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800-V SUPERFET® III MOSFET for High Efficiency and Reliability in Low-Power Applications

AND90123/D

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APPLICATION NOTE

Introduction

The key design challenge for an LED lighting driver and battery charger focuses on higher efficiency, lower temperature and lower cost. Quasi−Resonant (QR) flyback converters are very popular for low−power applications because of its simplicity and cost effectiveness. Low stored energy in the output capacitance; EOSS and the low switching losses of the MOSFET are critical factors needed for high efficiency flyback design [1]. The new 800−V SUPERFET III MOSFET is optimized as a primary side switch, since it enables lower switching losses and low case temperature without sacrificing EMI performance due to its optimized design.

800−V SUPERFET III MOSFET Technology

800−V MOSFETs are widely used in many power converter applications such as lighting, chargers, adapters, solar inverters and industrial 3−phase topologies as shown in Figure 1. However, there are silicon limits hindering significant reduction in the on−state resistance ($R_{DS(ON)}$) for conventional planar MOSFET technologies.

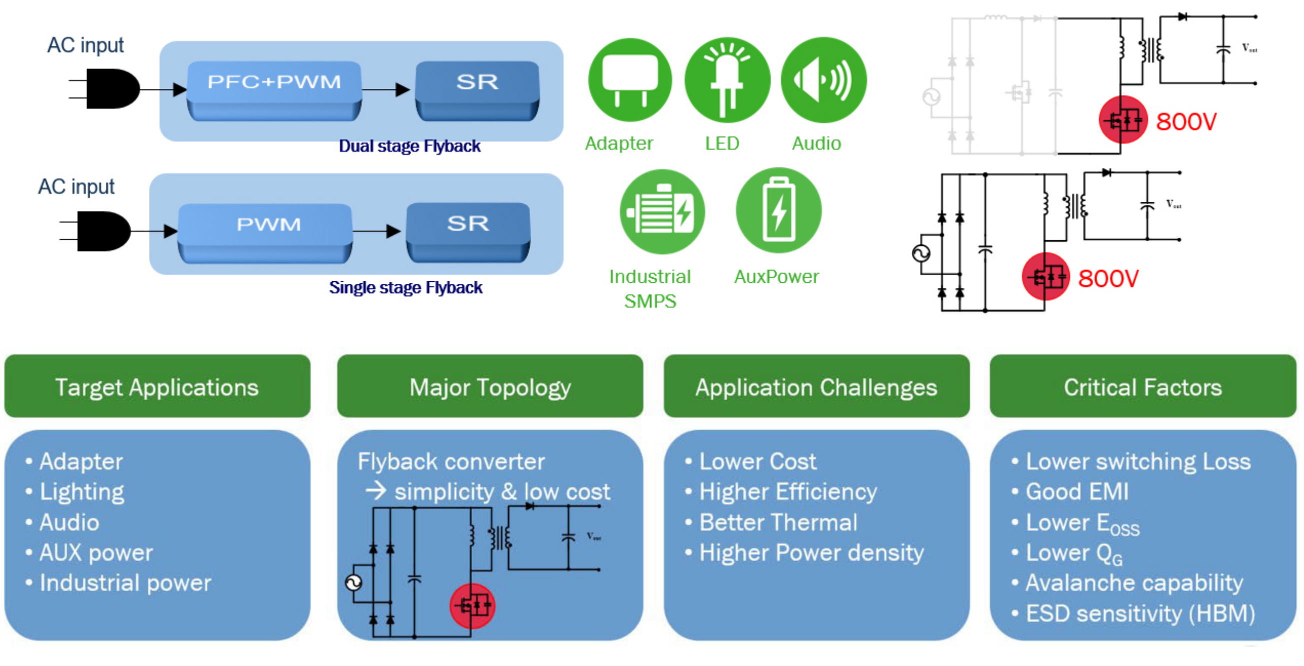


Figure 1. Target Applications/Topology and Challenges for 800−V SUPERFET III MOSFET

For an 800−V breakdown voltage rated MOSFET, the super−junction technology broke the silicon limit in terms of on−resistance and achieved one sixth of the on−resistance per unit silicon area, called specific on−resistance (R_{sp}), compared to the planar MOSFET silicon processes. This is depicted in Figure 2.

The important MOSFET requirements as a primary switch for the flyback converter are low stored output energy (E_{OSS}), low R_{sp}, low switching loss, low gate charge (Q_G), and high ESD capability. The R_{sp} of 800−V SUPERFET III MOSFET technology is 50% lower than the previous generation 800−V SUPERFET II MOSFET, which makes it optimized as a primary side switch.

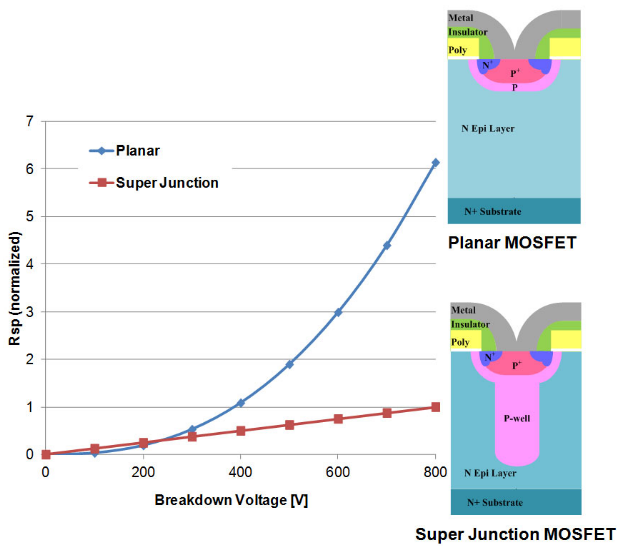
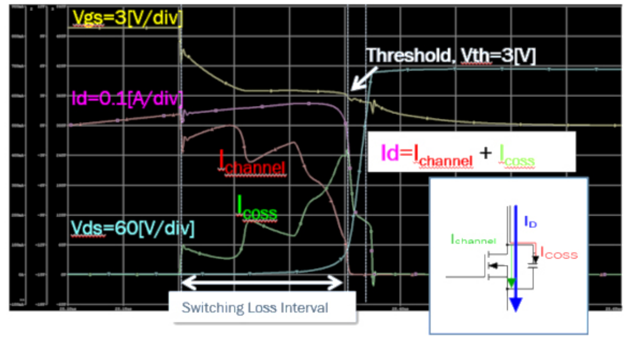


Figure 2. Specific $R_{DS(ON)}$ Comparison Between Conventional and Super−Junction MOSFET

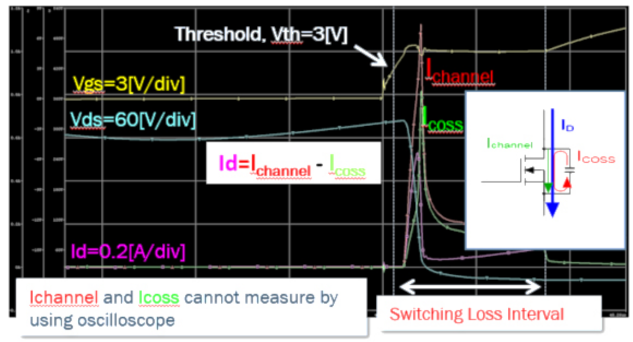
Stored Energy in Output Capacitance (E_{OSS})

E_{OSS} is very critical in hard−switching and low−power applications. During hard−switching, the E_{OSS} of the MOSFET that is stored during the turn−off transient is then internally dissipated through the MOSFET channel in the form of joule heating during the turn−on transient. The E_{OSS} is dissipated through the channel of the MOSFET during every turn−on cycle. This is depicted as I_{COSS} as shown in Figure 3b. For low−power flyback converters, lower $R_{DS(ON)}$ x E_{OSS}, Figure−Of−Merit (FOM) is the most important factor for minimizing switching power loss in primary−side MOSFETs.

As show in Figure 4, The 800−V SUPERFET III MOSFET has 39% lower E_{OSS} at 400 V compared to 800−V SUPERFET II MOSFET, while the $R_{DS(ON)}$ x E_{OSS} FOM of the 800−V SUPERFET III MOSFET is 31% lower than 800−V SUPERFET II MOSFET.



(a) Decreased MOSFET Channel Current During Turn−Off due to C_{OSS} Charging



(b) Increased MOSFET Channel Current During Turn−On due to C_{OSS} Discharging

Figure 3. MOSFET Channel Current and Drain Curren Waveform During (a) Turn−Off and (b) Turn−On

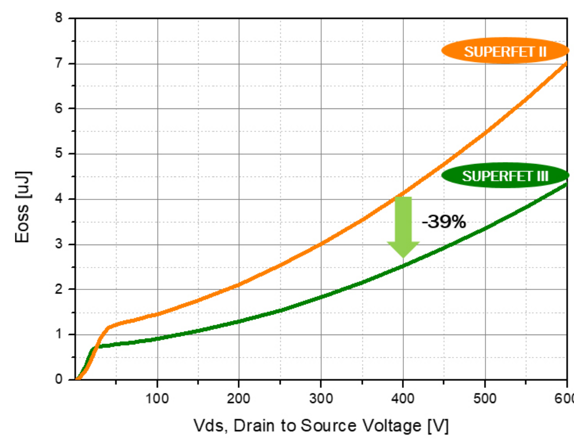
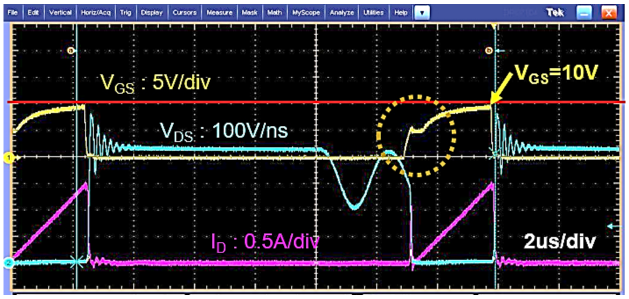


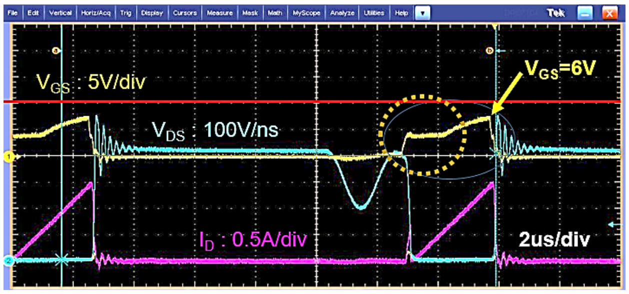
Figure 4. E_{OSS} vs Drain−Source Voltage Comparison

Gate Charge (Q_G)

The low gate−charge is also an important parameter in low power applications. It is directly related to the driving loss and also related to the MOSFET operation. If a large gate−charge MOSFET is applied in the system, it may not be fully turned−on with low driving current, shown in Figure 5b. Therefore, in order to fully charge the MOSFET gate, low gate−charge MOSFETs need to be used in low power applications. As shown in Figure 6, 800−V SUPERFET III MOSFET has 55% less Q_G compared to 800−V SUPERFET II MOSFET under same condition.



(a) Operation with Low Q_G MOSFET



(b) Operation with High Q_G MOSFET

Figure 5. The Comparison of Switching Waveforms Between Low Q_G and High Q_G MOSFETs

Figure 6. Gate Charge Comparison under V_{DD} = 400 V, I_D = 5.5 A, V_{GS} = 10 V

Benchmark of New 800−V SUPERFET III MOSFET

Due to the high peak currents of the flyback converter, the MOSFET and output rectifier diode have high switching and conduction losses, which results in relatively low efficiency. The most popular approach for increased power density is to increase the switching frequency, which reduces the size of passive components. For a flyback converter, the highest heat dissipation usually occurs in the transformer, the primary MOSFET and the secondary diode. Utilizing low power loss MOSFETs is critical since the power MOSFET dissipates much more power than any other component [2]. Low power loss is required for high efficiency. For long term reliability, it is not only an issue of efficiency, but also of thermal management. Losses in the MOSFET consist of switching loss, conduction loss and gate−driving loss.

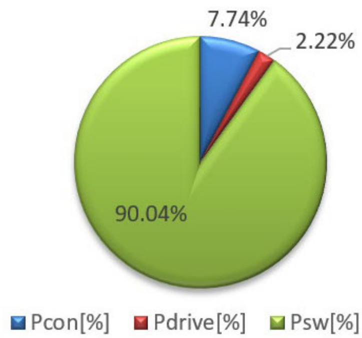


Figure 7. MOSFET's Power Loss Analysis in a 45 W Flyback Converter

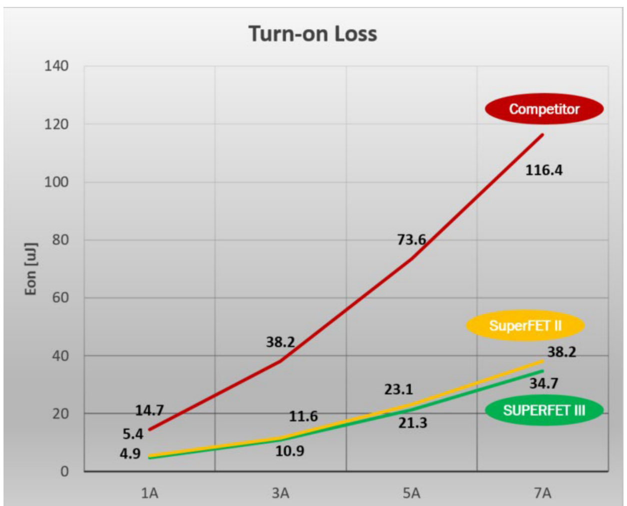
Figure 7 shows the power loss analysis of the MOSFET in a flyback converter used for laptop adaptor applications with V_{IN} = 230 V rms and P_{OUT} = 45 watt condition. As shown in Figure 7, the switching losses are the most critical. The switching losses, including output capacitance losses, are proportional to the switching frequency. Therefore, in order to increase both system efficiency and power density, switching loss on the primary−side MOSFET must be reduced. Table 1 shows the key parameter comparison of 450−mΩ SUPERFET III MOSFET, 400−mΩ SUPERFET II MOSFET and competitor. Switching related parameters such as E_{OSS} and Q_G of 800−V SUPERFET III MOSFET are greatly reduced compared to 800−V SUPERFET II MOSFET and competitor. Additionally, 800−V SUPERFET III MOSFET includes the integrated zener diode for additional ESD protection or robustness.

Table 1. CRITICAL SPECIFICATION COMPARISON OF 800V SUPER−JUNCTION MOSFET UNDER SAME CONDITION

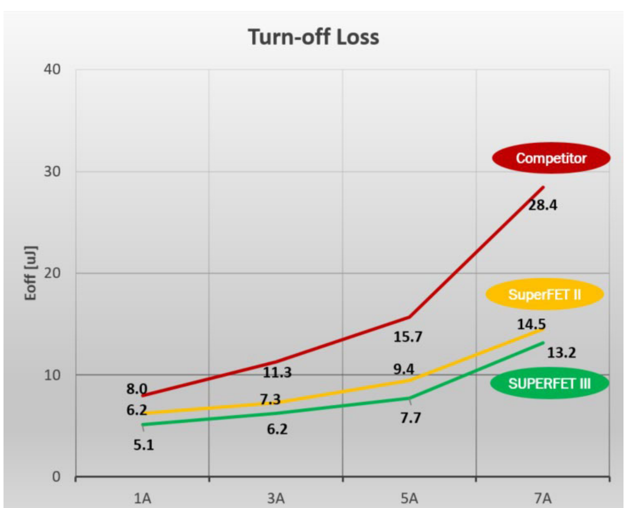
DUTs	NTPF450N80S3Z	FCPF400N80Z	Competitor
	SuperFET® III	SuperFET® II	
BV_{DSS} @ T_J=25℃	800V	800V	800V
I_D	11 A	14 A	11.5 A
FOM [$R_{DS(ON)}$max.×E_{OSS}.] FOM [$R_{DS(ON)}$max.×$Q_{G\_Typ.}$]	1.1 Ω ·μJ 9.0 Ω ·nC	1.6 Ω ·μJ 17 Ω ·nC	1.6 Ω ·μJ 9.5 Ω ·nC
$R_{DS(ON)}$ max	450 mΩ	400 mΩ	450 mΩ
Q_g @ V_{DD}=400V, I_D=5.5A, V_{GS}=10V	20 nC	* 44 nC	21 nC
E_{OSS} at 400V	* 2.5 μJ	4.1 μJ	3.5 μJ
R_g @ f = 1 MHz	* 4 Ω	2.3 Ω	30 Ω
Body diode, Q_{RR} @ I_{SD}=2.5A, di/dt=100A/μs	1.6 μC	3 μC	1.8 μC
Peak diode recovery dv/dt	10 V/ns	20 V/ns	4.5 V/ns
MOSFET dv/dt	100 V/ns	100 V/ns	50 V/ns
Zener Diode (ESD Protection)	Yes	Yes	No

Switching Performance Comparison

Figure 8 shows the switching performance comparison of TO−220 F, 800−V, 450−mΩ SUPERFET III, 800−V, 400−mΩ SUPERFET II and 800−V, 450−mΩ competitor on a clamped inductive load (CIL) under same condition. V_{DD} = 400 V, I_D = 1~7 A, V_{GS} = 100 V and R_g = 10 Ω. Turn−on loss of SUPERFET III MOSFET is 8% less than SUPERFET II MOSFET (21.3 μJ vs 23.1 μJ) and 71% less than competitor (21.3 μJ vs 73.6 μJ) at I_D = 5 A. Turn−off loss of SUPERFET III MOSFET is 18% less than SUPERFET II MOSFET (7.7 μJ vs 9.4 μJ) and 51% less than competitor (7.7 μJ vs 15.7 μJ) at I_D = 5 A thank to its lower parasitic capacitances.



(a) Turn−On Loss Comparison



(b) Turn−Off Loss Comparison

Figure 8. Comparisons of Switching Performance (TO−220 F) : 800−V, 450−mΩ SUPERFET III, 800−V, 400−mΩ SUPERFET II and 800−V, 450−mΩ Competitor under V_{DD} = 400 V, I_D=1~7 A, V_{GS}=10 V, R_G = 10 Ω

Application Benchmark

System efficiency and case temperature of 800−V, 450−m Ω SUPERFET III in TO−220 F is compared with 800−V, 400−mΩ SUPERFET II and competitor 800−V, 450−mΩ super−junction MOSFETs in a 50−W flyback topology shown in Figure 9. As shown in Figure 10, the efficiency of SUPERFET III increases at light load by about 0.1% compared to SUPERFET II and 0.19% compared to the competitor. At heavy load the efficiency increases by 0.04% and 0.09% respectively compared to SUPERFET II and SJ competitor MOSFET. The major reason for the higher efficiency of SUPERFET III is the reduced switching losses due to lower E_{OSS} and Q_G.

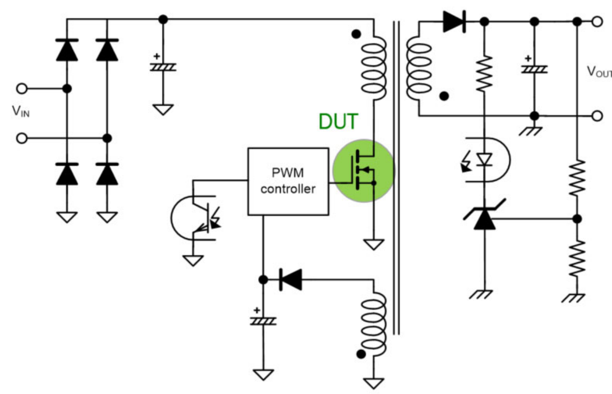


Figure 9. A 50−W Flyback Converter

Figure 11 shows the relative temperature performance comparison of SUPERFET III, SUPERFET II and the competitor SJ MOSFET in a 50−W flyback converter. The temperature difference between SUPERFET III versus SUPERFET II and competitor SJ MOSFET is 2 °C and 3 °C, respectively, which shows the outstanding thermal performance of 800−V SUPERFET III MOSFET at full load condition. Also, the SUPERFET III MOSFET provides better reliability due to higher ESD capability provided by the integrated gate to source Zener diode.

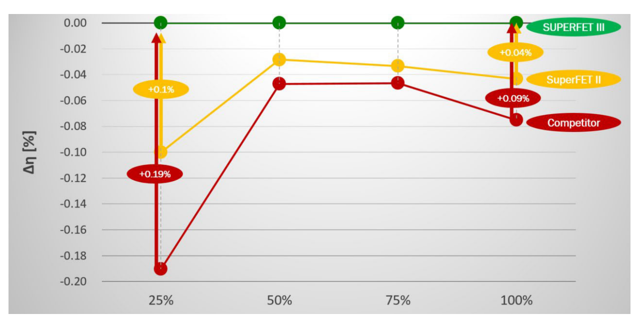


Figure 10. Efficiency vs. Output Power in a 50−W Flyback Converter: V_{IN} = 230 V rms, P_{OUT} : 50 W, F_{SW} = 33~44 kHz

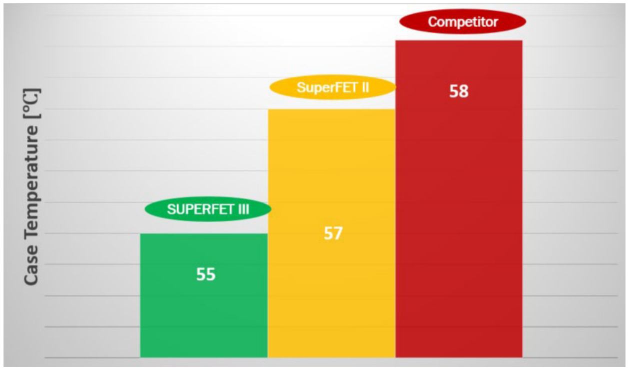


Figure 11. Case Temperature Comparison in 50 W Flyback Converter

Conclusion

The ON Semiconductor 800−V SUPERFET III high performance MOSFET family offers a rated 800−V drain−to−source breakdown voltage with reduced gate charge and lower stored output energy versus competitive 800−V solutions. The reduced input and output charge of the new 800−V SUPERFET III MOSFET increases switching efficiency and reduces driving and output capacitive losses. The value position of the 800−V SUPERFET III MOSFET is depicted in Figure 12. This new family of 800−V SUPERFET III MOSFETs enable more efficient operation, while enabling more compact and cooler solutions for power converter applications, which increases reliability. The SUPERFET III is ideal for many switching applications due to its remarkable performance in lighting, adapter and battery charger applications.

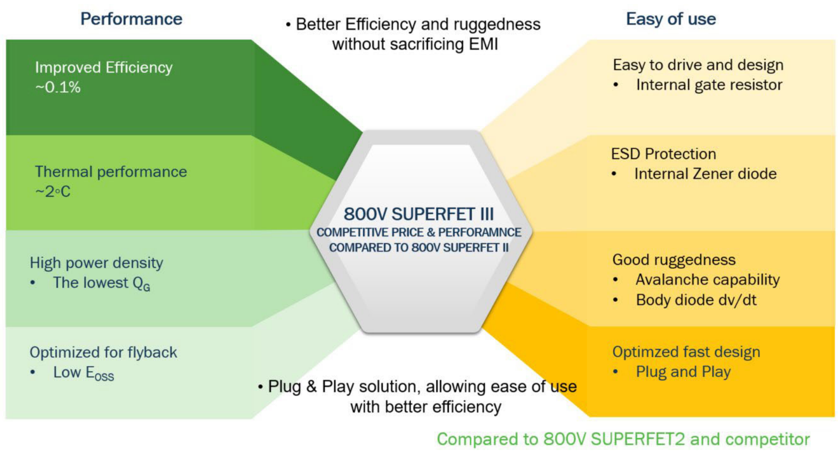
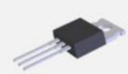
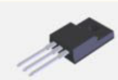


Figure 12. 800−V SUPERFET III Value Position

Table 2. 800−V SUPERFET III MOSFET LINEUP

PKG	DPAK	TO-220	TO-220F
RDS(on) / ID / Qg			
360mΩ / 13.5A / 20.0nC	NTD360N80S3Z	NTP360N80S3Z	NTPF360N80S3Z
450mΩ / 11.1A / 16.3nC			NTPF450N80S3Z
600mΩ / 8.5A / 12.3nC	NTD600N80S3Z		NTPF600N80S3Z

References

[1] ENERGY STAR® Program Requirements for Single Voltage External AC−DC and AC−AC Power Supplies
[2] S.−K Chung, "Transient characteristics of high−voltage flyback transformer operating" Applied IEE Proceedings Electric Power Applications, Vol. 151, No.5, pp.628−634, Sep.2004

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