

An ECU Architecture for Adaptive Headlights



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The electronic technology inside automotive headlights has advanced since the adoption of LEDs, especially for those headlights with adaptive control using LED matrix managers (LMMs). But the nature of LMM brightness control requires certain topologies for LED drivers in electronic control units (ECUs), making topology selection for the ECU a careful process.

Adaptive headlights

One of the key advantages of an adaptive headlight is its anti-glare feature. Conventional high-beam headlights create an unavoidable glare for other drivers. By not subjecting drivers to glare, anti-glaring functionality enhances road safety.

Other than the anti-glaring function, a matrix LED headlight can highlight objects by increasing a portion of the LED brightness.

In European countries, differing road conditions require different beam shapes. With adaptive headlights, it's possible to control the brightness of individual LEDs to form specific beams according to different road conditions.

LMMs

There are different ways to control the brightness of an individual LED. TI's LMMs control LED brightness with a maximum of six or 12 pixels connected in series, respectively.

The basic idea of an LMM is to place a shunt field-effect transistor (FET) parallel to each pixel. By controlling the turn-on and turn-off of the shunt FET at an invisible frequency (above 60 Hz for human eyes), the brightness will change according to the shunt FET's on/off duty cycle. (See the Related Websites section for short articles that discuss dimming in switched-mode drivers and a training

video that offers for more detail about shunt FET pulse-width modulation dimming.) **Figure 1** depicts a simplified block diagram of an LMM.

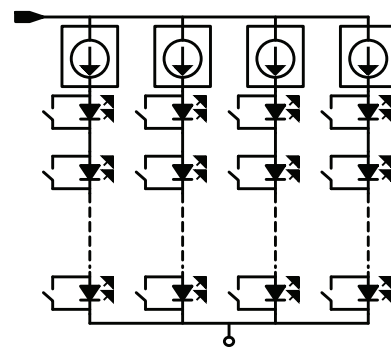


Figure 1. Simplified block diagram of an LMM.

The LMM brightness in TI devices has 10-bit resolution. Because it's possible to control the pixel brightness individually, there is a logic control unit inside the LMM that employs the Universal Asynchronous Receiver Transmitter (UART) protocol as a serial communication link from a microcontroller (MCU). Since every LED pixel is now connected to the LMM, it is possible to detect whether the pixel is open or short. An open pixel will be protected automatically by shorting out the shunt FET internal to the LMM, protecting the LEDs connected to that pixel from damage. This protection feature also ensures the normal operation of other pixels. The LMM's logic control unit will store pixel fault information so that the MCU in control can read from the UART link periodically to determine which pixel has a fault.

If an adaptive headlight has more than 12 pixels, the LMM is addressable by making a corresponding connection of “1” or “0” on address pins ADDR[n:0]. For headlights using binary-addressable LMMs, you can apply an analog voltage on ADDR[0] and signal through the logic control unit to have the internal analog-to-digital converter generate two or three more address bits on ADDR[0].

In total, there can be 31 LMMs in a system. With at most 31 devices and 12 pixels per device, the maximum number of pixels in a system connected to a single UART channel will be 372.

LED voltages with LMMs

As I explained above, shorting or opening of the internal FET of the LMM controls the LED brightness. But the LMM only controls the brightness of the LEDs; it does not provide current for the LEDs to exhibit light. For that capability, you will need an ECU comprising LED drivers (in Figure 1, the current source symbolizes an LED driver). What’s the criteria for choosing a LED driver compatible with an LMM?

Shorting or opening the internal FETs of the LMM to control pixel brightness implies that the LED string voltage is varying accordingly. **Figure 2** illustrates the variation of LED voltage.

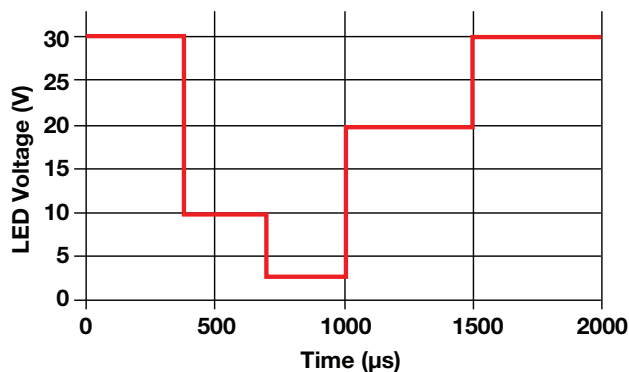


Figure 2. Variation of LED voltage (dynamic LED load).

LMMs characteristically have this dynamic variation of LED voltage; in Figure 5, you can see that the variation happens quickly. The LED driver must be able to handle such voltage changes within a short period of time, yet it cannot induce or generate too much current overshoot or undershoot.

LED driver selection for dynamic LED loads

For the best efficiency, LED drivers that provide more than 350 mA of output are usually based on DC/DC converters. A DC/DC converter provides a suitable output voltage according to the input voltage range; similarly, a DC/DC-based LED driver provides the output current for LEDs. Most popular DC/DC topologies require output capacitors to reduce either the output ripple voltage or the output ripple current. However, these output capacitors can be a source of current overshoot or undershoot in a dynamic LED load situation. **Figure 3** illustrates an example of an overshoot current where all 12 LEDs on the LMM turn off simultaneously.

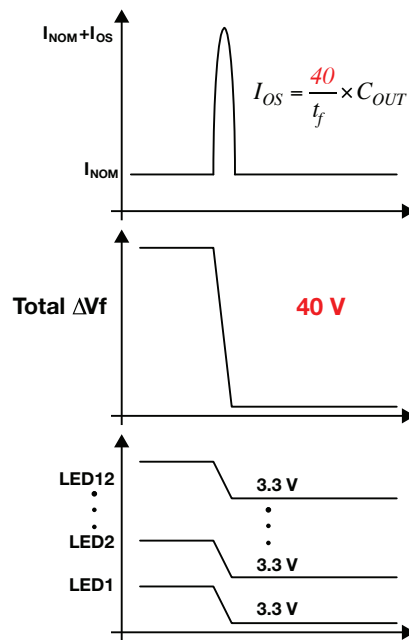


Figure 3. Overshoot current with all 12 LEDs on the LMM turning off.

If the LED driver has a 1- μF output capacitor with a falling slew rate of 2 μs , there will be an overshoot current (I_{OS}) of 20 A adding to a nominal output current (I_{NOM}). The LMM can alleviate part of the huge overshoot current by phase-shifting the turnoff of the LEDs. **Figure 4** illustrates an example of a phase-shifted turnoff of 12 LEDs on an LMM.

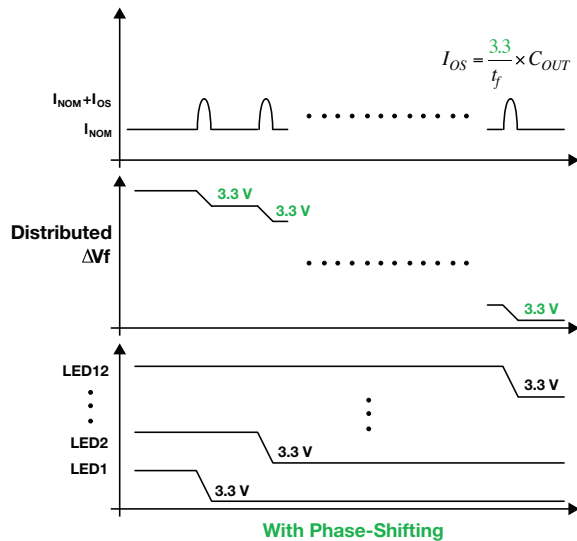


Figure 4. Phase-shifted turnoff of 12 LEDs on an LMM.

Phase shifting the 12 LEDs on the LMM reduces the overshoot current magnitude by 12 times, from 20 A to 1.67 A. However, it is still undesirable for the LEDs to be exposed to such an amount of overshoot current. If you elongate the rate of change from 2 μs to 10 μs through the slew-rate selection of the LMM, it's possible to reduce the overshoot current by about five times, to around 0.33 A. But 0.33 A is still too much overshoot current for a nominal current running at 0.5 A. If you reduce the output capacitor of the LED driver by 10 times (from 1 μF to 100 nF), the overshoot current will drop from 0.33 A to 33 mA, an acceptable current level.

Let's revisit the output current of different DC/DC

topologies to gain a better understanding of how to reduce or even eliminate the output capacitor for LED drivers. **Figure 5** shows the output current of a boost converter (boost-to-input and single-ended primary-inductor converters [SEPICs] have the same output current as a boost converter).

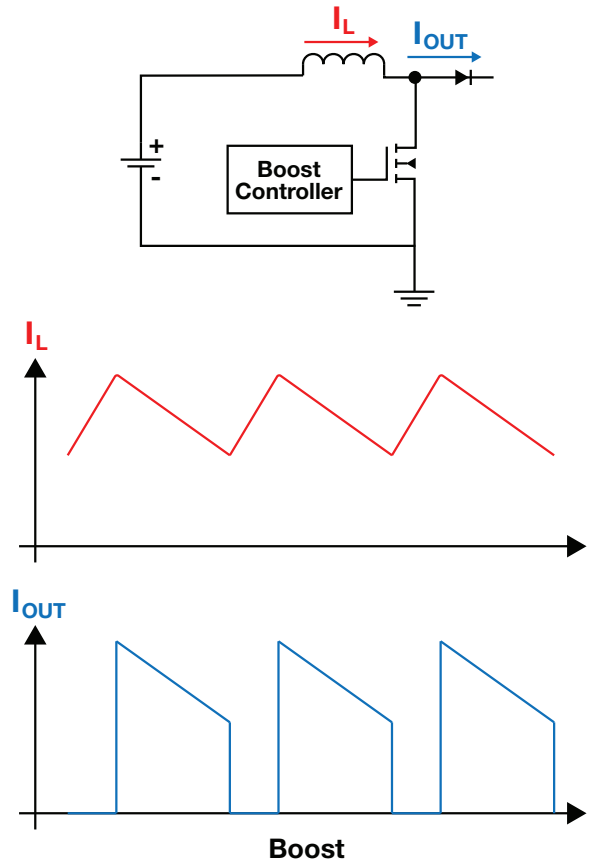


Figure 5. Output current of a boost converter.

You can see that the output current of a boost converter is discontinuous; you will need an output capacitor to provide continuous current to the LED load. Conversely, the output current of a buck converter is the same as the inductor current; it's continuous, as depicted in **Figure 6**. It requires a very small output capacitor for a buck converter to feed this continuous output current to the LED load.

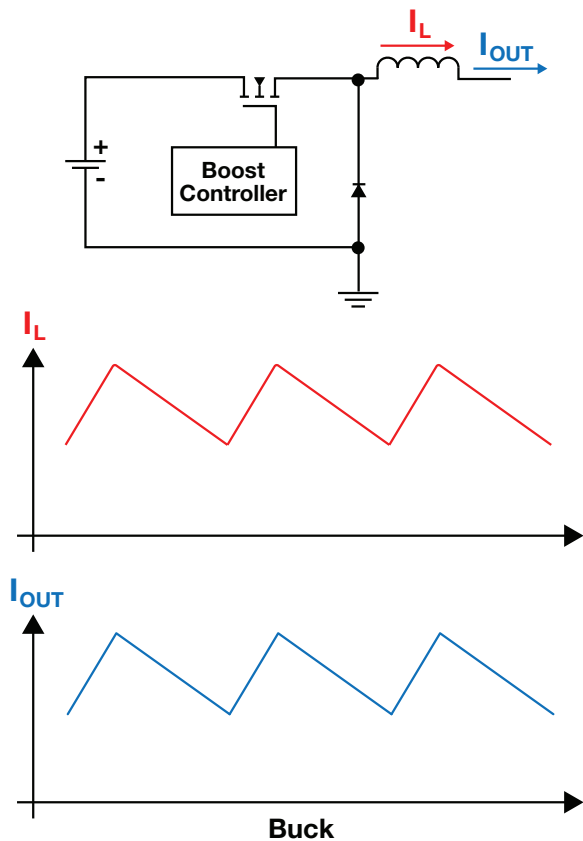


Figure 6. Output current of a buck converter.

Another consideration in selecting a suitable DC/DC LED driver for an ECU compatible with LMMs is the control mechanism. There are two main control mechanisms: peak current-mode control (PCM) and hysteretic control (HC).

PCM DC/DC LED drivers require negative feedback. The duty cycle of the DC/DC LED driver will be determined by the error fed back from the output, compared to a reference voltage internal to the DC/DC LED driver through an error amplifier. A compensation network (compensator) ensures the stability of the DC/DC LED driver. **Figure 7** is a block diagram of a typical PCM DC/DC buck converter.

The advantage of a PCM DC/DC LED driver is that the switching frequency is fixed. It has tight output-current accuracy control due to the negative feedback mechanism. However, there must be a time delay in order for the negative feedback operation to respond to load changes, meaning that a PCM DC/DC LED driver could not effectively support the fast-changing dynamic LED loads imposed by LMM operations.

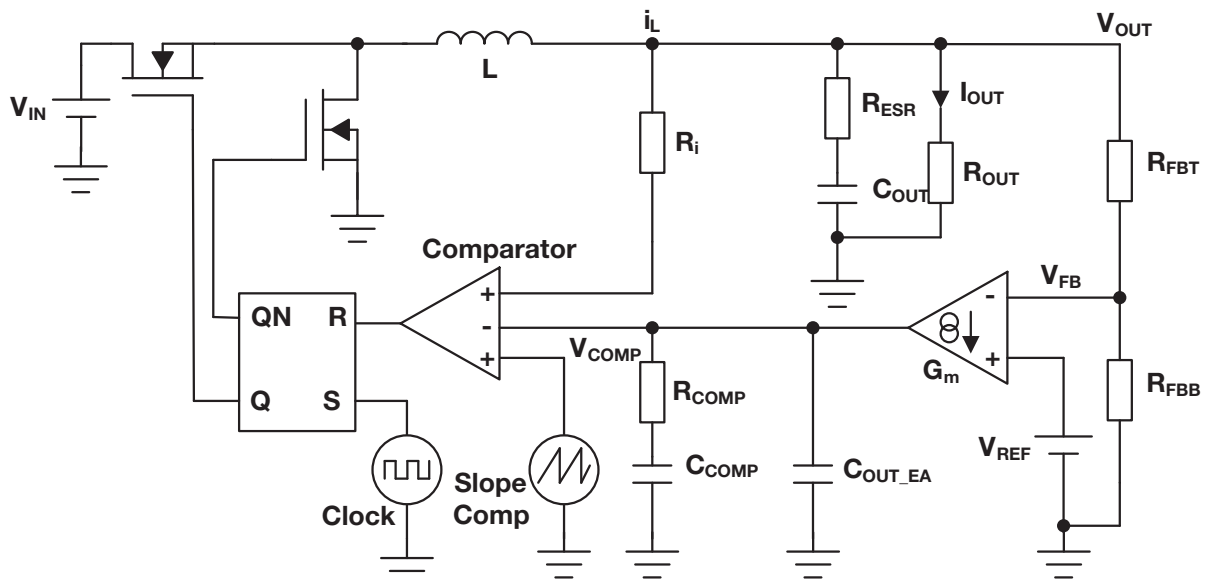


Figure 7. Block diagram of a typical PCM buck converter.

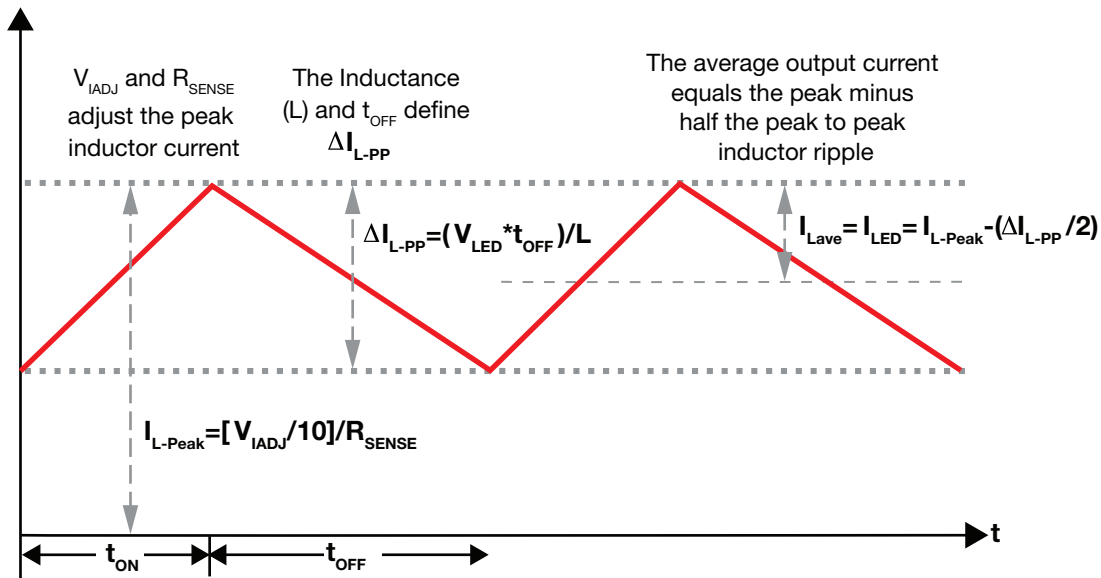


Figure 8. Hysteretic operation of an HC DC/DC LED driver.

On the other hand, a HC DC/DC LED driver is an open-loop-based control mechanism. It does not have feedback and thus needs no compensator for stability. **Figure 8** shows the operational principle of an HC DC/DC LED driver.

As Figure 8 shows, the basic control mechanism is to determine the duty cycle by a fixed peak current limit and a fixed off-time of the main switch of the DC/DC LED driver. The duty cycle changes according to the load changes; thus, the switching

frequency of the DC/DC LED driver changes accordingly while keeping the inductor current ripple (and average current) nearly the same across different loads. Without the compensator, an HC LED driver works faster and can respond to the fast-changing dynamic LED loads imposed by LMMs. **Figure 9** contrasts HC and PCM DC/DC LED drivers by showing the inductor current response during a shunt FET dimming event.

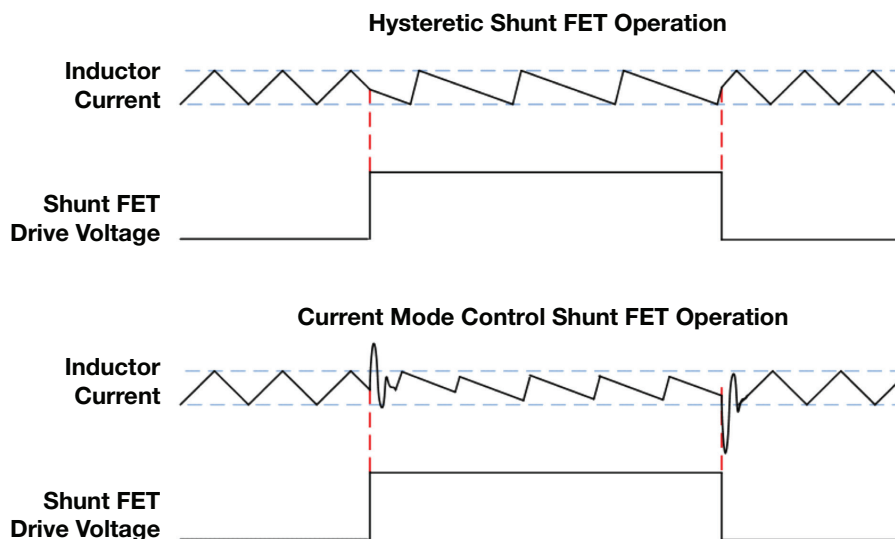


Figure 9. Difference between HC and PCM DC/DC LED drivers with shunt FET dimming.

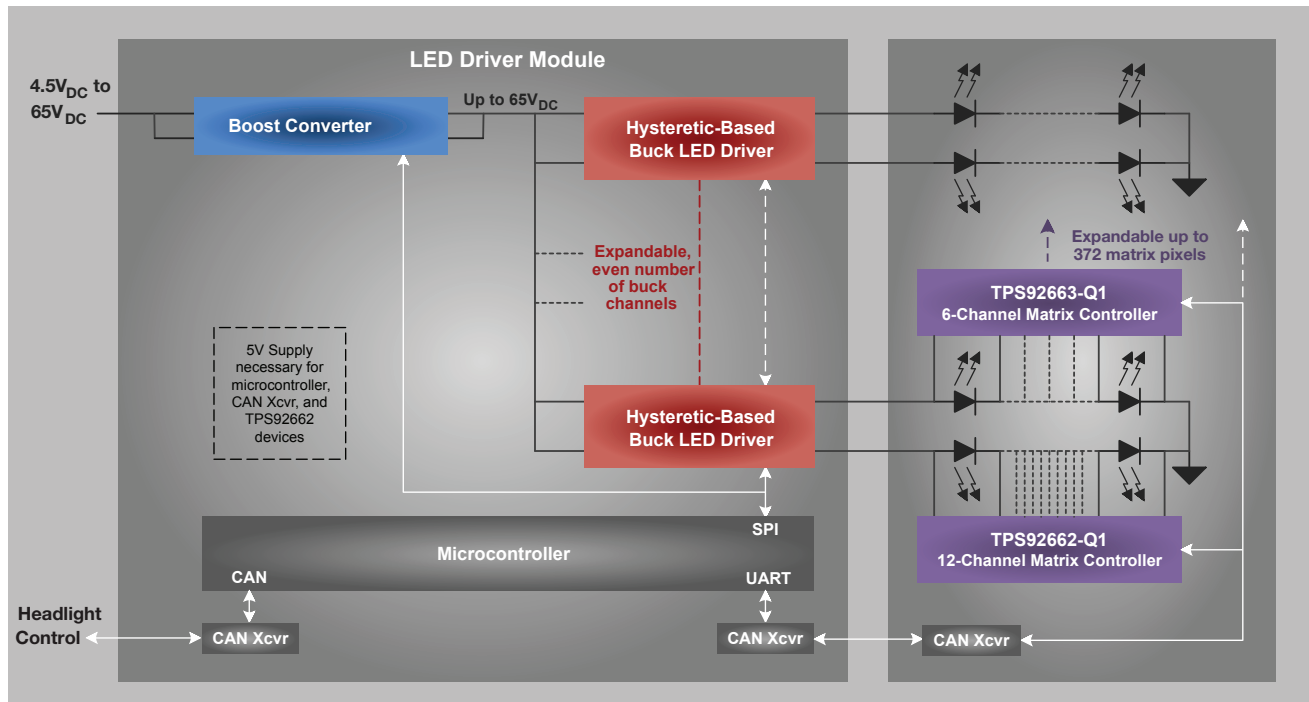


Figure 10. Suggested ECU architecture with an LMM.

ECU architectures compatible with LMMs

It's clear that an HC DC/DC buck LED driver is best for LMMs. However, because most automotive batteries run from 8 to 18 V, a buck LED driver is very limited in the number of LEDs in series due to the voltage is limited to less than 8 V. A boost converter can convert the car battery to a higher voltage and enable an HC DC/DC buck LED driver to provide enough output current to power 12 LEDs in series connected to an LMM. I suggest a two-stage boost-into-buck architecture. **Figure 10** shows an ECU block diagram compatible with LMM operation.

The boost converter not only works as an input voltage converter; it also helps handle battery transient situations such as crank or load dump. From an electromagnetic interference (EMI) perspective, having a two-stage ECU helps mitigate

EMI better, as both the input and output current to the ECU is now continuous.

One recent trend in automotive headlight ECUs is to use MCUs to communicate with the body control module (BCM) in order to perform lighting controls. The MCU receives commands from the BCM and translates into commands to control the LED current and even the boost voltage output level. The boost converter and buck LED drivers use a communication protocol such as Serial Peripheral Interface (SPI) that can talk to the MCU.

The [TPS92682-Q1](#) is a dual-channel multi-topology DC/DC controller with SPI control specifically designed for automotive headlight ECUs. The two channels can be programmed to work independently for voltage or current output, or programmed to work together as a two-phase voltage output boost/SEPIC converter in order to support a higher output power level.

Conclusion

Adaptive headlights employing LMMs enhance road safety by controlling the brightness of individual LED pixels. This paper discussed dynamic LED loads while LED pixels turned on or off with LMMs. A DC/DC boost converter plus an HC DC/DC buck LED driver are best for an ECU architecture because they help reduce overshoot current to the dynamic LED loads characteristic of an LMM.

Additional resources

- Review the product folders for [TPS92662-Q1](#) and [TPS92663-Q1](#).
- Read the technical articles:
 - [“LED brightness adjustment: high-frequency PWM dimming.”](#)
 - [“Dimming in switched-mode LED drivers.”](#)
- Watch the training video, [“Dimming Methods: PWM Dimming.”](#)

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