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International Journal Of Engineering And Computer Science ISSN:2319-7242
Volume 4 Issue 5 May 2015, Page No. 11889-11894

PAPR and SNR performance analysis of IFDMA and LFDMA technique in a single carrier frequency division multiple access system

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Abstract*:* The single carrier multiple access scheme is a novel method of radio transmission currently used in long term evolution (LTE) technology for uplink due to its high data rates and lower peak-to-average power-ratio (PAPR) as compared to OFDM technique. In this paper we analytically derive the time domain SC-FDMA signal and numerically compare the PAPR characteristics using the complementary cumulative distribution function (CCDF) of PAPR with the help of raised cosine (RC) and root raised cosine pulse (RR) shaping method and discuss the resulting PAPR of both the mapping schemes. Comparing the two forms of SC-FDMA, we find that interleaved (FDMA) has lower PAPR than localised (FDMA). We also discuss the SNR (signal to noise ratio) performance of both LFDMA and IFDMA schemes and find that the SNR performance of localised (FDMA) is better than interleaved (FDMA) technique.

Keywords:-SC-FDMA , LFDMA , IFDMA , PAPR

1.Introduction

Cellular communication has grown rapidly because of the demand of high data rates and throughputs. To support these demand of users a third generation partnership project (3gpp) has evolved a new technique called LTE/4G which uses orthogonal frequency division multiple access (OFDMA) technique for downlink communication and single carrier multiple access (SC-FDMA) technique for uplink communication.SC-FDMA is used in view of the fact that its peak-to-average-power-ratio (PAPR) is small and the more constant power enables high RF power amplifier efficiency in the mobile handsets-an important factor for battery power equipment. Moreover it has a similar throughputs and essentially the same overall complexity as the orthogonal frequency division multiple access (OFDMA) system

However, even though the SC-FDMA transmitted signal are characterised by low signal fluctuations, the performance degradation due to non-linearity of amplification substantially affect the link performance of the system. The PAPR of discrete time signal is defined as the ratio of the maximum peak power divided by the average power of the signal ,that is

$$\text{PAPR}=\frac{\max|x(t)|^2}{E\left\{|x(t)|^2\right\}}$$

As high PAPR becomes a major constraint in uplink communication because high PAPR of signal will degrade BER performance of the system. For signal with large PAPR, the average input power must be reduced. If the input power is not reduced then the signal distortion will occur which result in out-of-band spectral re-growth of the signal as the signal will be amplified in non-linear range. High power amplifiers are most efficient when they are driven into saturation region. So the input power back-off will reduce the efficiency of the power amplifiers. In order to avoid signal distortion the transmitter front end must have a wide linear range to include peaks in the transmitted waveform. Building such an amplifier is a costly affair. So the solution to this problem is to use SC-FDMA technique with different mapping schemes.[1]

In this paper, we analyze the different mapping scheme of SC-FDMA in time domain and compare their PAPR characteristics. We see that IFDMA performs better in PAPR reduction but at a cost of high bit error rate (BER) as compared to LFDMA. We also compared both the techniques with different roll-off factor. We see that upon increasing the roll-off factor, the PAPR performance of IFDMA is improved whereas there is no effect of roll-off factor on the PAPR performance of LFDMA scheme.[2]

1.2 SC-FDMA system model

The block diagram of the SC-FDMA system is shown in the figure 1.The base station have total U number of users with M number of subcarriers and each user have been allotted with N number of subcarriers The SC-FDMA system have much in common with of OFDM system except an extra DFT and IDFT block in transmitter and receiver respectively. But the main difference between the two techniques is that the SC-FDMA transmits information data sequentially rather than in parallel. This approach has the advantage of lowering the PAPR, which is important to increase cell coverage and to prolong the battery life of mobile terminal.

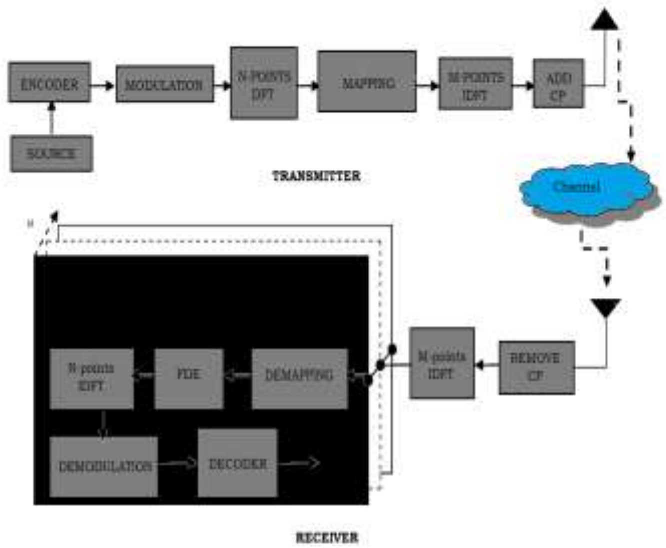

Fig.1 SC-FDMA transmitter and receiver diagram

As shown in the figure SC-FDMA transmitter sending one block of data to a receiver. The input of the transmitter and the output of the receiver are complex modulation symbols. Practical systems dynamically adapt the modulation technique to the channel quality, using binary phase shift keying (BPSK) in weak channel and upto 64-level quadrature amplitude modulation (64-QAM) in strong channel. The resulting modulated symbols are grouped into blocks, each containing N symbols and the DFT is performed. The signal after the DFT can be expressed as:-

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{\frac{-j2\pi}{N}nk} \qquad (1)$$

Where N is the input block size and $\{x(n):n=0......N\text{-}1\}$ represents the modulated data symbols. The output of these data symbols are then mapped using different types mapping schemes to M $(M>N)$ orthogonal subcarriers.

Subcarrier mapping scheme can classified into two parts[3]-

1) Localised Mapping (LFDMA).
2) Distributed Mapping.

In localized mapping each user is given a set of adjacent sub-carriers. This scheme provides multiuser diversity even in the presence of frequency selective fading by assigning each user to subcarriers in the portion of the signal band where that user has favourable transmission characteristic (high channel gain). This requires channel dependent scheduling (CDS) of subcarriers. CDS requires the system (base station) to monitor the channel quality as a function of frequency for each terminal and adapt assignment of subcarriers according to changes in channel frequency response of all other user terminals. However LFDMA has the disadvantage, whereby it loses frequency diversity in the channel because a set of subcarriers are not spread over an entire signal bandwidth. In distributed mapping each user is provided a set of sub-carriers that are distributed over the entire signal bandwidth. This can ensure high frequency diversity. Interleaved sub-carrier mapping (IFDMA) is a special case of distributed mapping where sub-carrier are allotted for user will be equidistant to one another. It was found that LFDMA can provide better BER performance than IFDMA because of its better immunity to multiple access interference (MAI)[3]. However, the reduction of PAPR is more dominant in IFDMA as compared to LFDMA technique.

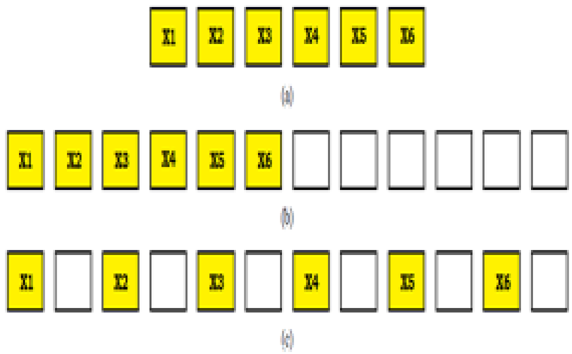

Fig.2 Subcarrier mapping schemes (a) DFT outputs (b) localized mapping scheme (c) interleaved mapping scheme.

After subcarrier mapping (LFDMA or IFDMA) is done the M points IDFT are used to convert the output to a time domain signal sequence M=QN which is the output block size .Q is the maximum numbers of users that can be transmitted simultaneously. We can note that the remaining M-N subcarriers may be used by the other user communicating in the cell. The resulting signal after the IDFT can be given as follows:

$$\bar{x}(m) = \frac{1}{M} \sum_{i=0}^{M-1} \bar{X}(l) e^{\frac{j2\pi}{M}ml} \qquad (2)$$

Where $\{\overline{X}(l): l = 0,....M-1\}$ represent the frequency domain samples after the subcarrier mapping scheme. The transmitter in the Fig.1 performs two other signal processing operations prior to transmission. It inserts a set of symbols referred to as cyclic prefix (CP) in order to provide a guard time to prevent inter block interference (IBI) due to multipath propagation. The CP is a copy of the last part of the block. If the length of CP is longer than the maximum delay spread of the channel, or roughly the length of the channel impulse response then there is no IBI otherwise, yes. The transmitter also perform a linear filtering operation referred to as pulse shaping in order to reduce out of band signal- energy. Commonly used pulse-shaping filters are raised cosine pulse filter and root raised cosine pulse filter.[4,6]

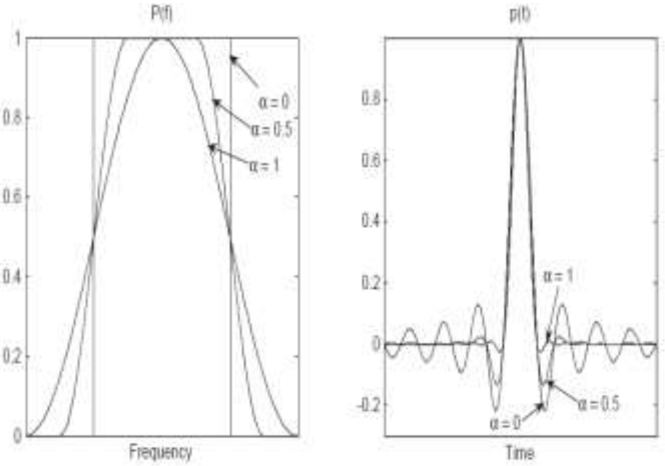

Fig.3 Raised cosine filter with varying roll-off factors

2. Raised cosine pulse filter

A raised cosine pulse filter is a filter commonly used for pulse shaping in digital modulation technique due to its ability to reduce inter symbol interference (ISI). The raised cosine filter is an implementation of low pass nyquist filter i.e one has a property of vestigial symmetry. This means that its spectrum exhibit odd symmetry of about 1/2T, where T is symbol period. Fig.3 shows a systematic diagram of raised cosine pulse filter in frequency and time domain with different roll of factor values. In time domain the raised-cosine pulse can be described as follow:-

$$r(t) = \sin c\left(\pi \frac{t}{T}\right) \frac{\cos\left(\frac{\pi a t}{T}\right)}{1 - \frac{4\alpha^2 t^2}{T^2}} \quad (3)$$

Here, the roll-off factor $\alpha = 1 - \frac{w}{w_0}$ Where, w is the nyquist bandwidth and w_0 is the utilized bandwidth .The main advantage of raised cosine filter is its adjustable bandwidth with α ranging from 0 to 1 and if α=0,than the filter is an ideal bandpass filter that suppresses all out-of-band radiation .As α increases ,the out of band radiation increases. Therefore the choice of filter roll-off factor requires a compromise between the goals of low out-of-band radiation and low PAPR.

2.1 root raised cosine filter

A root raised cosine filter is a square root of raised cosine filter in frequency domain

$$H_{rrc} = \sqrt{H_{rc}} = \sqrt{\frac{1}{2}(1 + \cos \pi\omega / 2\omega_c)}\ , |\omega| < 2\omega_c \quad (4)$$

When the transmitter and receiver filter are cascaded we get raised cosine filter

$$H_{rc}(\omega) = H_{rrc,tx}(\omega) H_{rrc,rx}(\omega) \quad (5)$$

3.Time domain symbols of IFDMA

For IFDMA,the frequency samples after subcarrier mapping $\{\overline{X}(l)\}$ can be described as follows.

$$\overline{X}(l) = \begin{cases} X_{l/Q} & , l = Q.k \ (0<k<N-1) \\ 0 & , \text{otherwise} \end{cases} \quad (6)$$

We derive time symbols $\{\overline{x_m}\}$ which are obtained by taking DFT of $\{\overline{X}(l)\}$.

Let $m=Nq+n$, where $0<q<Q-1$ and $0<n<N-1$ then,

$$\overline{x}(m) = \frac{1}{M}\sum_{l=0}^{M-1}\overline{X}(l)e^{j2\pi\frac{m}{M}l} = \frac{1}{Q}.\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{j2\pi\frac{m}{N}k} \quad (7)$$

$$= \frac{1}{Q}.\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{j2\pi\frac{Nq+n}{N}k} \ where, m = Nq+1 \quad (8)$$

$$= \frac{1}{Q}.\left(\frac{1}{N}\sum_{k=0}^{N-1}X(k)e^{j2\pi\frac{n}{N}k}\right) \quad (9)$$

$$= \frac{1}{Q}x(n) \quad (10)$$

From the equation (10) it is clear that the resulting time symbols $\{\overline{x}(m)\}$ are simply a repetition of the original input symbols $\{x(n)\}$ scaled by a factor Q in the time domain. Therefore, the PAPR of IFDMA signal is the same as in the case of conventional single carrier signal. An example of IFDMA is shown in fig.2(c).

3.1 Time Domain symbols of LFDMA

For LFDMA, the frequency samples after subcarrier mapping $\{\overline{X}(l)\}$ can be described as follows:-

$$\overline{X}(l)=\begin{cases} X(l) & , 0\le l\le N-1 \\ 0 & , N\le l\le M-1 \end{cases} \tag{11}$$

Let $m=Qn+q$, where $0\le n\le N-1$, and $0\le q\le Q-1$.

$$\overline{x}(m)=\overline{x}(Qn+q)=\frac{1}{M}\sum_{l=0}^{M-1}\overline{X}(l)e^{j2\pi\frac{m}{M}l} \tag{12}$$

$$\frac{1}{Q}.\frac{1}{N}\sum_{l=0}^{M-1}\overline{X}(l)e^{j2\pi\frac{Qn+q}{QN}l} \tag{13}$$

If $q=0$,then,

$$\overline{x}(m)=\overline{x}(Qn)=\frac{1}{Q}.\frac{1}{N}\sum_{l=0}^{N-1}X(l)e^{j2\pi\frac{Qn}{QN}l} \tag{14}$$

$$=\frac{1}{Q}.\frac{1}{N}\sum_{l=0}^{N-1}X(l)e^{j2\pi\frac{n}{N}l}$$

$$=\frac{1}{Q}x(n) \tag{15}$$

If $q\neq 0$ since

$X(l)=\sum_{p=0}^{N-1}x(p)e^{-j2\pi\frac{p}{N}l}$, then (13) can be

expressed as follow after derivation.

$$\overline{x}(m)=\overline{x}(Qn+q)=\frac{1}{Q}\left(1-e^{j2\pi\frac{q}{Q}}\right).\frac{1}{N}\sum_{p=0}^{N-1}\frac{x(p)}{1-e^{j2\pi\left\{\frac{(n-p)}{N}+\frac{q}{QN}\right\}}} \tag{16}$$

As can be seen from (15) and (16), in the time domain, LFDMA signal has exact copies of input time symbols in the N-multiple sample positions. In-between values are sum of all the time input symbols in the input block with different complex-weights, which would increase the PAPR. An example of an LFDMA signal is shown in Fig. 2(b).[2]

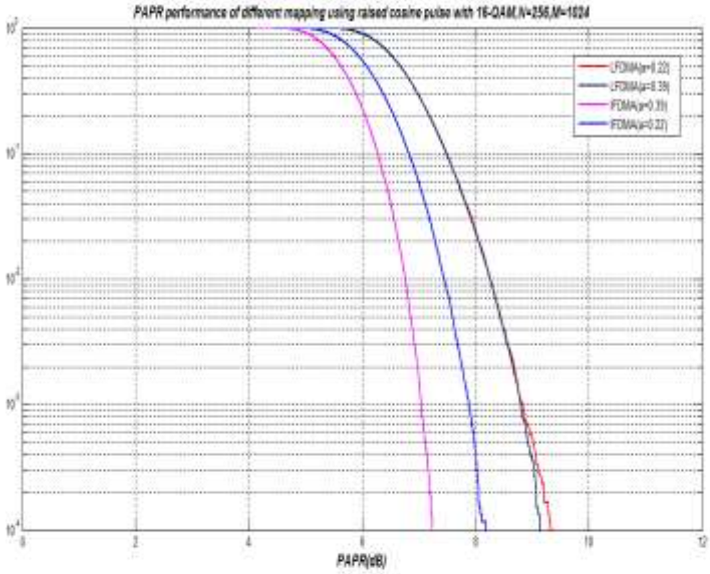

Fig.4 shows the PAPR performance of LFDMA and IFDMA technique using RC filter with 16-QAM modulation and roll-off factor α=0.22 and 0.33.CCDF=PAPR>$PAPR_0$[7]

In Fig.4 we can see that the PAPR performance of IFDMA is better than LFDMA and further improves by varying the roll-off factor close to 1.

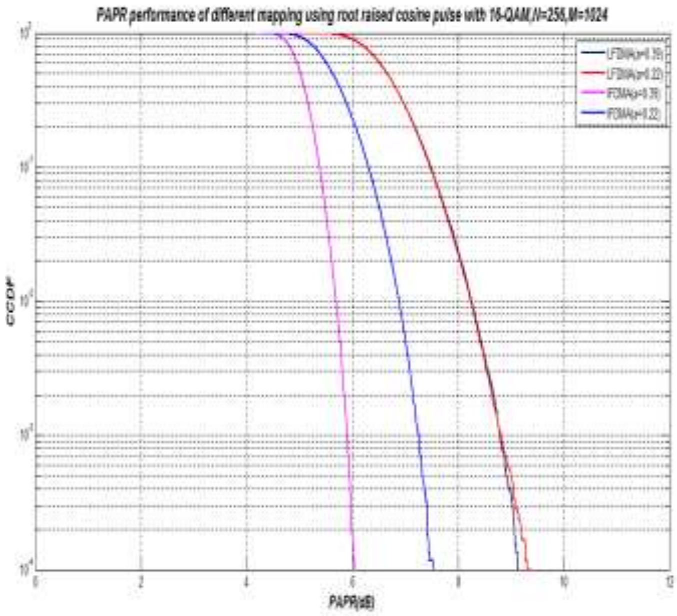

Fig.5 shows the PAPR performance of LFDMA and IFDMA technique using RR filter with 16-QAM modulation and roll-off factor α=0.22 and 0.33 CCDF=PAPR>$PAPR_0$

In the Fig.5 we see that the PAPR performance of IFDMA is better in case of root raised cosine pulse filter as compared to raised cosine pulse filter.

4. Numerical results and analysis

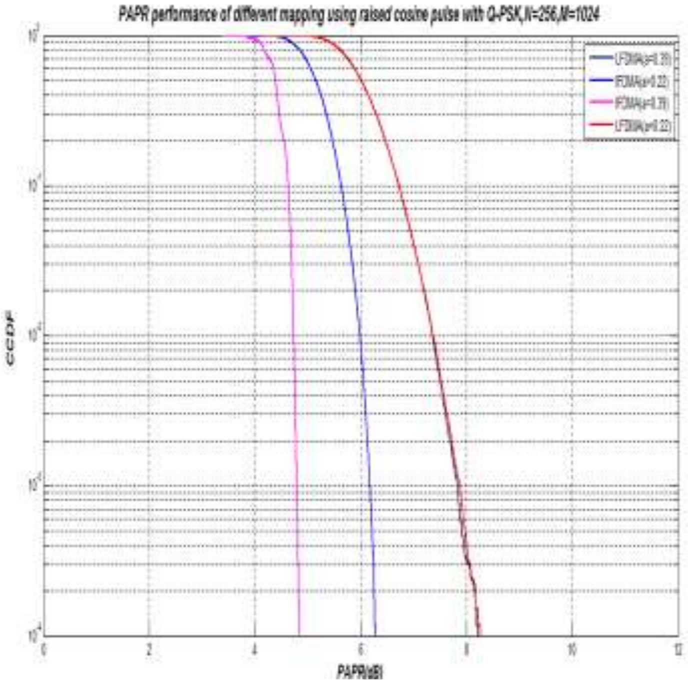

Fig.6 shows the PAPR performance of LFDMA and IFDMA technique using RC filter with QPSK modulation and roll-off factor α=0.22 and 0.33. CCDF=PAPR>PAPR$_0$

In Fig.6 we can see that that the PAPR performance of both LFDMA and IFDMA technique were improved by replacing 16-QAM with QPSK type modulation.

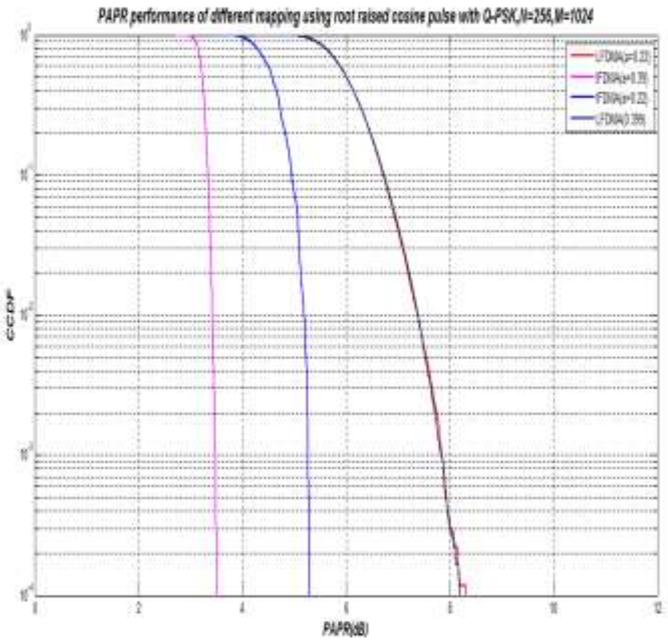

Fig.7 shows the PAPR performance of LFDMA and IFDMA technique using RR filter with QPSK modulation and roll-off factor α=0.22 and 0.33. CCDF=PAPR>PAPR$_0$

Fig.7 shows the PAPR performance of IFDMA is more improved by using RR filter and Q-PSK modulation. PAPR performance of LFDMA remains same as compared to in Fig.6

Table for Fig.8

In block size of FFT block	256
Total FFT size	1024
Cyclic prefix length	20
Modulation type	16-QAM
Equilizer type (FDE)	MMSE
Code Rate	1/2

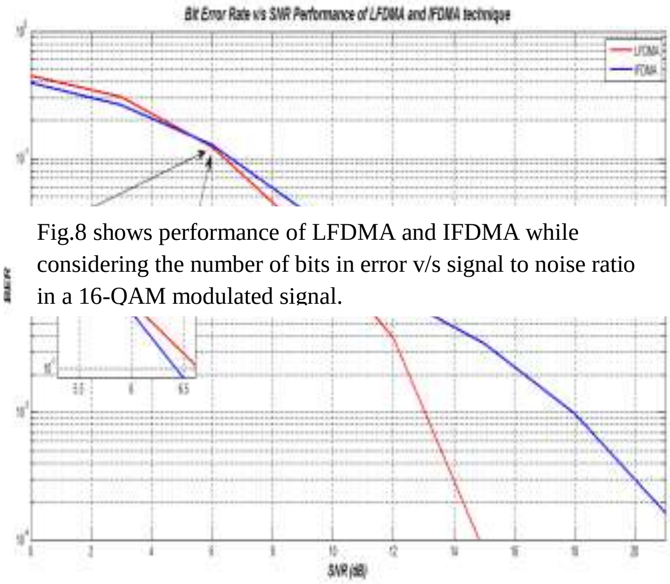

Fig.8 shows performance of LFDMA and IFDMA while considering the number of bits in error v/s signal to noise ratio in a 16-QAM modulated signal.

In the Fig.8 we see that the BER v/s SNR performance of LFDMA is better than IFDMA technique because of its robustness against multiple carrier interference (MAI).[5]

5.Conclusion

In this paper we analyze the PAPR performance of both LFDMA and IFDMA technique using raised cosine (RC) filter and root raised cosine (RR) filter. We numerically found the time domain symbol representation of IFDMA and LFDMA technique and compare the PAPR characteristics using CCDF of PAPR. It is shown that IFDMA technique indeed have lower PAPR as compared to LFDMA technique. Another noticeable fact is that the roll off factor have significant impact on the PAPR performance of IFDMA. So the pulse shaping should filter should be designed carefully in order to reduce PAPR in the system. So, if the roll off factor is chosen systematically than the performance of IFDMA is far better as compared to LFDMA technique.

6.References

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