1700 V Enhancement-mode SiC VJFET for High Voltage Auxiliary Flyback SMPS

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Abstract

The performance of a recently developed 1700V enhancement-mode SiC JFET targeted for high-voltage auxiliary SMPS is evaluated. Standard flyback-converter cores requiring high breakdown transistors as the primary switch are typical. A side-by-side comparison in performance of the new 1700V, 550mOhm EM SiC JFET and a 1500V ESBT in a commercial auxiliary SMPS evaluation board is presented. This auxiliary SMPS is capable of 150W with an input voltage range of 250VDC-850VDC input and 24V and 5V outputs. The 1700V SiC JFET demonstrated 4.5x less $R_{DS(ON)}$, 84% less total switching losses at low line, 62% less total switching losses at high line, and sufficient voltage rating for inputs up to 1000V+ making it ideal for replacement of high-voltage Si unipolar devices in auxiliary flyback SMPS applications.

1. Introduction

Auxiliary power supplies are an essential component of most power converter/inverter applications: motor drives, ups, solar inverters, etc. Auxiliary supplies are regularly used to derive the supply voltages for analog/digital control circuits, gate drivers, and feedback sensing circuits. Output voltages typically range from 3.3 V to 48 V with input voltages ranging from 200 V – 1200 V or higher. Similar to most power electronic systems, key design concerns include overall size and efficiency.

The most common converter topology used for auxiliary power supplies is the flyback converter. The flyback converter presents a simple, galvanicly isolated, low part count solution that drives a lower system cost compared to other topologies. This topology is ideal for applications with wide input-output voltage ratios and is easily adapted to produce multiple output voltages with the addition of multiple secondary windings. However, the main disadvantage to this topology is that it requires high breakdown voltage ratings for the primary switch. As input voltages of new designs are increasing, the need for more efficient high voltage transistors is critical.

While IGBTs possess maximum breakdown voltages that exceed the needs for auxiliary SMPS, they suffer from long tail currents due to the minority carrier injection and are not suitable for the high frequency operation in this application. This drives designers to look for other switch alternatives such that higher switching frequencies and higher system efficiencies are possible. Table 1 provides a comparison of the device characteristics of three high voltage transistors that exhibit more efficient switching behavior than IGBTs. First are the 1500 V PowerMESH© MOSFET [1] and ESBT [2] developed by ST Microelectronics. Both devices prove to demonstrate more efficient switching characteristics than an IGBT while increasing the maximum voltage rating beyond the current limit of 900 V for typical Si power superjunction MOSFET. However, these devices also exhibit significantly higher breakdown voltage – on-resistance products. Also, a breakdown voltage of 1500 V only allows for input voltages up too $850V_{PK}$ for an auxiliary flyback SMPS. The recently developed 1700 V SiC JFET [3] allows designers to push this input voltage even higher and obtain efficient unipolar switching behavior. Based on Table 1 the SJEP170R550 demonstrates higher breakdown voltage, lower $R_{DS(ON)}$, lower intrinsic capacitance, and lower total gate charge requirements.

2. Device Design

This 1700V enhancement-mode SiC JFET is very similar to SemiSouth's previously reported enhancement-mode devices [4]. The channel design is identical to 1200V-class devices however the drift layer thickness and doping have been adjusted for 1700V operation. Figure 1 shows the device structure which consists of a vertical n-channel gated by p+ regions. The drift, channel and source layers are epitaxially grown on a 4H-SiC substrate followed by trench etching, p+ gate formation, and contact metallization. The total die area is 1.7 mm^2 with 0.8 mm^2 active area. At 25 ℃, the on-resistance and saturation current are 0.5 Ω and 8 A respectively. At 125 ℃, the on-resistance increases to 1 Ω while the saturation current drops to 4 A.

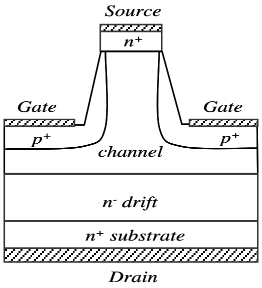

Figure 1. Device structure of SiC vertical channel JFET

3. Experimental Results

A commercially available auxiliary flyback SMPS demo board, STEVAL-ISA007V1 [5], developed by ST Micro was obtained for a side-by-side comparison evaluation of devices. The high-voltage switch supplied with the STC08DE150HP SMPS is the 1500 V Si ESBT. The switching performance, case temperature, and total system efficiency of the unmodified demo board was first evaluated. A SiC SJEP170R5500 was then inserted in the place of the ESBT requiring only a change in value for the originally installed gate resistor and the addition of a bypass capacitor in parallel with the gate resistor. This simple RC driver allows the gate of the SiC JFET to be driven back a standard COTS driver IC. Performance of this driver has been previously reported for use with SiC JFET drop-in replacement applications in solar inverters and PFC circuits [6-7]. The proportional base driver circuit was disconnected from the drive circuit as it is not required to drive the SiC JFET. Figure 2 and Figure 3 provide screen captures of the switching waveforms for the Si ESBT and SiC JFET respectively. Table 2 provides a comparison of the switching losses measured for the SiC JFET and Si ESBT in the auxiliary flyback SMPS demo board at the full rated 150W of output power swept from low line to high line. Total switching losses for each device are plotted in Figure 4 with the measured case temperature for the full input voltage range plotted in Figure 5. The input and output power of the demo board was also measured and plotted to provide a comparison of resulting system efficiency when using a SiC JFET or Si ESBT as the power transistor, Figure 6.

As shown in Figures 4 - 5, the SiC JFET demonstrated 84% lower total switching losses at low line and 62% lower total switching losses at high line resulting in significantly lower case temperatures for the full range of input voltages. At low line the SiC JFET was 60^{o}C cooler and at high line where the switching losses were greatest the SiC JFET was still 40^{o}C cooler than the Si ESBT at the same operating point. Figure 6 compares the total system efficiency for the auxiliary SMPS first using the Si ESBT as the power transistor and then replacing the ESBT with a SiC JFET. Figure 6 illustrates using the SiC JFET in place of the Si ESBT allowed for a significant efficiency improvement of 8% at low line at 16% at high line. Other factors that likely contributed to the increase in system efficiency when using the SiC JFET in place of the Si ESBT is a reduction gate charge and gate/base current requirements. Similarly, both devices require both dynamic and static drive conditions

Table 1. Comparison of device characteristics for three high voltage transistors targeted for auxiliary power supplies

Device	STW9N150	STC08DE150HP	**SJEP170R550**
Device Type	Si MOSFET	Si ESBT	**SiC JFET**
V_{DS_MAX}	1500 V	1500 V	**1700V**
$R_{DS(ON)\_MAX}$	2.5 Ω	---	**0.550 Ω**
C_{OSS}	294 pF	---	**20 pF**
Q_G	89.3 nC	12.5 nC	**10 nC**
Max Converter Input Voltage	850 V_{PK}	850 V_{PK}	**1000+ V_{PK}**

Table 2. Comparison of device switching performance in auxiliary flyback SMPS demo board

	STC08DE150HP		**SJEP170R550**	
Vin (V)	E_{ON} (µJ)	E_{OFF} (µJ)	E_{ON} (µJ)	E_{OFF} (µJ)
300	90.21	24.91	9.69	8.50
400	94.26	26.89	13.09	8.31
500	95.23	30.52	19.79	8.45
600	95.51	36.85	24.83	10.40
700	99.38	41.68	31.33	12.90
800	102.1	44.97	41.00	15.27

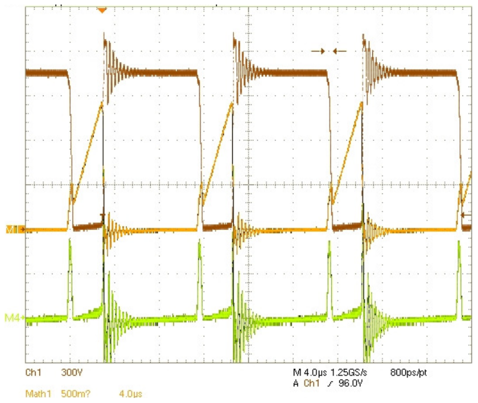

Figure 2. ESBT switching waveforms for demo board operating with 800 VDC input at 150W. V_{CS} - 300V/div, brown, I_C – 500mA/div, orange, P_D – 185W/div; green.

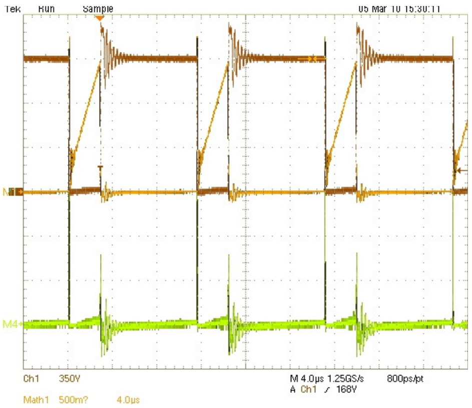

Figure 3. 1700V SiC JFET switching waveforms for demo board operating with 850 VDC input at 100W. V_{CS} - 350V/div, brown, I_D – 500mA/div, orange, P_D – 200W/div; green.

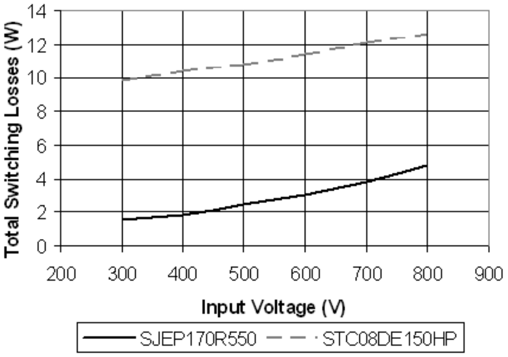

Figure 4. Total switching loss for SiC JFET and Si ESBT.

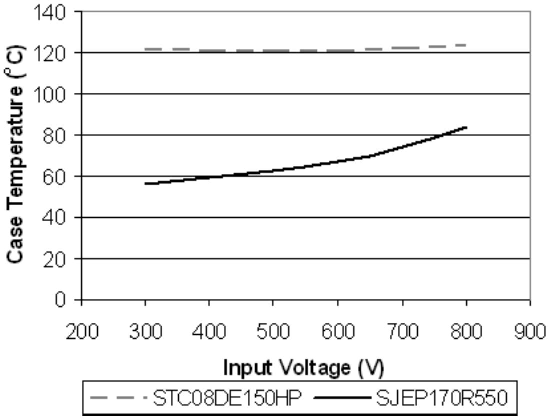

Figure 5. Measured case temperature

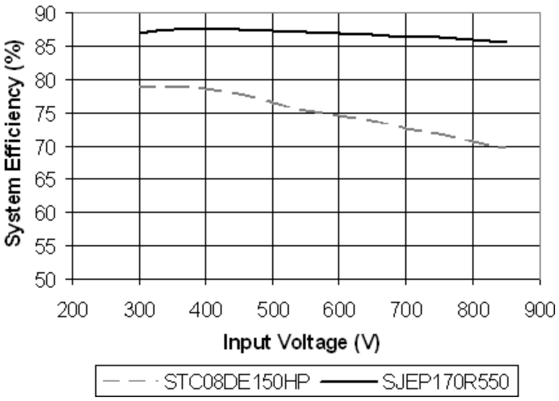

Figure 6. Measured system efficiency

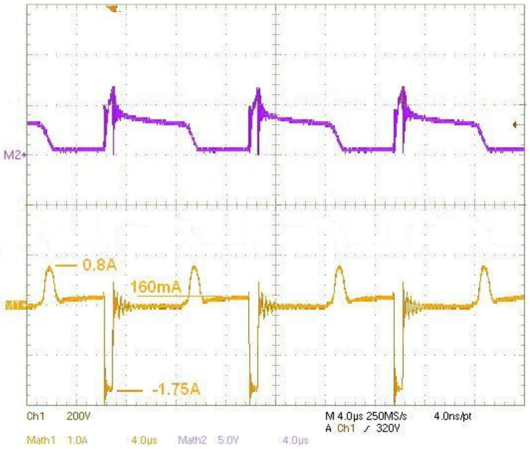

Figure 7. V_{BS} and I_B waveforms for ESBT

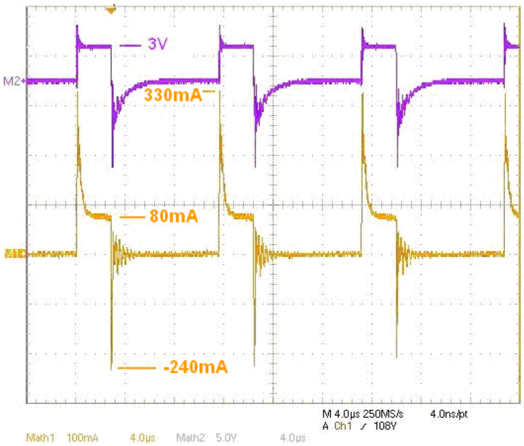

Figure 8. V_{GS} and I_G waveforms for ESBT

be met. High peak currents are required to drive the devices into conduction with a DC current required to keep the devices in the conduction state. For the Si ESBT a dynamic charge is required to drive both the gate and base of the device. To maintain conduction the base of the ESBT must be supply a DC current just as is necessary with any power BJT. The peak dynamic current at turn-on is much higher for the ESBT than the SiC JFET as is the steady state DC current requirements. Figure 7 provides a screen capture of the base-source voltage and base current. At turn on a peak current of 0.8A is required by the high side BJT, a DC gate current of nearly 160mA, and a peak sink current of -1.75A at the base to turn the device off. Figure 8 shows the gate-source voltage and gate current for the SiC JFET. A peak gate current of 0.33A was sufficient for fast turn-on of the JFET, with a DC gate current of 80mA required to maintain conduction. A peak sink current of 0.24A quickly discharged the input capacitance for a fast turn-off. Since SiC JFET is compatible with standard COTS driver ICs and possesses only one control terminal the proportional base driver circuit can be completely eliminated further reducing system power loss.

4. Conclusion

The new 1700 V EM SiC JFET is an ideal candidate for the replacement of MOSFETs/IGBTs/ESBTs in high voltage auxiliary flyback SMPS with input voltages up to 1000 V. The 1700 V EM SiC JFET has *4.5x lower* $R_{DS(ON)}$ than the 1500 V PowerMESH© MOSFET and is a simpler, more efficient, and easier to drive device than the 1500V ESBT. As shown in past publications the SiC JFET can be driven by standard MOSFET/IGBT driver IC's using a simple RC driver interface. Since the SiC JFET is a normally-off device there are no negative gate bias requirements, thus making it directly compatible with the drive circuit used in the STEVAL-ISA700V1 demo board. Since the SiC JFET was compatible with the driver IC there was no need for the proportional base driver circuit that was required by the Si ESBT. Elimination of the extra circuitry along with the much reduced gate charge and DC gate current requirement of the SiC JFET a reduction in driver power loss was realized.

Switching results presented here showed the SiC JFET demonstrated much faster switching speeds yielding 62% less total switching losses than the Si ESBT in the same aux SMPS demo board at high line and full load. This allowed for a significant improvement in total system efficiency. The combination of reduced driver power and reduced switching losses allowed for an increase in full load total system efficiency of 8% at low line and nearly 16% at high line. The reduced device losses of the SiC JFET also provided steady state case temperatures measuring a maximum of 60°C lower at low line and full load compared to the Si ESBT case temperature of 120°C. A 40°C reduction in case temperature was measured for the SiC JFET at high line and full load.

5. References

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[2] Datasheet, STC08DE150HP, ST Microelectronics, Available at <www.st.com>

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[4] D. C. Sheridan, A. Ritenour, V. Bondarenko, P. Burks, and J. B. Casady, "Record 2.8mΩ-cm^2 1.9kV enhancement-mode SiC VJFETs," *21st International Symposium on Power Semiconductor Devices & IC's*, (ISPSD ’09), pp. 335-338, 2009.

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