Light Emitting Diode

Precautions for Designing LED Tubes

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1. Overview

Recently LEDs have been increasingly introduced into lighting fixtures as the LED performance advances. LED tubes have been substituted with conventional tube fluorescent lamps in the marketplace.
This application note describes some important factors to design LED tubes with some evaluation results.

2. LED Tubes

2.1. LED Tube Structure

Figure 1 shows the typical LED tube structure which does not incorporate a power supply. Table 1 summarizes the features of the component materials.
The LED performance can be affected by some component materials depending on their properties; therefore, customers should evaluate the component materials and confirm whether they would affect the LED performance.

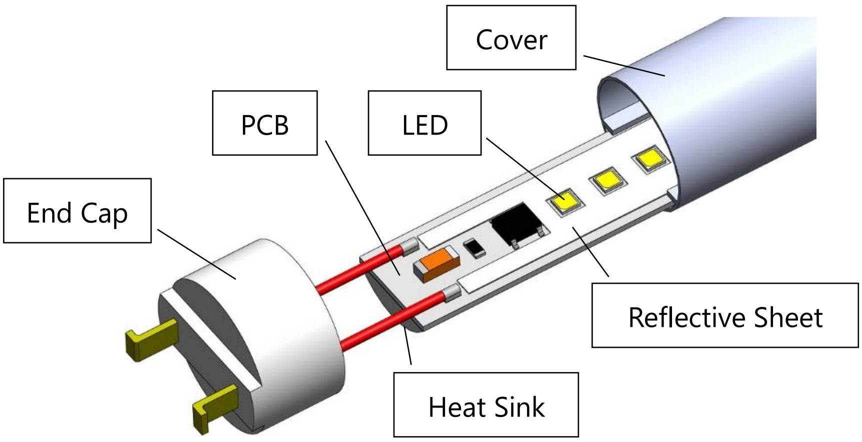


Figure 1. LED Tube Structure

Table 1. Features of Component Materials

Component Material	Note
Cover	Protects the LEDs and diffuses the light. Made of glass and resin such as polycarbonate. The cover with high transmission rate can contribute to minimizing the depreciation rate of the lamp's luminous flux; on the other hand, it reduces the light diffusion, and the individual LED's emission light can be visible through it.
PCB	Printed circuit board with LEDs, protection device, etc. mounted on In general, aluminum, glass epoxy (FR-4), glass composite board (CEM-3), etc. are used for PCBs. Thermal conductivity rate: aluminum > CEM-3 > FR-4 To uniformly dissipate the heat generated from LEDs, large copper foil patterns should be formed on the PCB. High reflective ink should be used for the solder resist to increase the lamp's luminous flux. (cf. Section 4)

Reflective Sheet	Increases the lamp's luminous flux like the high reflective solder resist
Heat Sink	Helps to dissipate the heat generated from LEDs and secure the housing's strength. In general, the LED-mounted PCB is attached to the heat sink with adhesive tape and/or screws. The heat dissipation can be insufficient and the heat distribution can be uneven depending on the attachment method.
End Cap	Electrically and mechanically connects the LED tube with the control system.

2.2. Luminous Flux Decrease and Color Shift of LED Tubes

The LED tube's optical characteristics can be affected by the following factors:

1) Lamp cover
2) Reflective sheet
3) Relation between the LED pitch and the light diffusion
4) Relation between the LED junction temperature and the luminous flux

2.3. LED Tube Specifications for Evaluation

Table 2 and Figure 2 show the LED tube specifications to be used for the evaluations herein. We evaluated the impact of each factor (cf. Section 2.2) on the LED tube.

Table 2. LED Tube Specifications

Item	Specification	Notes
Size	1,200mm	LED Pitch: 7mm
LED Model	NFSW757D-V1	
Quantity of LED	160pcs.	16 series, 10 parallel
LED Tube Luminous Flux	2,400lm	Including the luminous flux decrease due to the lamp cover(10%) and thermally saturated.
LED Tube Electrical Current	350mA	35mA per 1 LED
LED Tube Voltage	45V	
LED Tube Power	16W	
LED Tube Efficacy	150lm/W	Lamp Luminous Flux / Lamp Power
Color Temperature	5,000K	
General Color Rendering Index (Ra)	80	

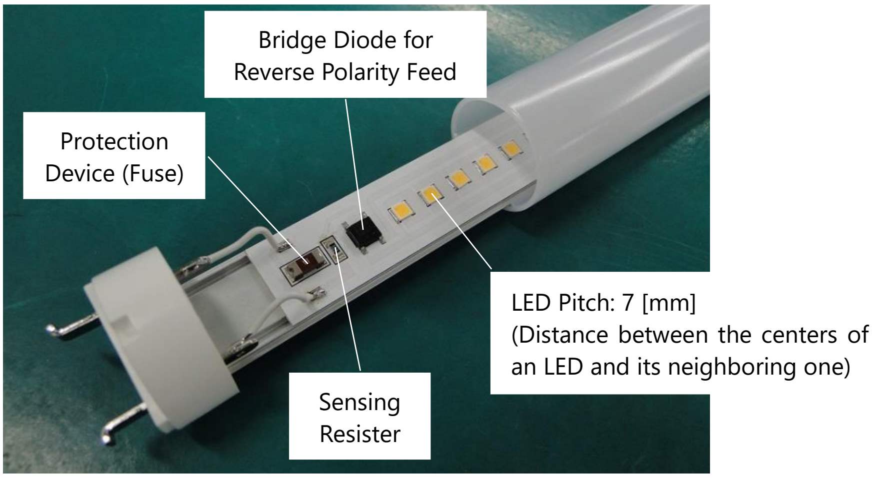


Figure 2. LED Tube Structure

3. Impact of Lamp Cover on Optical Characteristics

We evaluated the impact of several kinds of lamp cover on the optical characteristics.

3.1. Evaluation Method

We measured the luminous flux/color/color rendering of the LED tubes with Covers A, B, C, and no cover to evaluate the impact of the covers on each characteristic. We also evaluated the light diffusion (light evenness through each cover). Each item was measured just after the LEDs were operated to eliminate the thermal impact due to the cover.

Table 3. Lamp Cover for Evaluation

	Cover A	Cover B	Cover C	No Cover
Appearance				
Property	Resin	Glass	Resin	-
Light Transmission Rate(%)[1]	57	67	77	-
Diameter(mm)	25	25	33	-
Thickness(mm)	1	1	1	-

Note:

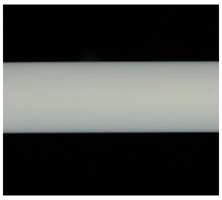
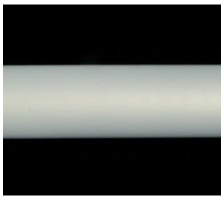
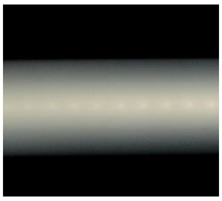
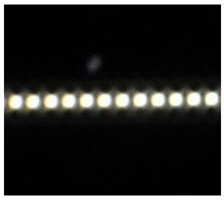
[1] Rate of light which vertically penetrates the cover and passes through it

3.2. Evaluation Result

Table 4 shows the evaluation results.

Figures 3, 4, and 5 (Page 5) show the relation between the transmission rate and the luminous flux depreciation, the color shift, and the changes in the general color rendering index, respectively. The luminous flux depreciation rate, color shift, change of Ra were calculated on the basis of the measurement values of the LED tube with no cover.

Table 4 Evaluation Results of Lamp Covers

		Cover A	Cover B	Cover C	No Cover
Lamp's Luminous Flux(lm)		2,692	2,779	2,868	2,958
Luminous Flux Depreciation Rate(%)		9.0	6.1	3.0	-
Color	x	0.3453	0.3443	0.3436	0.3423
	y	0.3580	0.3570	0.3559	0.3546
Color Shift	Δx	+ 0.0030	+ 0.0020	+ 0.0013	-
	Δy	+ 0.0034	+ 0.0024	+ 0.0013	-
General Color Rendering Index (Ra)		82.2	81.8	81.8	82.0
Change of Ra		+ 0.2	- 0.2	- 0.2	-
Light Diffusion (Unevenness) (LED Pitch; 7mm)					

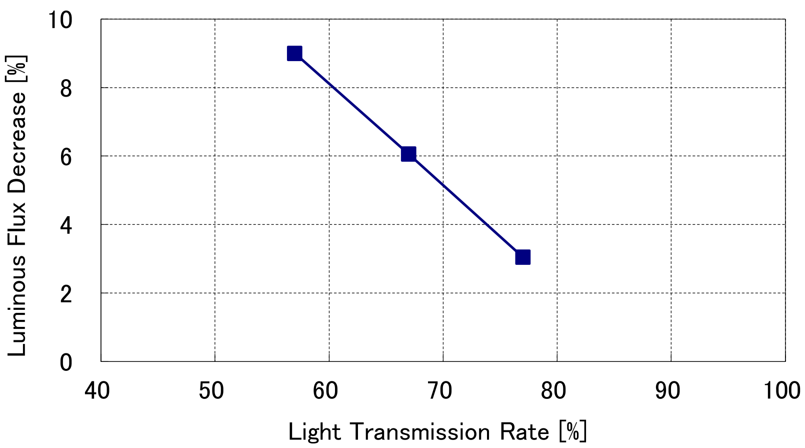


Figure 3. Light Transmission Rate – Luminous Flux Decrease

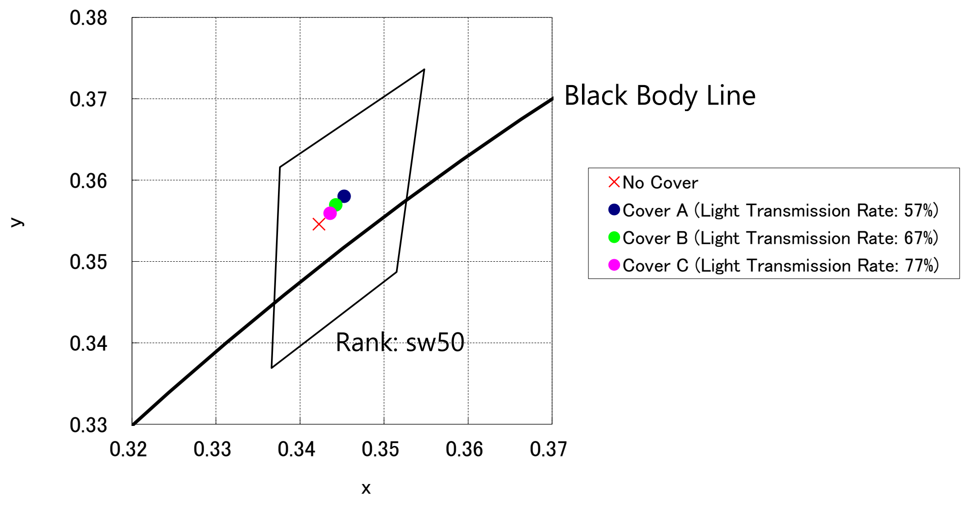


Figure 4. Color Shift due to Covers

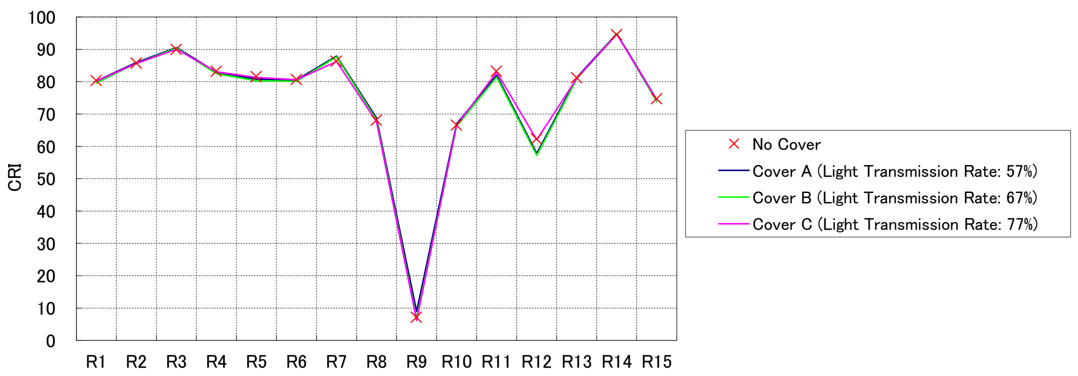


Figure 5. Impact of Covers on Color Rendering Properties

Based on the evaluation results, the highest luminous flux was obtained with Cover C which had the highest light transmission rate; the luminous flux was decreased by 3.0% with Cover C.

On the other hand, the individual LED's light under Cover C was easily noticeable when the tube was operated. The luminous flux decrease was the highest with Cover A; however, the individual LED's light was not noticeable but the light was evenly diffused, like a fluorescent lamp's light. We found that the light diffusion contradicts the luminous flux decrease.

Moreover, the lower the light transmission rate was, the more the color shifted.

As shown in Figure 4, using the milky white covers, the color shifted toward yellow in the + direction of x and y.

Figure 5 shows slight decreases in the figure of R12 (Blue) with Covers A, B, and C; however, R12 does not affect the General CRI (Ra).

4. Advantage of Reflective Sheet

Using the reflective sheet or the resist ink containing a highly reflective material on the board can enhance the light extraction efficiency, resulting in higher luminous flux (Figure 6).

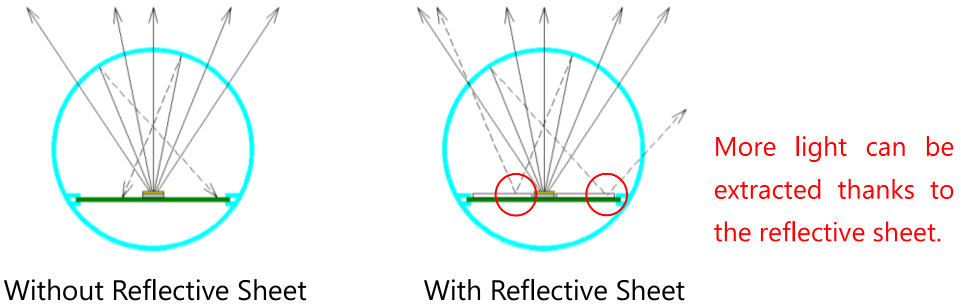


Figure 6. Comparison of Light Extraction

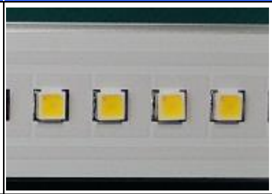
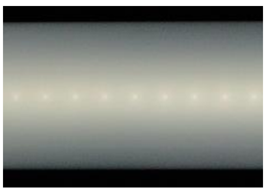
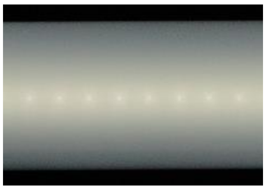
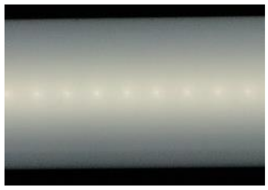
4.1. Evaluation Method

We measured the luminous flux and evaluated the light diffusion with two kinds of reflective sheet and a highly reflective resist, respectively.
We compared the luminous flux by using the three lamp covers (A to C), and compared the light diffusion by using Lamp Cover C with the least light diffusion. The luminous flux was measured just after the LEDs were operated to avoid the thermal impact.

4.2. Evaluation Result

The evaluation results are given in Table 5.
Figure 7 shows the relation between each reflective sheet's reflectance and the increase rate of the luminous flux. The increase rate with each reflective sheet was obtained on the basis of the luminous flux of the LEDs attached to the highly reflective resist layer (Reflectance: 80.2%).

Table 5. Evaluation Results of Reflective Sheets

		Reflective Sheet A (Reflectance: 98.8%)	**Reflective Sheet B** (Reflectance: 94.2%)	**Highly Reflective** Resist Layer (Reflectance: 80.2%)
Appearance				
Cover A (Light Transmission Rate: 57%)	Luminous Flux [lm]	2,757	2,753	2,692
	Increase Rate of Luminous Flux [%]	2.4	2.3	-
Cover B (Light Transmission Rate: 67%)	Luminous Flux [lm]	2,825	2,820	2,779
	Increase Rate of Luminous Flux [%]	1.7	1.5	-
Cover C (Light Transmission Rate: 77%)	Luminous Flux [lm]	2,885	2,880	2,868
	Increase Rate of Luminous Flux [%]	0.6	0.4	-
Light Diffusion (Unevenness) LED Pitch: 7mm, Lamp Cover C				

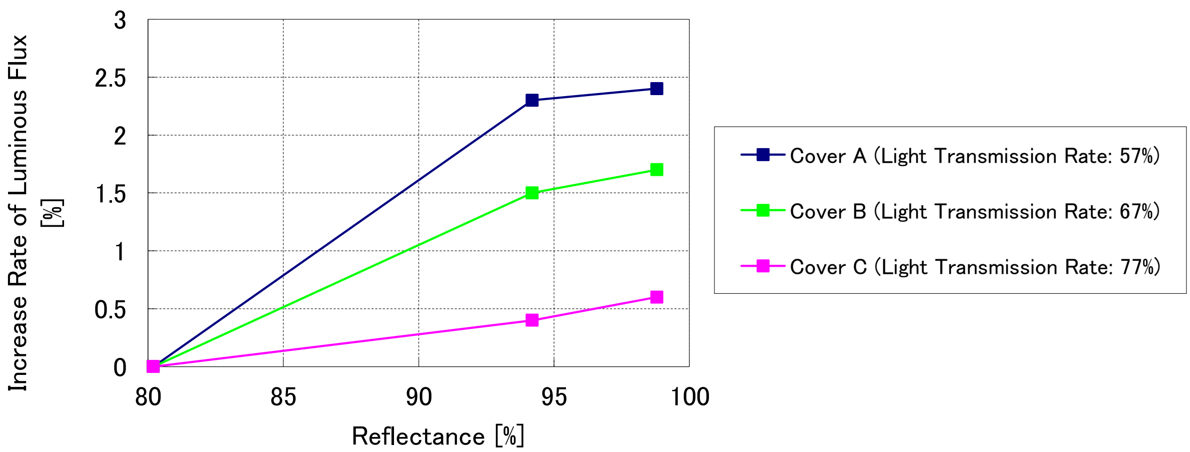


Figure 7 Relation between Reflectance and Increase Rate of Luminous Flux

Based on the measurement data, the higher the reflectance of the reflective sheet was, the higher the luminous flux became in each lamp; however, the higher the transmission rate of the lamp cover was, the lower the increase rate of the luminous flux was. For example, the increase rate of the luminous flux under Cover C was below 1% in each lamp with Reflective Sheet A/B. This is because much light is originally extracted through the covers with high light-transmission rate. Therefore, the reflective sheets are less effective to increase the luminous flux through the covers with high light-transmission rate.
In other words, the lower the light transmission rate of lamp covers is, the more effective the reflective sheets become. There was little difference in the light diffusion under Cover C among the strings.

5. LED Pitch and Light Diffusion

The individual LED's light may be noticeable with a lamp cover in an LED tube. The symptom can be reduced by changing the LED pitch and the distance between the LEDs' emitting surfaces and the lamp cover.

5.1. Evaluation Method

We evaluated the light diffusion (how much less noticeable the individual LED's emission light is) of the LEDs under the lamp cover by changing the LED pitch, the input electrical current, the distance between the LEDs and the cover (cf. Table 6).
The input electrical current in each LED pitch was calculated on the basis of the lamp length (1,200mm) and the lamp's luminous flux (2,400lm). We used a milky white cover in every condition.

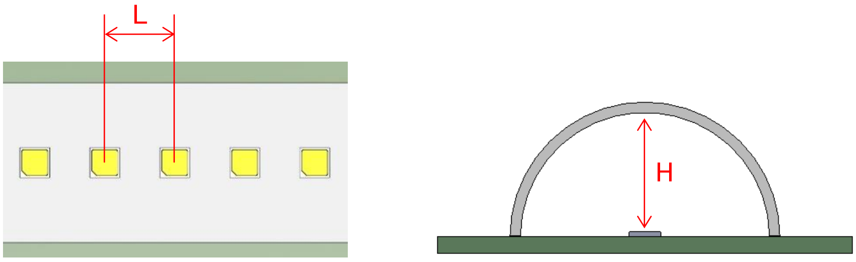
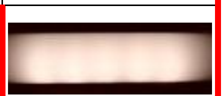


Figure 8. LED Pitch and Distance between an LED and a Lamp Cover

5.2. Evaluation Result

Table 6 shows the evaluation results.

Table 6. Evaluation Results

		L : LED Pitch				
		10mm	13mm	15mm	17mm	20mm
H : Distance between LEDs and cover	10mm					
	15mm					
	18mm					
Input Current [mA]		60	80	93	108	130

The individual LED's emission light can be noticeable on the red-encircled tubes. Based on our findings, the smaller the LED pitch is, also, the larger the distance between the LEDs and the cover is, the more the light can be diffused. Thus, the more the light is diffused on an LED tube, the less noticeable the individual LED's light is.

6. Junction Temperature and Luminous Flux

Most of Nichia's white LEDs emit white light by the combination of LED dice which emit blue light and yellow phosphor. As the LED die generates higher temperature, the light output from the die is reduced, decreasing the output excited by phosphor. Therefore, the higher the junction temperature gets, the lower the luminous flux becomes.

Customers may not be able to realize the designed luminous flux, if the junction temperature is high. Moreover, when there is variation in the junction temperatures among the LEDs, the emission light from the LED tube cannot be even.

Customers are required to optimize the thermal design for the LED tubes by making it possible to dissipate heat.

6.1. Evaluation Method

We measured the heat distribution over the LED-mounted board and the LEDs' junction temperature with/without heat dissipation system through a heat sink. A thermograph was used to evaluate the heat distribution. The LEDs' junction temperature was calculated by the following formula after measuring the soldering temperature with a thermocouple.

The measurements were done while the temperature was saturated within the closed assembly with a lamp cover (Ta=25°C).

The lamp's luminous flux was measured just after the LEDs were operated and while the temperature was saturated, and then, those values were compared to obtain the depreciation rate.

$$LED's\ Junction\ Temperature\ T_J = T_S + R_{\theta JS} \times W$$ Equation 1

T_S = Temperature at the soldering area (cathode): ℃

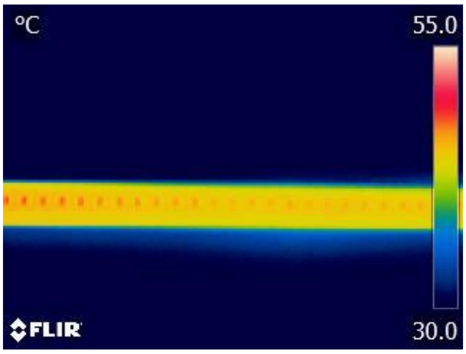
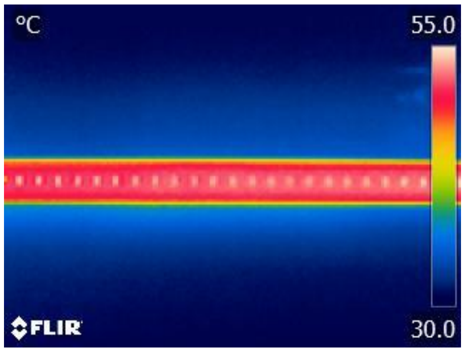
$R_{\theta JS}$ = Thermal resistance between the LED die and Ts measurement point: ℃/W

W = Input power (I_F * V_F) applied to each LED: W

6.2. Evaluation Result

Table 7 shows the measurement results. The luminous flux depreciation rate was calculated by the luminous flux measured just after the LEDs were operated and while the temperature was saturated.

Table 7 Evaluation Results (Ta=25°C)

	With Heat Sink		Without Heat Sink	
Thermal Distribution				
Junction Temperature (℃)	49.7		59.3	
Lamp's Luminous Flux(lm)	Just after operation	2,679	Just after operation	2,702
	Thermally saturated	2,625	Thermally saturated	2,615
Luminous Flux Depreciation Rate(%)	2.0		3.2	

In each tube, the heat was uniformly distributed all over the board, regardless of the existence of the heat sink. Therefore, there was no problem in the heat dissipation in either tube; however, the LEDs' junction temperature without the heat sink was approx.10°C higher than that of the ones with the heat sink. In the tube without the heat sink, the luminous flux depreciation rate was approx. 1% higher.
The findings show that decreasing the junction temperature contributes to minimizing the decrease of the lamp's luminous flux.
Please refer to "Thermal Design of LEDs" for precautions and evaluations for the thermal design of LEDs.

7. Summary

This application note includes very critical information about the lamps' optical characteristics such as luminous flux decrease. Customers should evaluate and design their LED products, with reference to the evaluation results described herein.

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