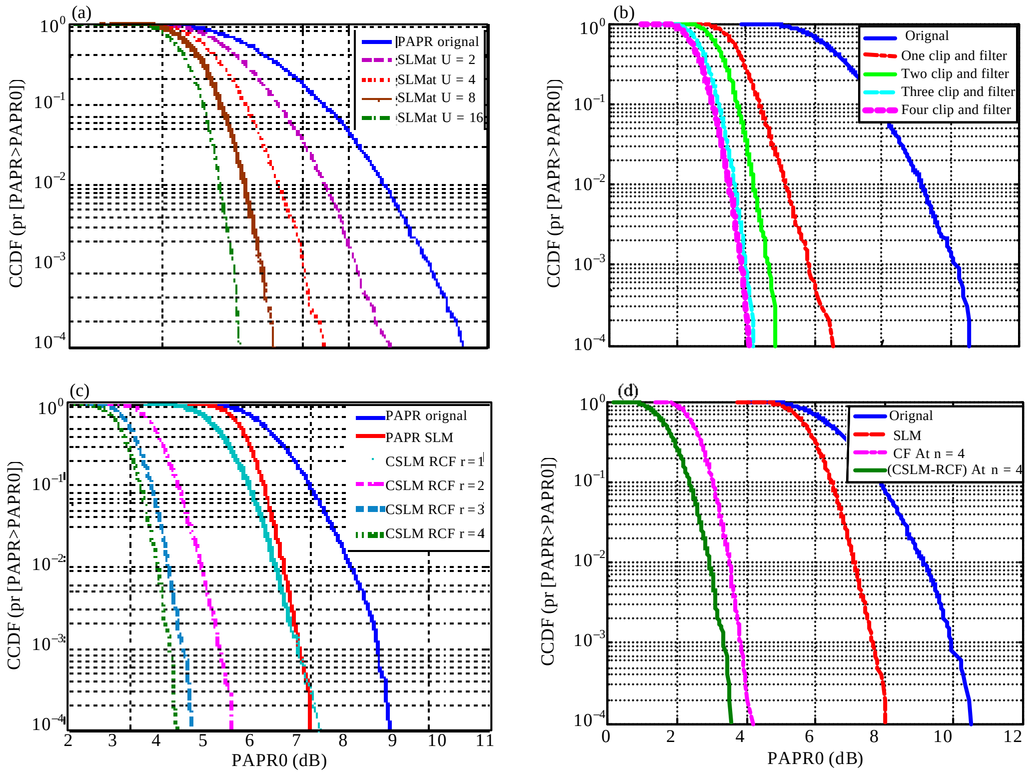

Fig. 5(a-d): CCDFs versus PAPRo of SLM technique with different values of "U" as compared to original OFDM system, (b) CCDF versus PAPR of clipping and filtering technique (CR = 4 and IF = 2) as compared to original OFDM system, (c) CCDF versus PAPR of the propose PAPR scheme (CSLM_RCF) for IF = 2, CR = 4 and U = 4 as compared to original OFDM system and (d) Performance comparison (CR = 4, n = 4, IF = 2and U = 4) between CSLM_RCF (proposed), RCF and SLM

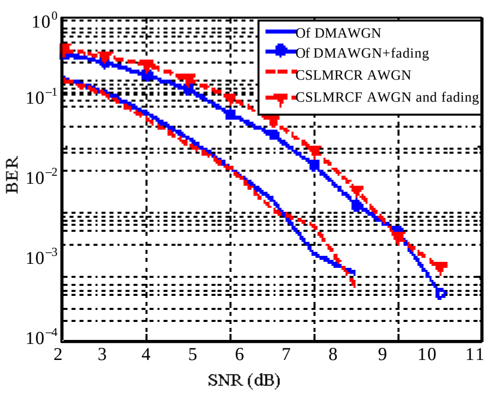

Fig. 6: BER performance versus variation in SNR for transmission over standard channel models

the original OFDM system. In fact, the vector U (complex exponential) is random in nature and it is multiplied by the data vector. Thus, as number of candidate phase vector U increases, possibility of PAPR reduction will increase as it is clear from Fig. 5a. Second, performance evaluation of the clipping and filtering technique for different clipping ratios is presented in Fig. 5b. As the number of stages n (number of iteration per one unit cell) increases the PRF increases. For example the difference in PAPR at n = 1 and n = 4 is about 3 dB. Third, performance of the proposed PAPR is illustrated in Fig. 5c. Performance the original OFDM system without any reduction technique is also present in Fig. 5c. The proposed PAPR has been achieved higher PRF as compared to either SLM or RCF alone. For example, at n = 4, PAPR is decreased by about 7.0 dB as compared to the original OFDM system. Fourth, a performance comparison between the presented novel PAPR and the other two techniques (SLM and RCF each alone) is illustrated in Fig. 5d. It is clear from this figure, the proposed PAPR scheme has been achieved the best PRF as compared to the other mentioned techniques. For

Table 1: Comparison between CSLM_RCF, SLM and RCF schemes (CR = 4, n = 4, IF = 2, U = 4)

	OFDM	SLM	RCF	Proposed PAPR
CSLM_RCF				
M_PAPR				
In dB	6.689	4.984	2.517	1.713
D_PAPR	-	1.705	4.14	4.977
PRF (%)	-	32.400	60.900	68.170

example, for n = 4, U = 4, IF = 2 and CR = 4 PAPR is decreased by 4.5 dB and 7.0 dB as compared SLM and original OFDM system, respectively.

A final performance comparison between the proposed PAPR s cheme and the other techniques presented in this study is illustrated in Table 1. The definitions of the parameters listed in the first left column are defined as follows. The mean value of PAPR in dB is denoted by M_PAPR. The difference between the mean PAPR values of OFDM system with and without PAPR reduction scheme is denoted by D_PAPR. The ratio of absolute values of M_PAPR of OFDM system after and before the reduction technique subtracted from one and multiplied by 100 is denoted by PRF%. It is clear from this table that the proposed PAPR has a superior performance over the other presented PAPR techniques by a PRF of 68.2%.

A last set of curves presented in Fig. 6 illustrates the performance of OFDM transceiver (bit error rate BER versus variation in the signal-to-noise ratio: SNR) with and without PAPR techniques. System parameters in this case are assumed as follows: IF = 2, CR = 6 dB, U = 4 and QPSK modulation. A pilot signal has been inserted to enable the receiver to estimate the channel coefficients (in time or frequency domains). Repeating clipping and Filtering is used with SLM (CSLM-RCF) method to have optimum PAPR reduction. Cyclic prefix is inserted to each OFDM symbol in order to eliminate the interference between successive OFDM symbols. The main drawback of PAPR reduction technique is the negative effect on BER performance, but actually the proposed PAPR reduction technique didn't affect on BER level in both fading and noisy channel models.

CONCLUSION

Two well-known PAPR techniques have been combined in specific order to obtain a novel effective PAPR reduction scheme as compared to the other techniques. A convolution code followed by selected mapping module and then, a repeating clipping and filter module has been proposed and presented. The propose PAPR scheme is denoted by CSLM_RCF. Simulation results showed that PAPR has been lowered by 6 dB as compared to original OFDM system (without any PAPR reduction technique). However, for lower PAPR values, less immunity of transmitted data to noise will be resulted. Therefore, the Bit Error Rate (BER) at OFDM transceiver should be examined. Simulation results show that the overall BER after the proposed PAPR is almost the same as the original OFDM system. For example, at SNR = 6.0 dB, original OFDM BER is of order 10^{-03} in the presence of fading channel and it is of order 10^{-02} in case of the proposed PAPR scheme. Therefore, the proposed PAPR scheme is very practical solution to the OFDM PAPR problem with moderate complexity as well as insignificant additional signal processing time.

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