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Mid-Voltage Shielded PowerTrench® MOSFET in High Step-Up DC-DC for Edge-Lit LED TV Backlighting

1. Introduction

Thanks to lower power consumption and longer life, coupled with increased demands for a wide color gamut; light-emitting diodes (LEDs) are steadily replacing the Cold-Cathode Fluorescent Lamp (CCFL) as the backlight source for Liquid Crystal Display (LCD) panel television sets. To generate sufficient brightness for large-scale LCD TVs, backlight requires many series or parallel LED arrays. Arrangement of the arrays determines whether an LED Backlight Unit (BLU) is an edge-lit or a direct-lit type, as shown in Figure 1 and Figure 2. Because the number of LEDs and strings can be reduced, edge-lit BLUs are increasingly popular. In edge-lit BLUs, high-efficiency and high step-up ratio DC-DC converters are required to operate the serially connected LED strings. Fairchild's mid-voltage shielded PowerTrench® gate technology allows reduced on-resistance ($R_{DS(ON)}$) without incurring a gate-charge (Q_g) characteristics penalty, which results in reducing conduction loss and switching loss in high step-up DC-DC converters.

Figure 1. Edge-Lit LEDs

Figure 2. Direct-Lit LEDs

2. Edge-Lit LED BLU Power Requirement

The BLU in LCD TV sets plays an important role in the overall cost of the application. It can account for 30-40% of the total cost and is integral in the final angular luminance, contrast ratio, and brightness.

For an edge-lit BLU in large-size TV sets, approximately 36 LEDs are placed in series at the edge of the BLU. This requires the power supply to deliver a high voltage, up to 120V, from 24V of SMPS output and a stable current source over a 40-inch panel.

Table 1. Edge-Lit LED BLU Power Build Example

Panel Size	>40 Inches
V_{IN}	24V
V_{OUT}	120V
I_{LED}	120mA
f_{SW}	300KHz
LEDs per String	36
Strings	4

3. Coupled-Inductor Boost DC-DC Converter

To meet the requirements of edge-type LED backlight power, such as high step-up voltage gain and high efficiency, a coupled-inductor boost DC-DC converter like the one shown in Figure 3 is a viable solution. It can deliver high step-up voltage gain without the penalty of extreme duty ratio and can reduce the conduction loss of the MOSFET because a lower B_{VDSS} MOSFET can be applied against single-boost DC-DC converter by using the turn ratio of the coupled inductor.

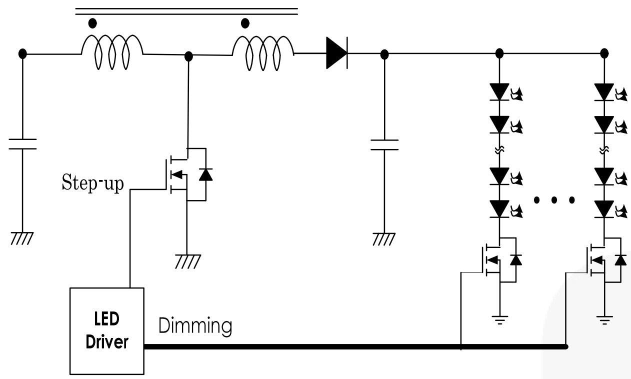


Figure 3. Simplified LED Driver Block Diagram: Coupled-Inductor Boost Converter

A coupled-inductor boost converter has two operation modes in one switching cycle, MOSFET on and off state, as shown in Figure 4. Figure 5 shows converter waveforms through one switching cycle. During $t_0 - t_1$, the MOSFET is turned on and the output rectifier D_{out} is reversed-biased. The magnetizing inductor, L_m, is charged linearly by the input voltage source. When the MOSFET is turned off, all magnetizing current is reflected to the secondary winding, N_s, from the primary winding, N_p, during $t_1 - t_2$. The output rectifier, D_{out}, is conducting and all the energy stored in the inductor has been delivered to the output load.

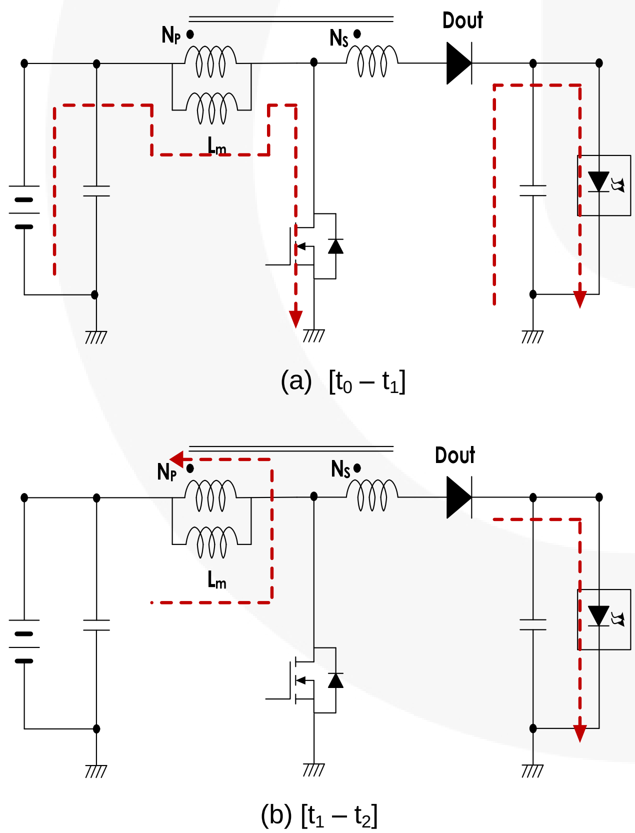


Figure 4. Topological Stages with Reference Directions of Key Current

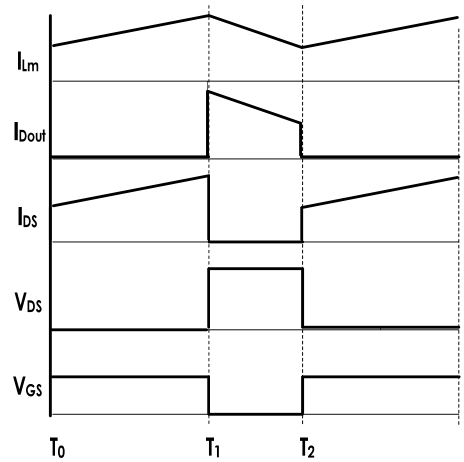


Figure 5. Converter Waveforms

The voltage conversion ratio is given by:

$$D = \frac{V_{OUT} - V_{IN}}{V_{OUT} + N \times V_{IN}} \quad \text{Eq 1}$$

where D is duty cycle and n is the turns-ratio of the coupled inductor, calculated as:

$$n = \frac{N_s}{N_p} \quad \text{Eq 2}$$

4. Mid-Voltage Shielded Power Trench® MOSFET

The trend in TV set power-supply design focuses on increasing efficiency by reducing power losses. To maximize a power system's efficiency, it is important to select a switching device with low on-resistance ($R_{DS(ON)}$) and gate charge (Q_g) characteristics.

A new trench MOSFET process allows for a reduction in $R_{DS(ON)}$ without incurring a Q_g penalty. This technology, known as shielded gate, enables reduction of the epi resistance associated with achieving the B_{Vdss}, the key component of $R_{DS(ON)}$, in mid-voltage MOSFETs. This technology has particular benefits in the >100V area.

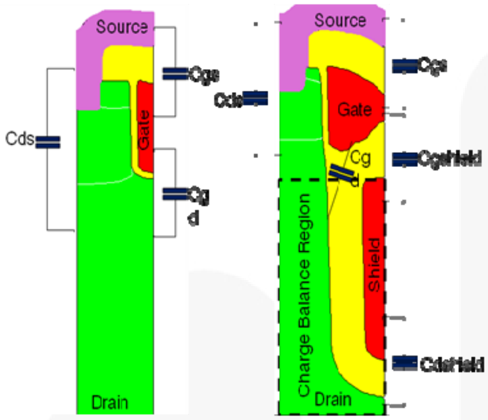
Table 2. Components of $R_{DS(ON)}$ for Conventional Trench, $R_{DS(ON)}$ V_g = 10V, 200A/cm²

	V_{DS} = 30V	V_{DS} = 100V
R_{Chan}	47%	16%
R_{EPI}	29%	78%
R_{Sub}	24%	6%

Table 2 shows the $R_{DS(ON)}$ components, comparing a 30V-rated with a 100V-rated conventional trench MOSFET. The $R_{DS(ON)}$ contribution from the epitaxial is a much larger percentage for the 100V MOSFET. Using a charge-balance technique like the shielded gate, this epitaxial resistance can be reduced by more than half without increasing the total Q_g or the Q_{gd} component.

5. The Charge Balance Technique

Figure 6 compares the cross-sections of a conventional and a shielded-gate trench device. By incorporating a shield electrode for charge balancing, the resistance and length of the voltage-supporting region is reduced and a significant reduction in $R_{DS(ON)}$ can be realized.



(a) (b)

Figure 6. Conventional (a) vs. Shielded-Gate (b) Charge-Balance Trench Structure

The shield electrode resides below the gate electrode, converting most of the gate-to-drain capacitance (C_{gd} or C_{rss}) at the bottom of the conventional trench MOSFET to gate-to-source capacitance (C_{gs}). The shield electrode shields the gate electrode from the drain potential.

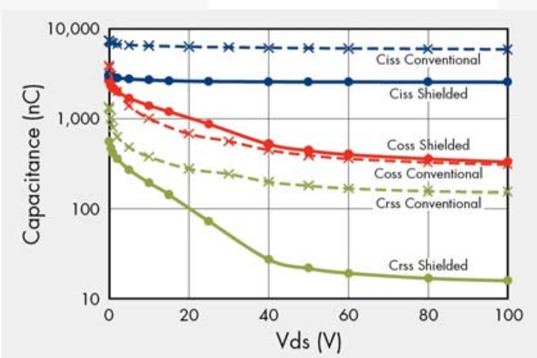


Figure 7. Comparison of Capacitive Components for Conventional and Shielded-Gate Trench with Equivalent 20A $R_{DS(ON)}$ 5.7mΩ

Figure 7 compares the capacitive components of a conventional and a shielded-gate trench MOSFET with equivalent $R_{DS(ON)}$. By reducing C_{rss}, switching losses are minimized by shortening the time it takes to transition from OFF to ON state or from ON to OFF state. In particular, reducing the Q_{gd}, as show in Figure 8, reduces the switching energy losses by minimizing the time the device has the simultaneous application of high voltage and current.

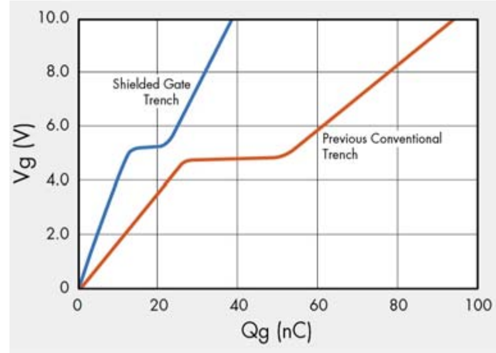


Figure 8. Comparison of Q_g Curves at 20A and 50V for Conventional and Shielded-Gate Trench with Equivalent 20A $R_{DS(ON)}$ 5.7mΩ

The shield and its resistance act as a snubbing resistance (R_{shield}) and capacitance ($C_{dshield}$) network, depicted as a component of the C_{oss} in Figure 9.

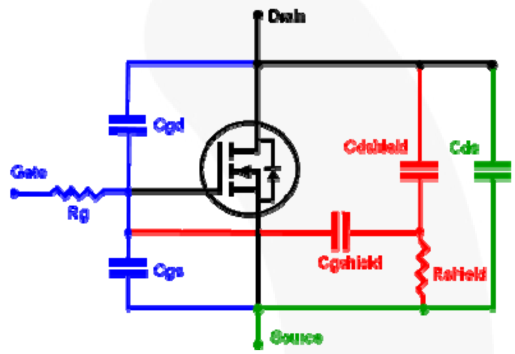


Figure 9. Shielded-Gate MOSFET Resistive and Capacitance Equivalent Circuit

This snubbing network slows down the transition of the switching from low to high voltage. This feature of the shielded gate helps to reduce EMI, dv/dt induced turn-on, and avalanching during switching transitions.

Fairchild Semiconductor offers all these features of mid-voltage shielded PowerTrench® gate technology (B_{VDSS}: 60-150V), which provides low gate-charge and on-resistance ratings to achieve low switching, conduction losses, and minimized EMI.

6. Performance Improvements in Coupled-Inductor Boost DC-DC Converter

Fairchild's 100V-rated FDD86102 shielded PowerTrench® MOSFET is compared with conventional trench MOSFET on a coupled-inductor boost DC-DC converter to step up from 24V to 120V, which is a suitable solution for a more than 40-inch edge-lit type BLU. Table 3 shows the shielded device's superior $R_{DS(ON)}$ and Q_g performance with shielded PowerTrench® process. Figure 10 shows how much switching energy can be reduced with FDD86102 compared to conventional trench-gate technology.

Table 3. Comparison with Conventional Trench $R_{DS(ON)}$: Max. Value, R_{sp}(Die Size x $R_{DS(ON)}$, Relative)

Device	$R_{DS(ON)}$	Rsp	Q_g	Q_{gd}	Q_{gs}	FOM
FDD86102	24	1	13.4	3.7	4	88.8
Conventional	28	2.2	38.5	10	8	280

In Figure 10 through Figure 12, the FDD86102 with shielded PowerTrench® MOSFET shows a minimum of 3.5% efficiency improvement and better thermal performance than conventional trench-gate technology by minimizing conduction loss and switching loss.

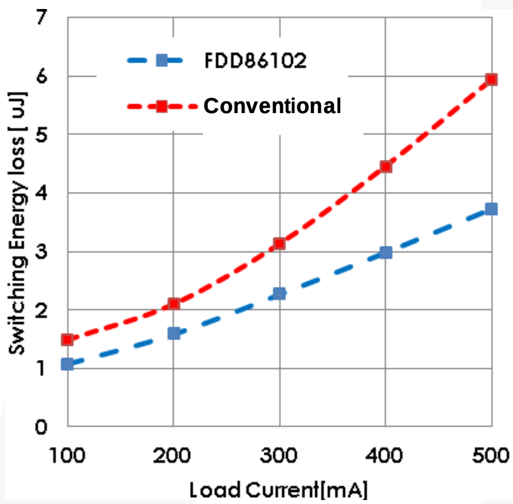


Figure 10. Switching-Energy Loss Comparison $24V_{IN}$ $120V_{OUT}$ 300KHz 500mA I_{OUT}

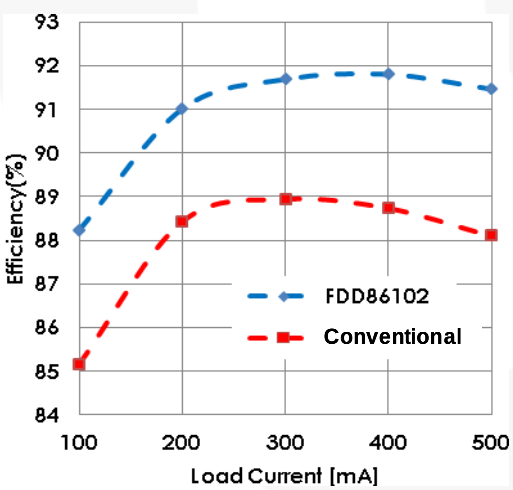
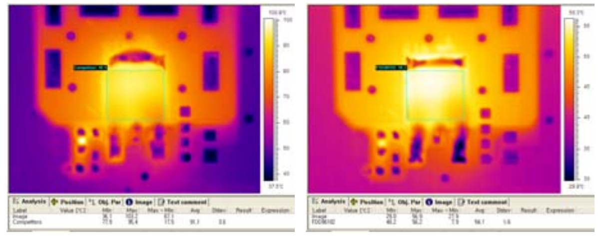


Figure 11. Efficiency Comparison $24V_{IN}$ $120V_{OUT}$ 300KHz 500mA I_{OUT}



(a) FDD86102: 56.2°C (b) Conventional: 95.4°C

Figure 12. Thermal Performance Comparison $24V_{IN}$ $120V_{OUT}$ 300KHz 500mA I_{OUT}

Higher efficiency and low temperature characteristics are critical parameters in LCD displays with respect to size and thickness. Generally, a thermal increase of the main component in display systems, such as a MOSFET and inductor, should not exceed 65ºC at 25ºC room temperature without airflow.

7. Conclusion

Compare with conventional trench MOSFET, Fairchild's mid-voltage shielded PowerTrench® MOSFET technology can achieve higher efficiency by minimizing conduction loss and switching loss.

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Related Datasheets

FDD86102 — 100V N-Channel PowerTrench® MOSFET

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