مراقبة تشتت نمط الاستقطاب PMD من خلال قياس مطال النبضات الناتجة عن جمع مركبتي الاستقطاب المتعامدتين

د. حيدرا عبد الرحمن عبد الله[1]

الملخص

في هذا البحث تم اقتراح تقنية جديدة لمراقبة تشتت نمط الاستقطاب polarization mode dispersion (PMD) في شبكات الألياف الضوئية. تعتمد التقنية على تحويل مركبتي الاستقطاب المتعامدتين للإشارة الضوئية المراقبة إلى نفس حالة الاستقطاب ومن ثم يتم جمعهما معاً بفرق طور (180 درجة). يتم قياس مطال النبضات الناتجة والتي تتناسب مع تأخير المجموعة التفاضلية differential group delay (DGD) الذي يصف تشتت (PMD) لوصلة الليف الضوئي.

تتميز التقنية المقترحة مقارنة بتقنيات المراقبة الأخرى، بمجال مراقبة جيد، وحساسية عالية، وعدم الحاجة لتعديل جهاز الإرسال، وبنية بسيطة، وعدم تأثرها بالتشتت اللوني (CD)، وزمن استجابة سريع والقدرة على العمل بمعدلات بت مختلفة.

تم استخدام برنامج المحاكاة الضوئي VPIphotonics لإثبات صحة عمل وحدة المراقبة المقترحة، وتحليل أدائها.

الكلمات المفتاحية: اتصالات الألياف الضوئيةـ مراقبة الأداء الضوئي، مراقبة تشتت نمط الاستقطاب، تأخير المجموعة التفاضلي.

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Polarization Mode Dispersion Monitoring by Measuring the Amplitude of the Pulses Produced by Combining the Two Orthogonal Polarization Components

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Abstract

In this paper, a new polarization mode dispersion (PMD) monitoring technique is proposed in optical fiber networks. It is based on converting the two orthogonal polarization modes of the monitored signal to the same state of polarization and then they are coupled together with a phase difference of (180º). The amplitude of resulting pulses is measured which is proportional to the differential group delay (DGD) of the fiber link which describes the PMD of the optical fiber link.

The proposed technique is characterized, compared with other monitoring techniques, by good monitoring range, high sensitivity, no modification of the transmitter, simple scheme, not affected by chromatic dispersion (CD), fast response time and the ability to work with different bit rates without requiring any hardware modification,

VPIphotonics simulator was used to demonstrate the validity of the proposed monitoring technique and to analyze its performance.

Keywords: Optical fiber communication, optical performance monitoring, polarization mode dispersion monitoring, differential group delay.

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1.INTRODUCTION:

Polarization mode dispersion (PMD) is a form of modal dispersion where two different polarizations of light in a waveguide travel at different speeds due to random imperfections and asymmetries, creating a differential group delay (DGD) between the two modes that results in pulse spreading and inter-symbol interference (ISI). PMD is a crucial limitation in high-speed wavelength-division multiplexed (WDM) systems due to either high-PMD legacy fiber or PMD of many in-line components. PMD accumulates in the fiber link and many in-line components. It is time varying, temperature dependent and may change with the network reconfigurations. Therefore, real-time PMD monitoring is required in order to dynamically tune a compensator or for network control and management [1].

Several PMD monitoring techniques have been demonstrated for dynamic optical networks in recent years. However, many current techniques suffer from a number of potential disadvantages. One method has been suggested based on the stimulated Brillouin scattering (SBS) in optical fber [2]. A fixed analyzer method with deep neural network for (PMD) measurement was proposed [3]. In [4] singular value decomposition (SVD) denoising algorithm is applied to monitor PMD. Other method was reported to measure DGD by monitoring the degree-of-polarization (DOP) of received signal [5]. This method is dependent on the pulse width of the signal and the DGD monitoring range is small for short pulses. Besides, it is also dependent on modulation formats. Another technique was proposed to measure PMD by observing the fading of added RF tones [6]. This method requires transmitter modification and it needs high-speed devices. Moreover, the tone could interfere with data and cause deleterious effects. It is also affected by chromatic dispersion (CD) which causes ambiguity in PMD monitoring. Eye diagrams and delay-tap sampling (DTS) plots reveal the effect of PMD [7,8]. However, the PMD monitoring results are still degraded by both optical signal-to-noise ratio(OSNR) variations and CD effects. Another major disadvantage of asynchronous DTS is that the delay value between the taps is a function of data rate and hence needs to be precisely adjusted for various data rates. This would require a high precision tunable electrical delay line with large tuning range depending upon the range of data rates being monitored. It has been shown in [9] that a slight mis-adjustment in the tap- delay value may lead to very large monitoring errors. Furthermore, DTS technique has slow response time.

In this paper, a new PMD monitoring technique is proposed. It is based on measuring the DGD by converting the two orthogonal polarization modes (E_x,E_y) of the monitored signal to the same state of polarization and frequency band and then they are coupled together with a phase difference of 180º. After that, the amplitude of resulting pulses is measured which is proportional to the DGD. This technique has the following advantages: (1) good PMD monitoring range. (2) high sensitivity. (3) no modification of the transmitter. (4) simple scheme and cost effective. (5) not affected by CD. (6) fast response time. (7) the ability to work with different bit rates without requiring any hardware modification

The remainder of this paper is organized as follows: In Section (2), the operation principle of the proposed PMD technique is explained. Section (3) displays the simulation model of the proposed technique which is prepared by VPI photonics simulator. Section (4) shows the results of the simulator that demonstrate the validity of the proposed technique. The effect of the CD and amplified spontaneous emission (ASE) noise on the PMD and the ability to work with different bit rates are also investigated in this section. Finally, Section (5) summarizes the paper.

2. Operation principle of the proposed PMD monitoring technique

Optical signal propagating in optical transmission links is split into two orthogonal polarization modes (Transverse Electric(TE), Transverse Magnetic(TM)). Due to the effect of PMD, each component travels along the fiber at different speeds, creating a differential group delay (DGD) between the two modes which describes the PMD of the optical fiber link [10], as shown in Fig. 1.

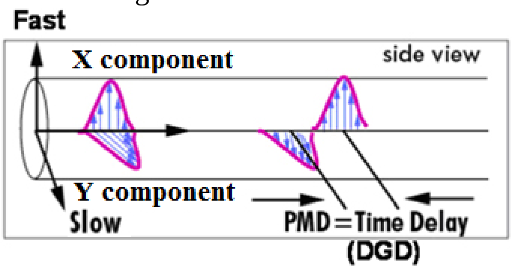

Fig. 1. Polarization-mode dispersion.

Fig. 2 shows the schematic diagram of the proposed PMD monitoring technique which measures the DGD as follows. First, the received optical signal is passed to polarization beam splitter (PBS) which gives the two orthogonal polarization modes (X, Y). They carry the same data information. Suppose that the (X) component is E(t), then the (Y) component is E(t-DGD). After that, both signals are coupled with low power continuous wave (CW) at a frequency away from the optical carrier (f_c+250GHz). The coupled signals are passed to semiconductor optical amplifier (SOA) which works as an optical wavelength converter based on cross-gain modulation (XGM) [11]. An optical band-pass filter is used after SOA to pass (CW) signal only. Therefore, the resulting signals in the two paths are now at the same state of polarization and frequency band. The phase of upper path signal is shifted (180°) and then the two paths are combined by a coupler.

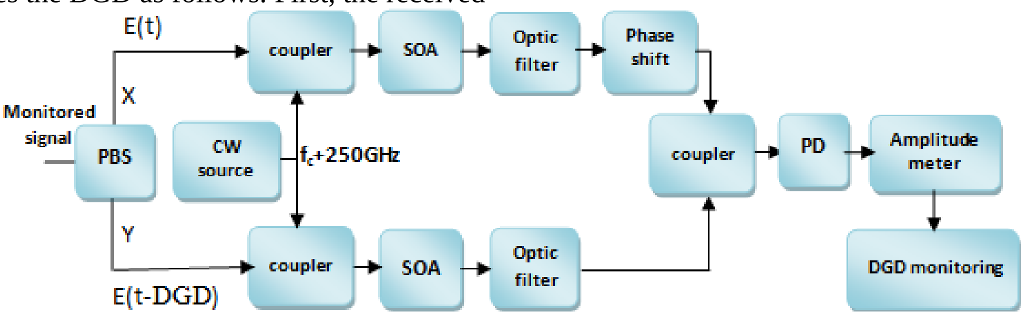

Fig. 2. Schematic diagram of the proposed PMD monitoring technique

Finally, the resulting optical pulses are detected by a photodiode (PD) and the amplitude of resulting electrical pulses is measured. If DGD=0, the (X) and (Y) signals are synchronized (matched in time), so they interfere destructively (cancel each other out completely), and hence there is no pulses (after the coupler) as shown in Fig. 3(a). On the other hand, if DGD≠0, the (X) and (Y) signals are not synchronized. So, they do not cancel each other out completely and hence there are some pulses at the output of coupler as shown in Fig. 3(b). The amplitude of the pulses is proportional to the unknown DGD value which can be exploited to monitor DGD.

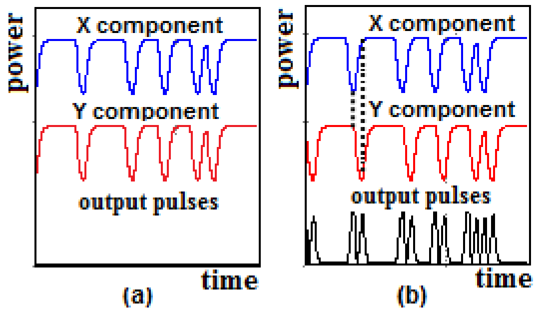

Fig. 3. X and Y components after the SOA with the output signal after the coupler for (a)DGD=0, (b) DGD≠0.

3. Simulation setup

The simulation model of the proposed monitoring technique was prepared by VPI photonics simulator as shown in Fig. 4 in order to demonstrate the validity of the proposed technique. It consists of the following parts:

1- RZ-OOK transmitter module: In this section, a laser light is modulated externally by 50% return to Zero (RZ) data bit sequence at 10Gb/s using mach-zehnder intensity modulator to generate RZ-OOK (on-off keying) signal.

LaserCW element to generate laser light. PRPS element to generate bit sequences. RZ-coder to convert bits into RZ coding. Rise time to set the rise time of the bits. ModulatorMZ is mach-zehnder modulator.

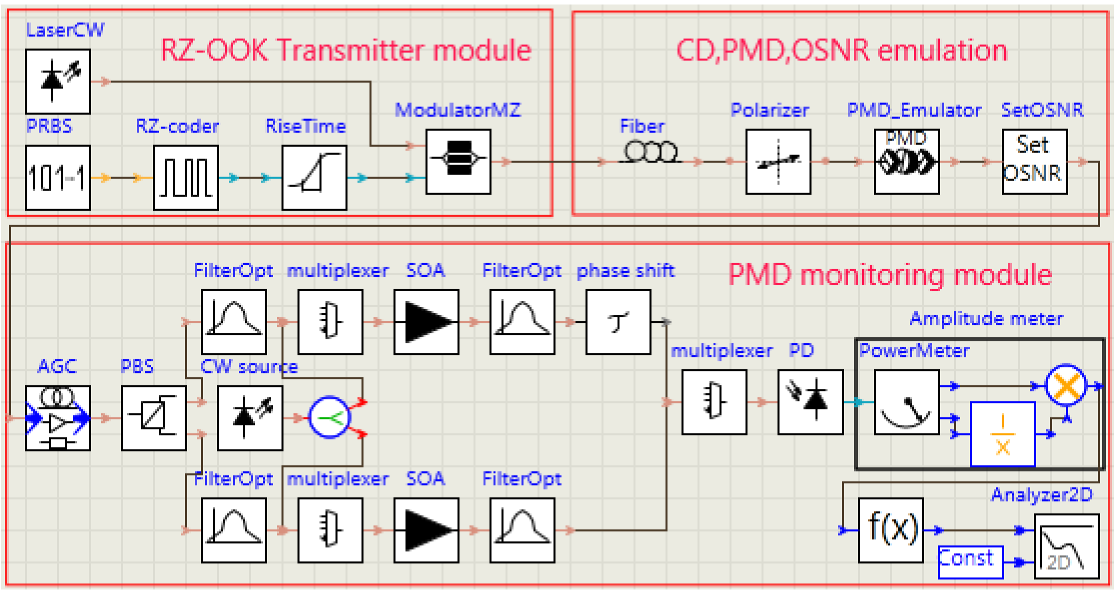

Fig. 4. Simulation setup for the proposed PMD monitoring.

2-CD,PMD and OSNR emulation: In this section, the transmitted signal is passed to an optical fiber which adds CD to study the effect of the CD on the PMD measurement. Then, a polarizer and PMD emulator is used to change DGD of the two polarization component. The added DGD represents the unknown value, which should be measured by the proposed monitoring unit. After that, ASE noise is inserted to the transmitted signal using (OSNR) element for testing the work of the technique with ASE noise.

3-PMD monitoring module: In this section, the received signal is firstly sent to AGC (automatic gain control) element to set the same power for the optical pulses, then it passes to PBS element to extract (X) and (Y) signals which after that they are coupled with the same CW signal at frequency (193.1THz+0.25THz) and are inserted to

PBS element is polarization beam splitter. FilterOpt represents optical filter. Multiplexer is used to combine multiple optical signals. SOA represents semiconductor optical amplifier. PD is photo detector. Power meter element and Reciprocal(1/x) are used to calculate the amplitude of the electrical pulses. F(x) is used to calculate the amplitude in dB. Analyzer2D to display results in 2D.

SOAs. Optical band pass filter is used to pass the CW signal only. Therefore, we obtain the same frequency and state of polarization in the two branches. The phase of (X) component is shifted (180º) and then it is combined with the other signal by a multiplexer. Finally, the resulting optical pulses are detected by (PD) and the amplitude of the electrical pulses is measured which can be used to monitor unknown DGD. Table 1 shows the most significant simulation model parameters.

Table 1 : Simulation model parameters.

Parameter	Value
Bit rate (R_b)	10Gb/s
Average power of transmitted signal	5 mW
Frequency of the laser light (f_c)	193.1 THz
DGD range	[0,50] ps
CD range	[0,400] ps/nm
OSNR range	[20,40] dB
SOA bias current	500 mA
SOA length	500 µm
CW source power	0.5 mW
CW source frequency	193.1 THz +250GHz
Responsivity of the PD	1 A/W

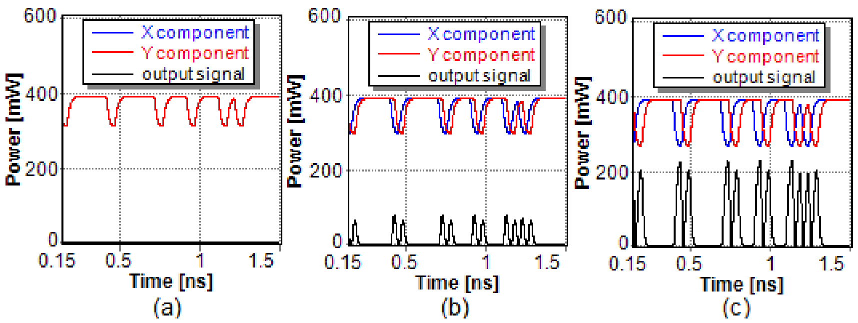

Fig. 5. The data bits of (X) component and (Y) component signals resulting from PBS with the output pulses for (a) DGD=0ps, (b) DGD=25ps, (b) DGD=50ps.

4.Simulation results and discussion

4.1. The relationship between the amplitude of the output pulses and the DGD

The two orthogonal polarization modes carry the same data information but with relative delay resulting from PMD of the fiber. Fig. 5 shows data bits of the (X) component and (Y) component with the output optical pulses for DGD=0ps, DGD=25ps and DGD=50ps.

For DGD=0, there are no output pulses as the result of destructive interference completely between the two components. For DGD=25ps and DGD=50ps, there is some misalignment between the two components, so optical pulses appear. It is clear that the higher the DGD is, the higher the energies of the output optical pulses.

Fig. 6 shows the amplitude of resulting electrical pulses (after PD) as a function of the DGD for different cases of the data bit sequences(one sequences, alternate sequences and random sequences) with different powers of the monitored signal. As expected from the previous results shown in Fig. 5, the amplitude of output pulses grows with DGD and thereby this amplitude can be used for DGD monitoring. It is clear also that the amplitude of output pulses does not related with the data bit pattern and the power of monitored signal.

The DGD monitoring range is [0,T_b/2] because when the DGD is above (T_b/2), the amplitude of output pulses will almost not change with the DGD. For R_b=10Gb/s, the DGD monitoring range is [0,50] ps. Sensitivity is defined as the amplitude change of the output pulses per unit dispersion. The higher sensitivity gives higher monitoring accuracy. Sensitivity is meaningful at near zero DGD assuming a feedback control to minimize dispersion penalty [12]. So, we measure the sensitivity at near zero DGD and it is equal to 4.8 dB/ps. This indicates that the sensitivity of the proposed technique is high.

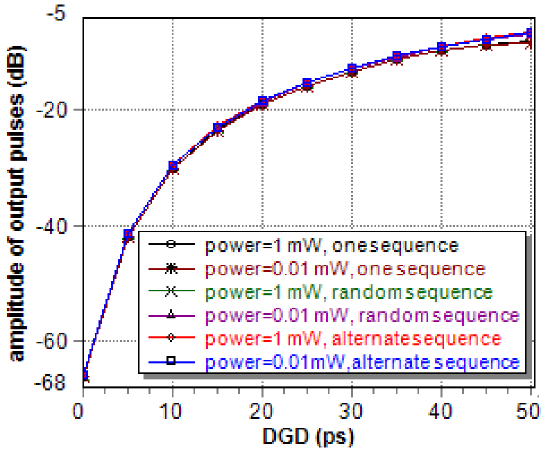

Fig. 6. The amplitude of output pulses versus the DGD value for different cases of the data bit pattern and power of monitored signal.

It should be noted that the results have been reached in this section under the assumption that there are no noise with the monitoring signal and in the absence of CD. In the next two paragraphs the impact of each on the DGD measurement is examined.

4.2. The effect of CD on DGD measurement

Various frequency components of an optical signal experience a slightly different index of refraction as they travel through the fiber. So, these various components travel at different speeds. The result is that a given pulse of light spreads out as the pulse propagates, giving rise to what is normally called chromatic dispersion [13]. Most of the proposed PMD monitoring techniques are affected by CD which cause errors in PMD estimation. In this section, we investigate the effect of CD on PMD measurement. Fig. 7 shows the amplitude of output pulses as a function of the DGD at different values of CD (0,100,200,300,400) ps/nm. It is obvious that the measured DGD is not almost affected by CD because CD does not affect the relative delay between the two orthogonal polarization modes of the monitored signal. As a result, the proposed technique is more suitable to use in optical fiber networks.

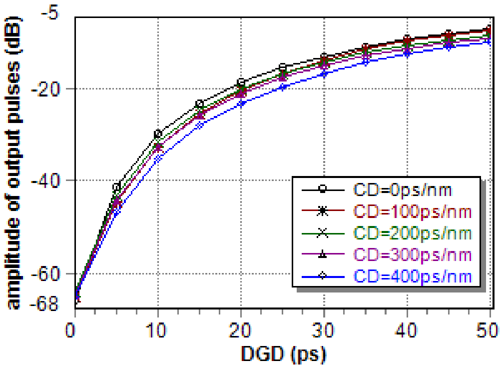

Fig. 7. The effect of CD on the PMD monitoring.

4.3. The effect of ASE noise on DGD measurement

Optical amplifiers that are used in long-haul networks provide an important and dominant noise known as amplified spontaneous emission (ASE) which is generated as a result of spontaneous emission process within the amplifier gap. This noise is uniformly distributed in frequency, phase and polarization, and is described by the term optical signal-to-noise ratio (OSNR) [13]. In this paragraph, the work of the proposed technique in presence of the ASE noise has been tested. Fig. 8 shows the amplitude of output pulses as a function of the DGD at different values of OSNR (20,25,30,35,40)dB. It is clear that when OSNR is above 30dB, the ASE noise does not almost affect the DGD measurement. Therefore, the proposed technique is affected by ASE noise and should work in OSNR above 30dB.

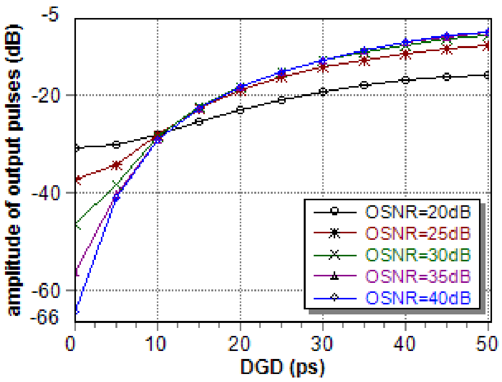

Fig. 8. The effect of ASE noise on the PMD monitoring.

4.4. The ability to work with different bit rates and modulation schemes

Since the envisaged future optical networks will probably incorporate multiple data rates, there is a considerable interest in the development of monitoring techniques which could accommodate different data rates. Such beneficial feature may significantly reduce the monitoring costs. Fig. 9 shows the relationship between the amplitude of output pulses and DGD for different bit rates (R_b=10Gb/s, R_b=15Gb/s, R_b=20Gb/s). As it is clearly, the proposed technique can be used with different bit rates without any modification of the monitoring hardware. The clock tone power detection and DTS techniques are function of data bit rate, so they need modification of the monitoring unit for measuring multiple bit rates. The measurement range of the proposed technique will differ as a function of bit rate. It is equal to the half of bit period (T_b/2) because when the DGD is above (T_b/2), the amplitude of the pulses is not change almost with the DGD variation (sensitivity will be very low). For R_b=10Gb/s the measured DGD range is [0,50] ps and for R_b=20Gb/s the measured DGD range is [0,25]ps.

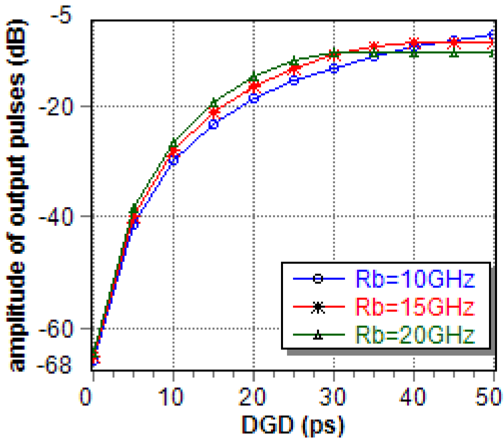

Fig. 9. The amplitude of output pulses versus the DGD value at bit rates (10Gb/s,15Gb/s,20Gb/s).

5. Conclusion

In this paper, a new PMD monitoring technique for optical fiber systems is proposed and analyzed. It is based on detecting the DGD by converting the two orthogonal polarization modes to the same state of polarization and frequency by using (SOA) based on XGM, which then the phase of one of them is shifted (180°) and are coupled together. The amplitude of resulting electrical signal is measured which is proportional to the DGD. The technique offers a robust and effective solution to realize in-line PMD monitoring for future high-speed flexible optical network. Table 2 summarizes comparison of proposed technique with some of the existing PMD monitoring techniques.

Table 2 : Comparison of proposed technique with other PMD monitoring technique

Property	AAH technique	DTS technique	Pilot tone	Clock tone	DOP	Proposed technique
DGD Monitoring range	It depends on bit rate and bits coding. For R_b=10Gb/s, RZ bit. Monitoring range is [0,50] ps.	It depends on bit rate and bits coding. For R_b=10Gb/s, RZ bit. Monitoring range is [0,50] ps.	It depends on pilot tone frequency. For f_p=10GHz, monitoring range is [0,50] ps.	It depends on bit rate For R_b=10Gb/s, monitoring range is [0,50] ps.	It depends on bit rate and bit coding. For R_b=10Gb/s, 50% RZ bit. Monitoring range is [0,50] ps.	It depends on bit rate and bit coding . [0, $+T_b/2$] . R_b=10Gb/s, 50% RZ bit. Monitoring range is [0,50] ps.
sensitivity	Quasi-linear	Quasi-linear	Non-linear	Non-linear	Linear.	Linear and high at near zero DGD
Effect of CD	Yes	Yes	Yes	Yes	Independent	Independent.
Effect of ASE noise	Yes	Yes	Yes	Yes	Yes	Yes
Response time	slow	slow	fast	Fast	fast	fast
Complexity and cost	simple	medium	Simple but need Modification of transmitter	Simple	simple	simple, without requiring any hardware modification.

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