# THE COMBINATION OF CLIPPING AND FILTERING WITH SELECTIVE MAPPING METHODS FOR PEAK TO AVERAGE POWER RATIO REDUCTION IN OFDM

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**ABSTRACT**

*The high Peak to Average Power Ratio (PAPR) is a serious drawback of the Orthogonal Frequency Division Multiplex (OFDM). In this paper, the advantages of two different approaches to PAPR reduction are exploited in order to reduce the PAPR more significantly. The first approach is based on clipping and provides a high PAPR reduction at the cost of signal distortion. The second approach (selective mapping) results in no distortion, but it suffers from higher complexity. Two cases of simulation setup have been chosen for the evaluation – one with a lower number of subcarriers (Wimax-like signal), the other signal is similar to the future DVB-T2 32K mode. The performance of the combined method is evaluated on the PAPR distribution function and on the Bit Error Rate as a function of both Signal to Noise Ratio ( Additive Gaussian Noise Channel) and Input Back Off (Saleh model of nonlinear power amplifier).*

***Keywords:*** *PAPR, OFDM, Selective mapping, Partial transmit Sequences, Interleaving, Saleh model*

## 1. INTRODUCTION

The Orthogonal Frequency Division Multiplex (OFDM) is a multicarrier technique with the orthogonality of individual subcarriers [1]. The use of the multicarrier transmission allows extending the symbol time interval by splitting the input bit stream into *N* parallel substreams. As a result of symbol time extension and orthogonality, the OFDM signal is less influenced by multipath propagation, and high spectral efficiency is obtained.

The main drawback of OFDM as well as of most multicarrier techniques is the high maximum to mean signal power ratio – Peak to Average Power Ratio (PAPR) [1]:

$$PAPR\{s(t),\tau\} = \frac{\max\limits_{t\in\tau}\left[s\left(t\right)\right]^2}{E\{[s(t)]^2\}}, \quad (1)$$

where the numerator and the denominator express the peak and the mean signal power, respectively. The PAPR of signal $s(t)$ is measured in the time interval $\tau$ (usually symbol interval).

Many methods for PAPR reduction have been proposed. They can be generally classified into two main groups. The methods from the first group do not induce signal distortions, which is their main advantage. A significant PAPR reduction can be obtained but at the cost of increased computational complexity. Moreover, the PAPR reduction often does not grow linearly with the complexity, as will be demonstrated later. The typical representatives from this group of methods are the Tone Reservation [1], Selective mapping [2] or Partial Transmit Sequences [3]. One of the important research foci in this domain is the complexity reduction [4].

The use of the methods from the second group results in OFDM signal distortion. They are often based on the clipping principle and their application is usually less complex. In order to suppress the negative effects of clipping (out-of-band emissions, BER increase), filtering can be used [5,6,7,8,9]. An alternative approach is the use of windowing [10] instead of hard clipping.

In this paper the advantages of both different approaches to PAPR reduction are exploited in order to reduce the PAPR more significantly. The paper is structured as follows. Part 2 briefly presents the methods used in the combination, and the signals used for the evaluation are introduced. The individual methods are further reviewed in part 3. Part 4 summarizes the results in terms of Complementary Cumulative Distribution Functions (CCDF) and Bit Error Rate (BER) as a function of Signal to Noise Ratio (SNR) and Input Back Off (IBO). The proposed combination results in a lower PAPR than in the case of any method from the individual methods used. In the critical low IBO region, the BER is only slightly degraded, but still lower than in the case of original signal.

## 2. SELECTED METHODS AND SIGNAL TYPES

In this paper, three methods and their suitable combinations have been considered. The first is the Partial Transmit Sequences (PTS) [3,4] method belonging to the family of distortionless methods. The second method, based on Interleaving [2] belongs to the same family. More specifically, both these methods fall into the subgroup of SeLective Mapping methods (SLM). The third, and the last particular method, hereinafter referred to as the Simplified Clipping and Filtering with Bounded Distortion (SCAFBD) [7] allows a limited signal degradation and thus represents the family of methods with distortions. The methods from the two above mentioned groups are suitable for the combination. The aim is to obtain a signal with lower PAPR than in the case of single SLM and with lower nonlinear distortions than in the case of the single SCAFBD method.

The new combined method is a concatenation of two from the above-mentioned methods. The signal is first processed by one of the distortionless methods. The signal at the output of the first method has a lower PAPR and is not distorted. In order to further reduce the PAPR, the signal is then processed using the second PAPR reduction method. Therefore two combinations have been proposed and evaluated – one using the PTS and SCAFBD methods, the other with Interleaving followed by the SCAFBD method.

All the above-mentioned standalone methods as well as their combinations were evaluated on the OFDM signals with the following parameters:

**Table 1** OFDM signals used for the evaluation

| | No. of carriers | FFT length |
|---|---|---|
| Wimax-like signal | 200 | 256 |
| DVB-T2-like signal | 27840 | 32768 |

These signals have been chosen to approximate the Wimax and the new DVB-T2 standard signals as these two standards represent the opposite cases with respect to the number of subcarriers. In Wimax, only 200 subcarriers are used, whereas the 32K mode with 27840 active subcarriers is proposed in the new DVB-T2 standard. For the sake of simplicity, the special pilot symbols are not simulated.

The resulting PAPR reduction is the main criterion for the evaluation. The other reported results are the Bit Error Rate (BER) as a function of both the received Signal to Noise Ratio (SNR) and the input back off (IBO) for Saleh nonlinear power amplifier (PA) model [11].

## 3. DETAILED DESCRIPTION OF METHODS

In the following text, the principles of methods for OFDM signal PAPR reduction will be briefly described.

### 3.1. Partial Transmit Sequences

The Partial Transmit Sequences [4] is the distortionless method for the PAPR reduction. A simple block scheme of this method is shown in Fig. 1. The input data are mapped according to the chosen constellation (16-QAM in the present case) and split into consecutive OFDM symbols. Each OFDM symbol is then partitioned into $M$ distinct subblocks, each of them completed with zeros to the original symbol length. Subsequently the Zero Padding (ZP) and the Inverse Fast Fourier Transform (IFFT) are performed on each subblock. After the IFFT, subblock outputs are multiplied by the vector of the so-called complex rotation factors. The resulting OFDM symbol is calculated as a sum of all multiplied subblock outputs. The rotation factors are generated in the rotation factor generator block and their resulting vector is optimized in order to reduce the PAPR. In our implementation, the possible values of complex rotation factors were limited to either +1 or -1 only in order to limit the search space for the optimization. For $M$ subblocks, all $2^M$ possible combinations of symbols 1 and -1 were tested for each OFDM symbol.

The information about the rotation factors used for the multiplication in each OFDM symbol is necessary at the receiver for correct decoding. This information is called Side Information (SI). Throughout this paper, the transmission of the SI is not considered, and the SI is expected to be perfectly known at the receiver. In the practical situation, the SI can be transmitted either through a special channel or by specified subcarriers excluded from data transmission.

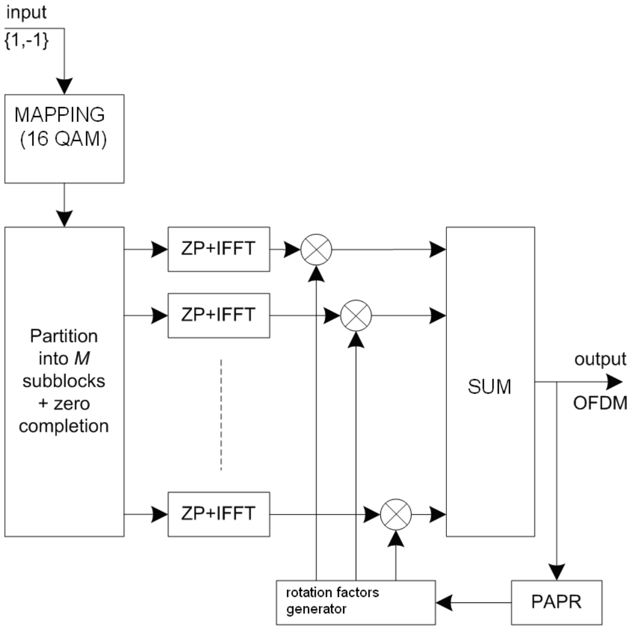


**Fig. 1** PTS block scheme

### 3.2. Selective Mapping through interleaving

The Interleaving method [2] is based on the creation of multiple OFDM signals by the bit interleaving of an input sequence. One of the simplest ways to perform interleaving is the use of matrix interleaver – data are written by lines and read by columns from the same matrix. The block scheme of the Interleaving method for PAPR reduction is shown in Fig. 2.

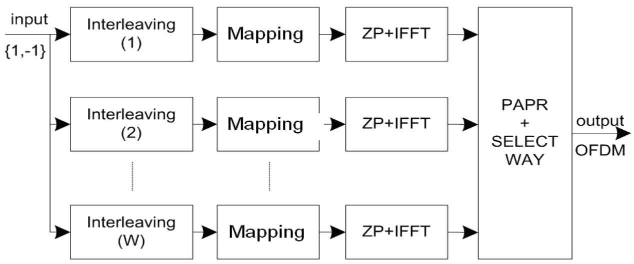


**Fig. 2** Interleaving block scheme

The PAPR reduction algorithm uses $W$ paths, each of them using a different interleaving matrix. After each interleaver, data mapping according to the selected constellation (throughout this paper 16QAM) is performed. After the IFFT operation on all signal alternatives, the resulting PAPR values are compared. Similarly to the PTS, the path with the lowest PAPR from all $W$ signal realizations is chosen for transmission. Note that similar to the PTS, the Zero Padding (ZP) is performed in order to approximate the continuous-time PAPR.

The same as in the PTS method, the side information indicating the interleaver index resulting in the lowest PAPR has to be sent through the radio channel. As in the previous case, the perfect knowledge of the SI at the receiver will be assumed below.

### 3.3. Simplified Clipping and Filtering with Bounded Distortion

Simplified Clipping and Filtering with Bounded Distortion (SCAFBD) [6] is a method based on clipping – limiting the time domain signal magnitude. The clipped signal $s_c(t)$ can be expressed by the following relationship:

$$s_c(t) = \begin{cases} A.e^{j\phi(t)}, & |s(t)| > A \\ s(t), & |s(t)| \le A \end{cases} \quad (2)$$

where $A$ is the clipping level, and $\phi(t)$ is the phase of input signal $s(t)$.
Although it results in PAPR reduction, clipping also introduces signal distortions resulting in emissions in adjacent channels and in increased bit error rate. This undesirable effect can be suppressed by lowpass filtering of clipped signal, which results in a new growth of the PAPR.

Armstrong [5] proposed a method based on $K$-times repetition of the clipping and frequency domain filtering process (repeated clipping and filtering method). The successive repetition of clipping and filtering produces signals with reduced PAPR, while the out-of-band distortions are completely eliminated. Note that the PAPR reduction is far from that obtained by mere clipping. The main drawback of the repeated clipping and filtering method is its high complexity. For each frequency domain filtering operation, two FFT calculations are necessary.

A method named simplified clipping and filtering [6] offers almost the same PAPR reduction as the repeated clipping and filtering method, but with significantly reduced complexity. Only 3 FFT's are required for the PAPR reduction equivalent to the iterative (repeated clipping and filtering) method irrespective of $K$.

In order to limit the BER as well, the constellation distortion can be bounded as has been proposed in [7]. A block scheme of the SCAFBD method is shown in Fig. 3.
During the SCAFBD method implementation, the input signal is first clipped to level $A$. The time-domain error signal is computed as the difference between the original signal and the clipped signal. This error signal is transformed into the frequency domain and multiplied by the constant $\beta$, corresponding to the chosen number of clipping and filtering processes. According to [6], the constant $\beta$ is calculated as:

$$\beta \approx \frac{1-(1-\alpha)^{\frac{3K}{2}}}{1-(1-\alpha)^{\frac{3}{2}}} \quad (3)$$

$$\alpha = \frac{2\sqrt{2}}{\sqrt{3\pi}} \frac{1}{\frac{A}{\sigma}} \quad (4)$$

where $K$ is the number of equivalent repetitions of the iterative repeated clipping and filtering method, and A is the clipping level. According to the central limit theorem, the real part of OFDM signal $s(t)$ has normal distribution with variance σ.

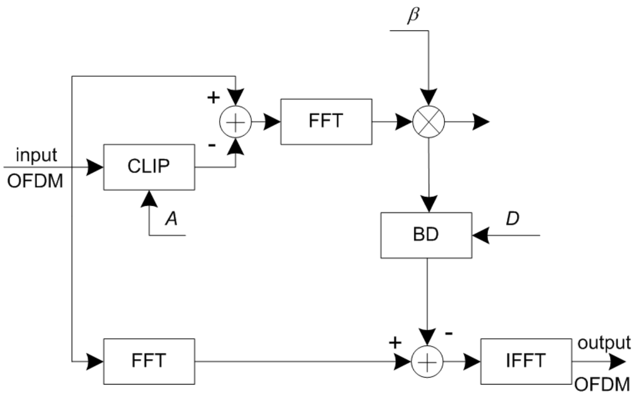


**Fig. 3** SCAFBD block scheme

After multiplication by constant $\beta$, the frequency domain signal is passed through the block ensuring the in-band bounded distortion (BD). The real and the imaginary parts of the error signal are limited separately to a predefined constant $D$, regardless of the symbols sent on the particular subcarriers. Other possible approaches to distortion limitation are described in [7,8].

The bounded error signal is finally subtracted from the original signal (both still in the frequency domain). The result is then transformed into the time domain using the IFFT.

### 3.4. Combined SLM-SCAFBD method

In the proposed combined method, the PAPR of input OFDM signal is first reduced using one of the SLM methods (PTS or the method using the interleaving). The number of signal alternatives generated through the PTS or the interleaving used for the PAPR reduction is limited in order to limit the complexity. This is also motivated by the fact that the PAPR reduction often does not grow linearly with the increased number of alternatives. This is illustrated in Fig. 4 for the case of interleaving-based SLM applied to an Wimax-like OFDM signal.

The resulting signal after SLM is then fed to the input of the SCAFBD block, which further reduces the PAPR, at the cost of slight signal distortions (controlled by the SCAFBD parameters).

## 4. RESULTS

During the simulations, the OFDM signals similar to Wimax and DVB-T2 standards have been used. The numbers of subcarriers and FFT lengths used are specified in Table 1. In order to approximate the continuous time PAPR [1], oversampling via zero padding has been performed. The 2-times oversampled signals were then normalized to the mean level 0dB.

For the interleaving-based method, $W$=8 paths have been used as a compromise between the PAPR reduction and the complexity. Equivalently, the PTS method with

*M*=8 subblocks has been simulated. These two parameters were chosen with respect to the similar modulator complexity requirement.

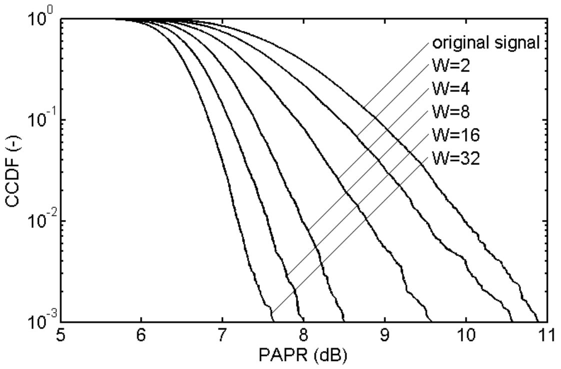


**Fig. 4** PAPR CCDF as a function of W in interleaving-based SLM

For the SCAFBD method, the clipping levels *A*=6dB and *A*=7dB have been used for Wimax-like and DVB-T2-like signals, respectively, with respect to different PAPR distribution of both signals. For both types of signal, the constant $\beta$ equivalent to 3-times repeated clipping and filtering process has been used. The distortion bound has been set to a level resulting in approximately the same BER for the case of both the signals used during the evaluation.

The simulation results are presented in Figures 5-10. The results for the original signals will be in the following represented by dash-dotted lines, the results for the standalone selective mapping methods by solid lines, the results for the standalone SCAFBD by dashed and the results for the combined methods by dotted lines.

In Figures 5 and 6 the Complementary Cumulative Distribution Functions (CCDF) of PAPR for the Wimax-like and DVB-T2-like signals are plotted.

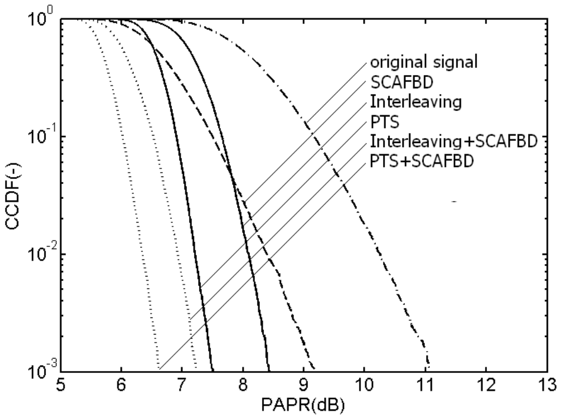


**Fig. 5** CCDF functions of PAPR for Wimax-like signals

The best PAPR reduction is obtained with [the]>a combination of the PTS and SCAFBD methods. Comparing these two figures, it is possible to observe a different behavior of the proposed methods towards signals with a different number of subcarriers. Moreover, it is possible to compare the PAPR reduction performance of different methods, especially for high PAPR probabilities. Among all the methods, the SCAFBD method has the most significant influence on PAPR reduction in this region. For signals with a higher number of subcarriers, the use of SCAFBD method outperforms the PAPR reduction provided by the methods based on the SLM approach.

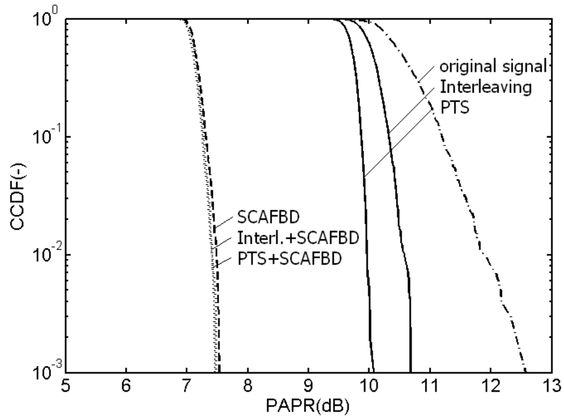


**Fig. 6** CCDF functions of PAPR for DVB-T2-like signals

The BER's as a function of the SNR's in the Additive White Gaussian Noise (AWGN) channel are shown in Figures 7 and 8 for the two input signals tested. These results are simulated without any nonlinear power amplifier.

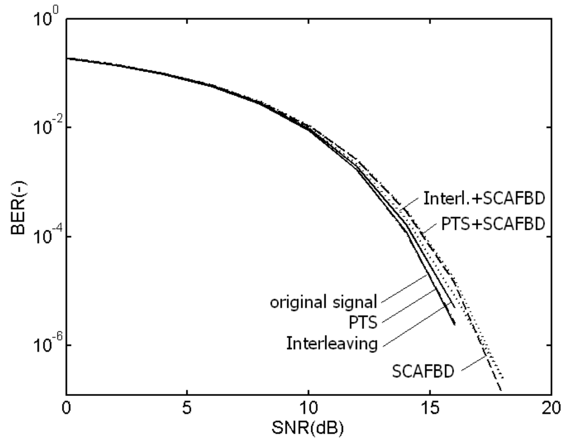


**Fig. 7** BER as a function of SNR for Wimax-like signals

The use of the SCAFBD method results in higher bit error rates as a consequence of the nonlinear distortion caused by the clipping operation. The combinations of SCAFBD with both the PTS and the Interleaving method can improve the bit error rate, but this effect is noticeable only for signals with a lower number of subcarriers. The BER curves for the cases of PAPR reduction methods without distortion are almost the same; in some cases they are identical. A minor difference between theses curves in the lower BER region is only a statistical error related to the finite length of the simulated signal. For the case of a high number of subcarriers, similar to DVB-T2 32k mode, the BER improvement due to the combination is almost absent. The importance of the proposed combination is not visible from these figures, nevertheless it will be evident on the BER curves in the presence of nonlinearity in the channel. As will be further demonstrated, a worse BER performance without nonlinearity does not mean a worse BER performance in the nonlinear channel.

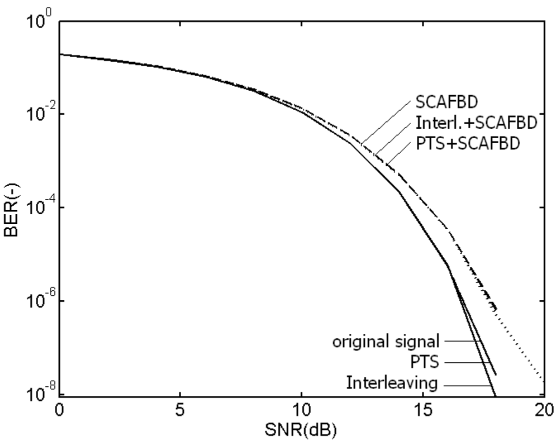


**Fig. 8** BER as a function of SNR for DVB-T2-like signals

The last two simulation outputs (Figures 9 and 10) demonstrate the BER performance in the presence of a nonlinear power amplifier (Saleh model) and additive Gaussian noise with the SNR=15dB. The operating point of the power amplifier is commonly defined by the Input Back Off (IBO) parameter. The IBO [11] is defined as the ratio of the PA's input saturation power $P_{\max,in}$ to the input signal average power expressed by the variance of OFDM signal $\sigma_x^2$:

$$IBO = 10.\log_{10}\left(\frac{P_{\max,in}}{\sigma_x^2}\right) \quad (5)$$

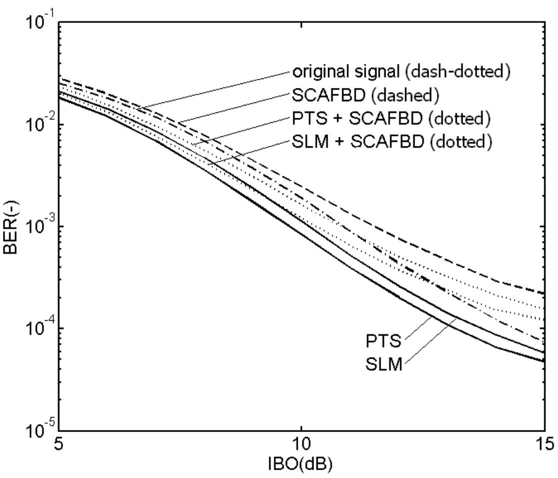


**Fig. 9** BER as a function of IBO for Wimax-like signals

As a consequence of the nonlinear distortions introduced by the PA nonlinearity, the BER increases as the signal average power approaches saturation (lower IBO values). Note that from the PA efficiency point of view, it is desirable to operate the PA in the region of low IBO. In this region, for the case of a lower number of subcarriers, all methods (except standalone SCAFBD) result in improved BER performance compared to the original signal. The BER for the signal processed by the SCAFBD method is only slightly degraded. On the contrary, the application of PAPR reduction to signals with a high number of subcarriers does not improve the BER significantly. Although in this case the BER of all the combined methods is degraded, the reduced PAPR is still advantageous due to the reduced dynamic range of analog/digital converters.

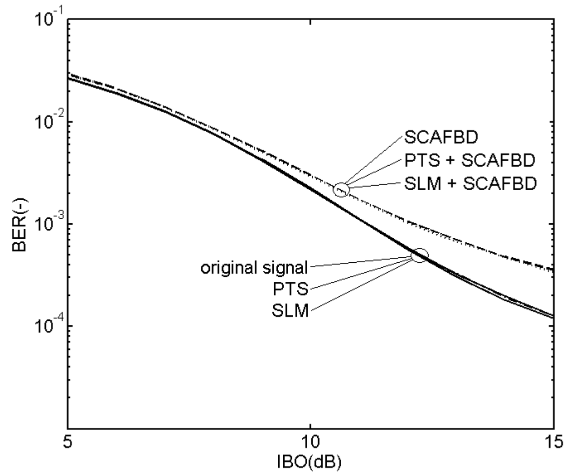


**Fig. 10** BER as a function of IBO for DVB-T2-like signals

## 5. CONCLUSIONS

In this paper, a combination of PAPR reduction methods based on an advanced form of the clipping method and two different selective mapping methods is presented.

The performance of the proposed methods is evaluated by simulation on two OFDM signals differing in the number of data subcarriers. In the case of a lower number of subcarriers, the PAPR reduction provides good results in terms of both PAPR reduction and BER improvement in the nonlinear channel.

For the signal with a very high number of subcarriers, the PAPR reduction is also evident but is not manifested by any BER improvement. An advantage of the reduced PAPR is thus only a reduced required dynamic range of analog/digital converters.

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