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Analysis Modulation Formats in DWDM Transmission System

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Abstract

In modulation and demodulation methods of the optical Differential Quadrature Phase Shift Key (DQPSK) and the different modulation formats including nonreturn-to-zero(NRZ), return-to-zero (RZ), carrier-suppressed return-to-zero(CS-RZ) are introduced, studying the different optical signals in the 40Gb/s high speed transmission system. The system is simulated in 200km optical fiber by way of dispersion compensation. It is showed that the ability of anti-dispersion and anti-PMD (Polarization Mode Dispersion) is better in the CS-RZ-DQPSK modulation format, and this format has the smallest eye-opening penalty (EOP) with a wider range of power into the optical fiber.

Key words: *Optical Communication, DQPSK, Modulation Format, PMD, EOP*

1. Introduction

The rapid development of 40Gb/s DWDM optical transmission system, selecting the appropriate codes and modulation formats can effectively reduce the transmission impairments, in addition to enhancing spectrum efficiency and transmission capacity. ODQPSK as a new type of modulation format was first proposed by R.A Griffin in the OFC2002. Due to its good tolerance capability of anti-dispersion and anti-PMD, high spectrum effectiveness and suppression of nonlinear effects, DQPSK modulation format is gradually becoming a research focus [1].

DQPSK modulation format with a four-level phase modulation and approximation constant envelope in intensity is helpful to resist nonlinear effects [2]. In comparison with the traditional phase modulation format DPSK, inserting the reference phase “π/2” in the DQPSK between the phase of “0”and “π” helps to double spectrum utilization. In the DQPSK modulation format, using two bits to represent each symbol not only reduce the transmission speed and lower the electric drive component cost, but also greatly enhance the flexibility towards PMD. Under the same condition of symbol rate, the transmission capacity of DQPSK system is twice of DPSK modulation format [3]. In contrast to the binary OOK modulation format, DQPSK has a good ability to resist nonlinear effects by nature. By using the balanced receiver, the sensitivity of DQPSK can be enhanced by 3dB and the requirements towards OSNR can also be reduced [4-5]. Besides, without the polarization multiplexing the channel utilization of DQPSK can be surpassed to 0.8b/s/Hz. Under using the polarization multiplexing, the spectrum effectiveness of 2b/s/Hz can be achieved in the DWDM transmission system, without giving rise to additional loss. Thus, code modulation formats for high speed optical communication transmission system are of great significance.

In the paper, take the 40Gbps for example, the way of modelization of NRZ, RZ and CS-RZ with computer analyzes the optical spectrum. The 40 Gbps signal transmitted in 200 km G.652 fiber by way of single channel with erbium-dope-fiber-amplifier (EDFA) is simulated for these three formats. Thus, we can get the better code-pattern with high spectrum efficiency and high tolerance for the optical noise and the non-linearity effect.

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2. The Principle and Characteristic of the Code-Pattern
2.1. The Principle of Chosen Code Pattern
There are three principles for the modulation format that we should follow: firstly, the compact modulation signal spectrum is good at enhancing the operating factor of the spectrum and the dispersive tolerance of group velocity; secondly, a high non-linearity tolerance; thirdly, the structure of the transmitter and receiver are simple as soon as possible.

2.2. The Principle of NRZ
We usually use the Mach-Zehnder modulator (MZM) and the consecutive wave (CW) laser in the modulation system. Except for the NRZ, their appearance would be performed by the two concatenation of MZM. These two concatenations of MZM play different roles. The first MZM is used to bring various pulses by the drive of the clock signal. The second one is used to load the data.

Figure 1 is the frame of the NRZ signal of the optics. When transmitted the “1”in the NRZ, optical signal impulse occupies a whole bit-time; when there is no optical pulse, the signal is “0”. The realization of the coding is simple, only needing a high speed exterior modulator that can work effectively at the speed of 10Gbps. The advantage of NRZ is the simplicity of application, low cost and high spectrum efficiency, which can be used widely into the synchronous digital hierarchy (SDH) and wavelength division multiplexing (WDM) system. Under the 10Gbps system, we use the NRZ modulation model. The disadvantage of NRZ is that the transition does not return zero between two codes, the sensitivity for transmission loss. So it is not suitable for high speed and the extra long-distance transmission.

2.3. The Principle of RZ and CS-RZ
Figure 2 is the frame about the principle of the generation of RZ and CS-RZ, which is all composed by the two concatenation of MZM. The technology of RZ code prevails recently, which is used in the high speed of 40Gps optical transmission system. In the pulse sequence of RZ code, the transition area which connects “1” amplitude of electric field has the independent time envelope. Because modulation format of RZ has different transition all the time in the code bits, thus it can bring more “neatness” optical signal in order to unscramble the receiver. The advantage of RZ is the low average of optical power; higher ability on anti-non-linearity effect and anti-polarization mode dispersion (PMD) [6]. RZ code is also more conducive to clock recovery. Because the consecutive “1” of NRZ is a whole, the eye pattern of RZ code stretches bigger, the better ability of anti-error-code performance, and the greater improvement on 3dB of the optical signal noise ratio (OSNR).providing

The CS-RZ code is based on the traditional RZ code, and join the phase separation of π in each adjacent sign bit (no matter the sign bit is “0” or “1”). The phase separation of the carrier can be regarded as the signal with a minus but the carrier is invariability. The typical value of this signal with positive and negative ambipolar is ‘0’, so there is no pinnacle in the zero frequency because of not having △function (impulse function), after multiplying the according carrier, and there is also no pinnacle in the carrier. In the CS-RZ, because the sign about consecutive code of amplitude of electric field is reversed, it can get the low width of spectrum. With the high power, it not only increases the dispersive capacity, but also enhances the resist of the non-linearity of self-phase modulation (SPM) and four-wave-mixing (FWM), and so on.

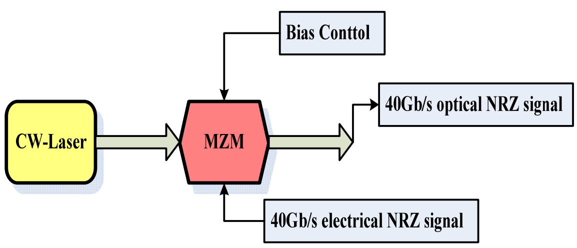

Figure 1. Blocks Diagram of NRZ

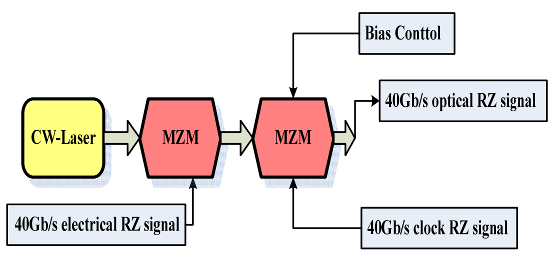

Figure 2. Blocks Diagram of RZ/CS-RZ

2.4. The Modulation Mode of Optical DQPSK

Three different modulation modes are currently researched: using two MZMs separately in series way and in parallel connections, besides, the third way is only using one signal phase modulator (PM) [7]. As shown in Figure 3, the series connection way is analyzed in the paper below. After the precoding, the branches of I and Q are respectively sent into two MZMs for four levels phase modulation. The phase modulation is made in branch I and Q. when the output of branch I is 0 and 1, the phase of optical signal is separately according to 0 andπ. The phase difference of branch I isπ, but in branch Q the phase difference isπ/2. That's to say, the output of branch Q is 0 and 1, which is separately according to 0 and π/2.

When the joint output of branch I and Q are (00, 01, 10, 11), the joint modulation of four level phases are (0, π/2,π,3π/2) which is the same as the series way. The output phase difference of DQPSK isπ/2, and the modulation way is inseparably related to the precoding.

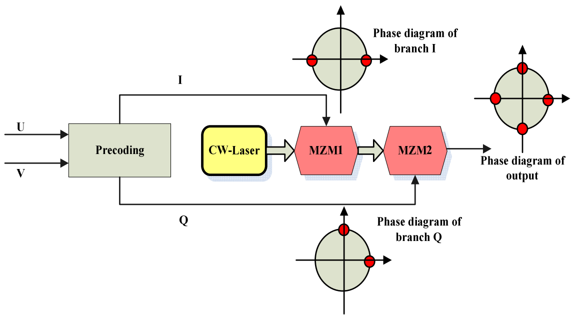

Figure 3. The Schematic Diagram of Series Modulation in DQPSK

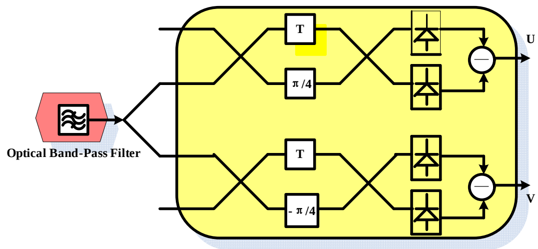

Figure 4. The Demodulation Schematic Diagram of DQPSK

2.5. Demodulation of Optical DQPSK

As shown in Figure 4, the balanced detection is used in the demodulation receiver of DQPSK. Two Mach-Zehnder Delay Interferometers (MZDI) are employed to make the phases of branch I and Q to achieve the delay T (the value is 2/B, B is information transmission rate) in the two arms, realizing the coherency and cancellation of the optical signals. Two balanced detectors are required in the receiver to make the upper and lower branches implement the phase difference separately by π/4 and -π/4. It is indicated that the receiving sensitivity of DQPSK is prior to the OOK modulation by 3dB. The strict control for wavelength is required in the receiver and MZDI, so the feedback control is needed in each MZDI to lock the wavelength of the transmitter [8].

3. Different Code Types and Spectrum Analysis of Optical DQPSK

The code type of optical DQPSK is produced firstly through two MZMs for the phase modulations, then followed by the clock signal for shaping, thus code types of different duty cycle are obtained. The modulation mode of DQPSK is employed series modulation, which concludes that three MZMs are needed in the paper [9]. The dual-driven MZM is used as modulator for producing different code types. The input optical signal is divided into two equal signals which can be sent into the two branches of MZM. The refraction index of MZM could change as the value of external imposed electrical signal, due to the variation of refraction index leading to the variation of phase, so when the two branches output of the modulator combines again though proper settings of modulation voltage in the two arms, the intensity modulation or phase modulation is achieved.

3.1. Principle of Different Duty Cycle RZ Codes Production

The production of different duty cycle RZ codes is required to pass two MZMs. One MZM is used to make the electrical NRZ signal into optical NRZ signal. The other MZM is modulated by electrical clock signal to produce different duty cycle RZ codes. RZ code in this paper is the represent of RZ code with the duty cycle of 33%, and the duty cycle of CS-RZ code is 67%.The following table is the related parameters value of MZM for the different duty cycle RZ signals:

Table1. Parameters Setting for Different Duty Cycle RZ Codes

	V_{m1}	V_{m2}	F(GHz)	Ψ_1	Ψ_2	V_{bais}
RZ	V_π	$-V_\pi$	R/2	-90	0	0
CS-RZ	V_π	$-V_\pi$	R/2	0	0	V_π

V_{m1} and V_{m2} are separately the modulation voltage of the two arms in the MZM, f is the modulation frequency of clock signal, ψ1 and ψ2 is the phase of clock electrical signal, Vbais is the bias voltage, R is the transmission speed of the optical signal. After the parameters setting of MZMs, the output optical signal frequency of different duty cycle RZ codes are both $2\omega_0$, the pulse width of RZ code and CS-RZ code is respectively $\pi/3\omega_0$ and $2\pi/3\omega_0$.

3.2. Analysis of Optical DQPSK Code Type and Spectrum

The emergency of different duty cycle optical DQPSK is divided into the process of phase modulation and signal shaping. Branch I and Q signals pass two MZMs and the phase difference of π and π/2 are separately carried out, thus the signal shaping is after the phase modulation and the following is the signal of NRZ-DQPSK. The below table is the parameters setting of NRZ-DQPSK in the MZM.

Table2. Parameters setting for series MZMs

	V_{SB}	V_{RF}	V_{m1}	V_{m2}	V_{bais}	ER
MZM1	V_π	V_π	4	4	0	100
MZM2	V_π	V_π	-2	-2	0	100

VSB and VRF is separately switch voltage and RF voltage, ER is the value of extinction ratio in the MZM. The following Figure 6 is the spectrum comparison of three different optical DQPSK codes.

Figure 5(a) is the code type of NRZ-DQPSK. Its spectrum width is narrow which is helpful to suppress the chromatic dispersion and reduce the crosstalk between the channels in the DWDM systems. But the wider pulse width is easy to cause inter-symbol interference (ISI) and nonlinear effects. From Figure 5(b) we can see that the widest optical spectrum of RZ-DQPSK reduces the tolerance of chromatic dispersion and goes against the control of chromatic dispersion [10]. In Figure 5(c) the pulse width of CS-RZ-DQPSK is between the other two code types. The narrow spectrum is not only enhancing the spectrum efficiency and transmission capacity, but also having higher tolerance of chromatic dispersion and nonlinear effects. In contrast with the RZ-DQPSK, CS-RZ-DQPSK has better effects on the suppression of crosstalk between channels. Besides, because of using the DQPSK modulation mode, from the spectrum of different code types we can see that this modulation mode largely reduce the emergence of linear spectrum, which could enhance the receiving accuracy of spectrum and lower the Interference and BER.

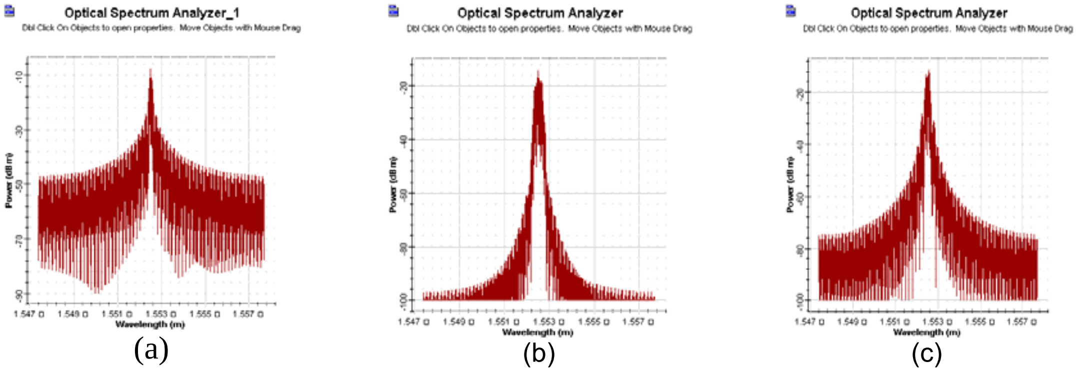

Figure 5. The Spectrum of Different Modulation Codes

4. Analysis of Transmission System Performance
4.1. Performance Analysis of Anti-chromatic

Figure 6 is the anti-dispersion performance comparison of different code types in DQPSK. CS-RZ-DQPSK has the best anti-dispersion performance, and the advantages are more obvious especially when the dispersion index is large. From the above-mentioned optical spectrum we know that the spectrum width of RZ-DQPSK is widest and reduce the tolerance of anti-dispersion performance. As the energy of different duty cycle RZ codes are more concentrated, it is helpful to enhance the sensitivity of the receiver and lower the cross-talk between pulses, which is proper for the high speed transmission. From the following figure 7, the difference between the RZ-DQPSK and NRZ-DQPSK is not very big when the chromatic dispersion index is small. But when the chromatic dispersion index is large, due to the wider spectrum of RZ-DQPSK code, the rate of increase with power penalty in the RZ-DQPSK code will pass the NRZ-DQPSK code. Chromatic dispersion is not only affecting the amplitude of the signal, but also the phase, besides enhancing the power penalty.

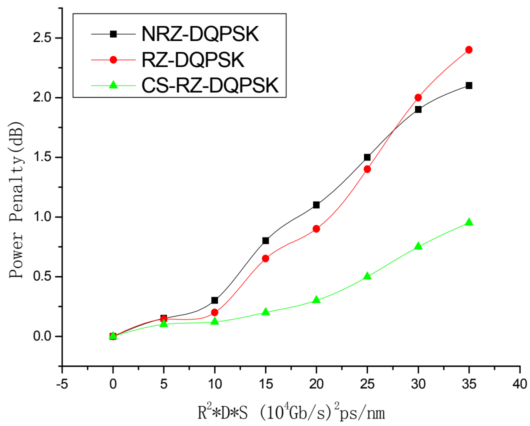

Figure 6. The Contrast of Anti-dispersion

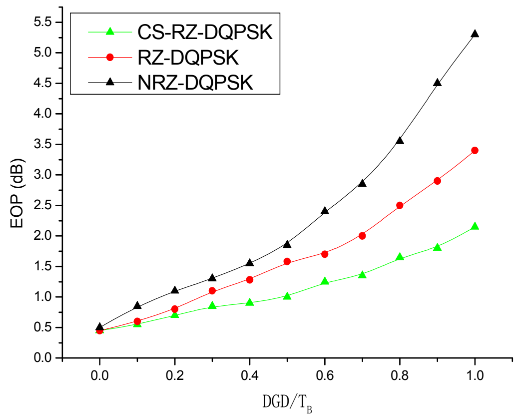

Figure 7. The Contrast of Anti-PMD

4.2. Performance Analysis of Anti-PMD

In the low-speed transmission system the PMD may not be taken into account, but for the speed of system surpassing 40Gb/s, the effects of PMD cannot be neglected. In the high-speed transmission system the PMD makes the pulse broadening and causes the power penalty, limiting the transmission distance without repeaters. Because the occurrence of PMD is random, so in this paper we only consider the first-order condition. The parameter of eye-opening penalty (EOP) is used to measure the performance of anti-PMD in the different modulation code types [11-13].

From figure 6 we can see that the CS-RZ-DQPSK has the best performance of anti-PMD. For the NRZ codes, its pulse width is the largest and the pulse is not sensitive to the difference of delays, decreasing the effects of PMD. But because of the reduction of time slot between pulses, the interaction between pulses is to be strengthened. The energy of RZ codes concentrate on the narrower region of the center of symbols, which requires a greater differential group delay than the NRZ codes causing the inter-symbol interference. So the RZ codes have a greater performance than RZ codes in anti-PMD.

For different codes existing an optimal duty cycle makes the Q factor in the system to the best. When the duty cycle is small, the pulse width is narrow and the margin of the pulse broadening is big, which is helpful to reduce the interaction between pulses. But as the decreasing of the pulse width, the delay difference of the two principal polarization parameters is more vulnerable to the pulse shape, which enhances the effects on PMD and leads to the deterioration of transmission performance. On the whole, the anti-PMD performance of the CS-RZ-DQPSK is better than the other two code types.

5. Simulation Analysis of the System Model

The operating parameters of each module in the system should be configured for simulations and related analysis. The wavelength used by the optical transmitter is 1550nm continuous wave laser. There are three MZMs in the transmitting terminals. The first two MZMs are employed to produce the NRZ-DQOSK after the modulations, and the third MZM is driven by the electrical clock signal to produce the RZ-DQPSK with different duty cycles. Supposing the transmission speed is 40Gbit/s and the distance is 200km carried out by the SMF and DCF. The concrete parameters settings are shown in the Table 3.

Table 3. Parameter of SMF and DCF

Item name	SMF	DCF
Attenuation（dB/m）	0.275	0.625
Disperse (ps/(nm*km))	17	-85
Disperse slope (ps/(nm^2*km))	0.058	-0.029
Available area (μm^2)	80	14.4
Non- linearity index (10-20m^2/W)	2.5	3.2

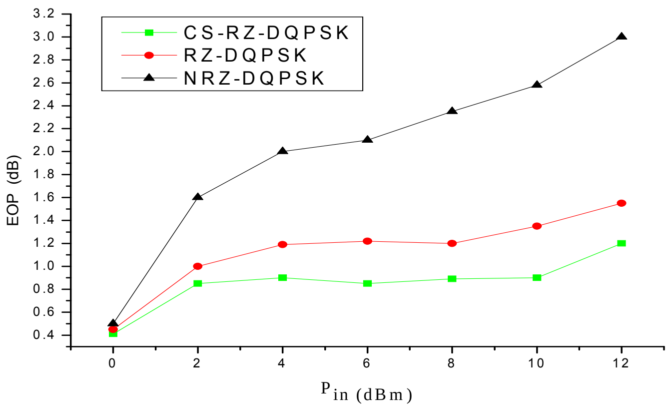

Figure 8. The Contrast of EOP with Different Code Types

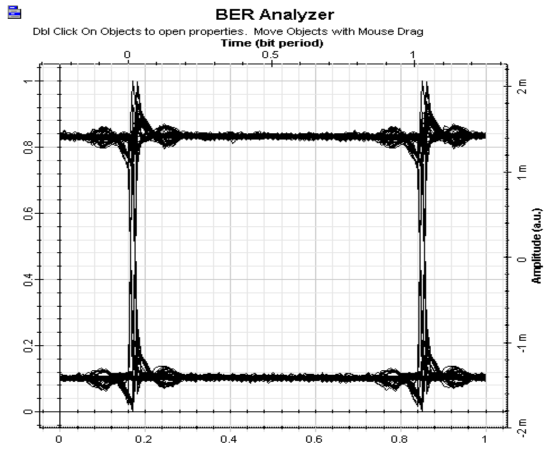

Figure 9(a)

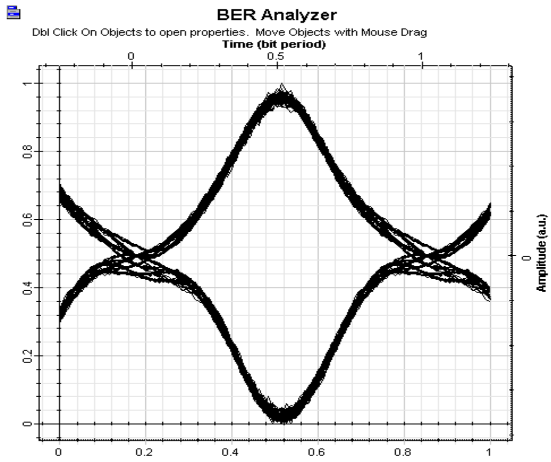

Figure 9(b)

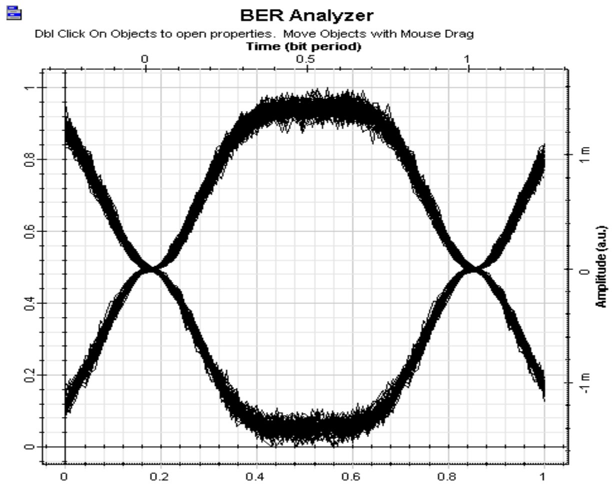

Figure 9(c)

Figure 9. Eye Diagrams of Different Receiver (a) NRZ-DQPSK (b) RZ-DQPSK (c) CS-RZ-DQPSK

In Figure 8 different code types gradually increase as the growth of power into the fiber. A stable process is appeared and different code types correspond to proper power into the fiber (Pin), which not only meets the demands of good performance of EOP, but also extend the transmission distance and capacity. CS-RZ-DQPSK has the best performance of EOP, especially for the large power into the fiber. Figure 9 is the demodulation eye diagram of different code types after the above-mentioned settings for the transmission parameters. In contrast to NRZ-DQPSK, CS-RZ-DQPSK has a higher performance on the tolerance of noise. Besides, the performance of timing error sensitivity and cross-point divergence of CS-RZ-DQPSK is better than the RZ-DQPSK code. On the whole, the transmission performance of eye diagram is best in the CS-RZ-DQPSK modulation format.

6. Conclusion

The principle of modulation and realization are researched in the paper. In contrast with three different optical modulation signals, the spectrum and eye diagram of demodulation are got after simulations. The results show that under the condition of dispersion compensation CS-RZ-DQPSK with the narrow spectrum has the best dispersion tolerance for PMD, which can be able to suppress the nonlinear effects in the optical fiber and get the smallest EOP with a wider range of power into the fiber. Besides, the modulation mode of optical DQPSK has the better performance on the receiving sensitivity and transmission capacity and lowers the requirements for the high speed of modulator. In the future, the DQPSK modulation format has a good application prospects on the long-distance large-capacity high-speed optical communication system.

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