Improve DC-DC Forward Converter Efficiency with eGaN FETs

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DC-DC converter designers can achieve higher power density at lower power levels by using forward converters with synchronous rectification and gallium nitride transistors. One very typical application is a 26 W, 48 V to 5 V , Power over Ethernet Powered Device (PoE-PD).

A simplified forward converter schematic for this application is shown in figure 1 using eGaN FETs and Linear Technology's LT1952 [1] in conjunction with the manufacturer's LTC3900 [2] synchronous rectifier controller on the secondary side. The eGaN FET synchronous rectifier circuitry is shown in figure 2 on the following page. The LTC3900 receives synchronization pulses from the primary side through an isolation/pulse transformer. Minimizing delay and on-off timings of the secondary side synchronous rectifiers is the key to reducing body diode losses and improving overall efficiency. A MOSFET and an eGaN FET-based converter were operated at 300 kHz and 500 kHz respectively to demonstrate the feasibility and advantages offered by the eGaN FET solution.

eGaN FETs have a better figure of merit (FOM) than equivalent state-of-the-art silicon devices [3], and this advantage increases with rated drain voltage. However, the eGaN devices also have a higher body diode forward drop, which can be detrimental at lower voltages and requires improved controller timing to overcome this limitation. With these advantages and limitations in mind, the MOSFET and eGaN FET devices used for this converter are listed in table 1.

	Part Number	V_{DS} (V)	I_D (A)	$R_{DS(ON)}$ (mΩ)	Q_G (nC)	Q_{GD} (nC)	Rectifier Figure of Merit	Switching Figure of Merit
Primary MOSFET	FDS2582	150	4.1	66	19	4.4	1254	290
Primary eGaN FET	EPC1012	200	3	100	1.9	0.9	190	90
S/R MOSFET	SIR464	40	50	4.2	28.2	9	118	38
S/R eGaN FET	EPC1015	40	33	4	11.5	2.2	46	9

Table 1: Comparison of MOSFETs and eGaN FETs used In forward converter.

The turn-on and turn-off waveforms for both the eGaN FET and MOSFET are compared in figure 3. The significant difference between their respective gate rise times is due to a 10:1 ratio in respective input capacitance (C_{ISS}). The improved turn-on time of the eGaN is due to the five times lower Miller charge (Q_{GD}), while the reduced drain rise time is due to the eGaN FET having about half the output capacitance (C_{OSS}) as compared to the MOSFET.

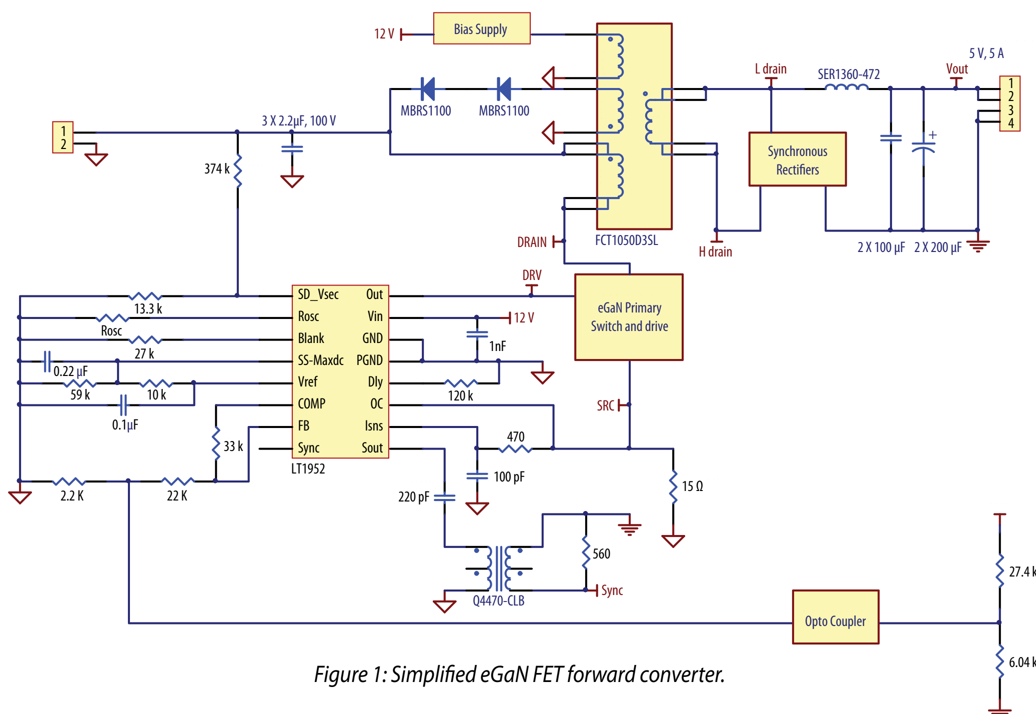

Figure 1: Simplified eGaN FET forward converter.

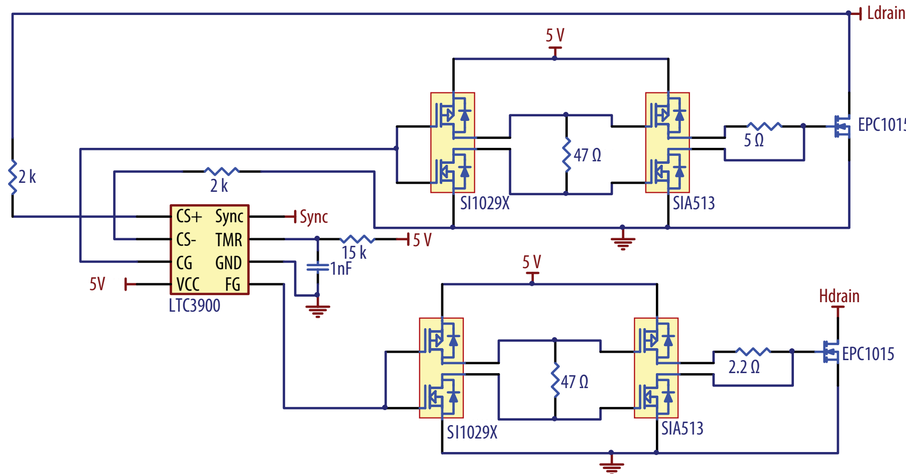

Figure 2: eGaN FET-based secondary side synchronous rectifier schematic detail for figure 1.

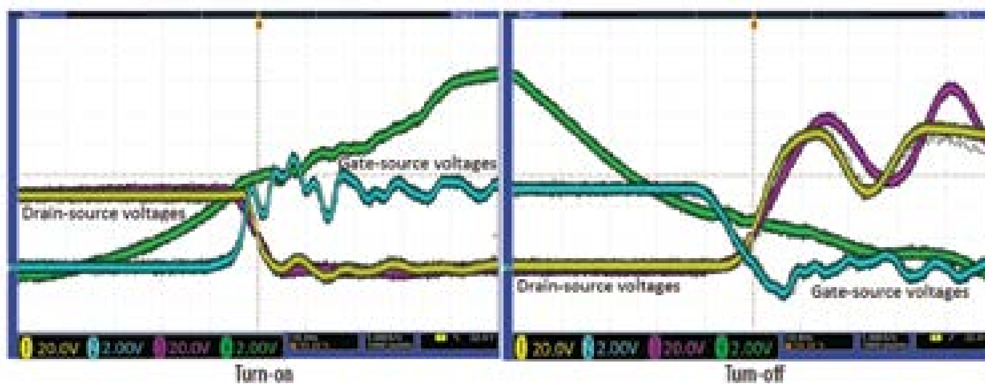

Figure 3: - LT1952 primary side gate and drain turn-on and turn-off waveforms (f=500 kHz V_{IN}= 48 V, V_{OUT} = 5 V, I_{OUT}= 5 A).

Figure 4 shows the efficiency of both MOSFET and eGaN FET converters operating at 300 kHz and 500 kHz respectively. There are three important points that can be made from evaluation of the efficiency results:

- At 300 kHz, eGaN FETs offer a small improvement in efficiency at light loads and have comparable efficiencies at full load despite a 50% higher on-resistance for the eGaN FET in the primary socket when compare to the MOSFET $R_{DS(ON)}$.
- The eGaN FET converter efficiency performance relative to the MOSFET design improves significantly as frequency increases, and is about 2% more efficient at full load and 5% more efficient at light loads at 500 kHz.
- The eGaN FET efficiency actually declines very little with an increase in frequency. This is almost entirely due to the use of two different output inductors for 300 kHz and 500 kHz versions chosen to maintain similar output current ripple between the two respective operating frequencies. This resulted in an approximately 5 mΩ reduction in inductor DC resistance (DCR) and halving the inductor volume. Subtracting this inductor improvement, the efficiency between 300 kHz and 500 kHz versions remain largely unchanged.

It should be noted that due to the higher forward drop of the eGaN FET body diode, the gate driver timing was adjusted to reduce diode conduction using a single adjustment over the entire load range.

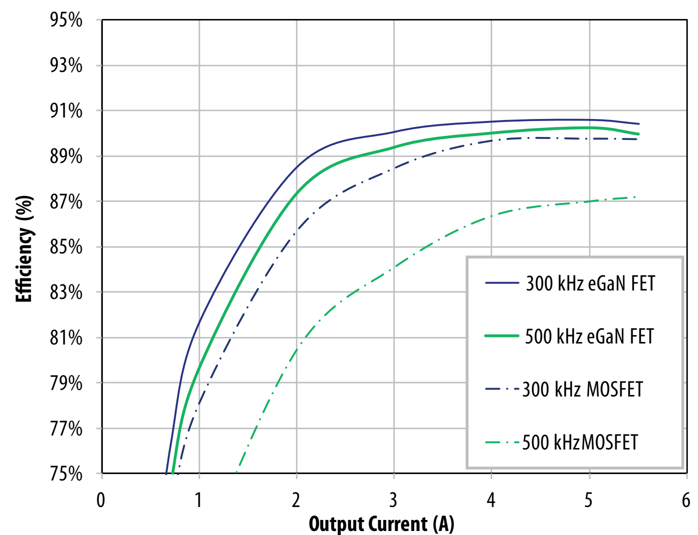

Figure 4: Efficiency comparison for MOSFETs vs eGaN FETs in a 48 V to 5 V, 26 W forward converter.

MAGNETICS

The above forward converter example shows that, despite a 50% higher $R_{DS(ON)}$ in the primary socket (see table 1), eGaN FETs will outperform their MOSFET counterparts as the switching frequency is increased. This improvement is mostly due to the primary side switching device; as the synchronous rectifier (SR) for the forward converter is of limited benefit, due to both the absence of switching loss and increased diode conduction losses that are present without proper synchronous rectification timing.

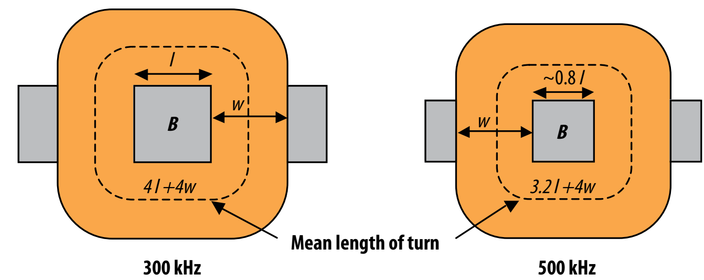

Figure 5: Cross sectional view of two equivalent transformer structures (constant flux density) for different switching frequencies.

In most applications, efficiency improvement is all that is required. The question becomes how can this efficiency improvement be converted into a cost advantage? To answer this question, consider a magnetic core with a specific cross-sectional core area and specific winding window area – this 'core-area product' number is commonly used to design magnetic structures [4] and can be directly related to the volume of the core. Even though the core cross-sectional area and winding window areas may be different for different cores, a constant core-area product results in similar losses and converter efficiencies for a given operating frequency.

What happens when the switching frequency increases? Without changing the magnetics, and assuming the higher switching frequency is still within the viable range of the core material used, the core losses will decrease at a higher rate than the frequency increases due to the non-linearity of these losses vs. flux density [5]. This effect can be seen in the eGaN FET forward converter results where the overall efficiency remains relatively unchanged with an increase in switching frequency even though the eGaN switching losses are increasing.

Can the core size be reduced in exchange for most of this core loss improvement? In other words, can the initial MOSFET efficiency be maintained by using an eGaN FET at a higher frequency and using a smaller/less expensive transformer? Consider an example where the switching frequency is increased from 300 kHz to 500 kHz. The core cross-sectional area can be reduced to increase flux density back to its original value at 300 kHz resulting in 60% of the original cross-sectional area (about 77% per side for a square core area). Cross-sectional views of two such cores are shown in figure 5 and yield the following results:

a) Core volume has decreased to about 60% of the original size.

b) Core losses per unit volume may have increased, depending on the core material used.

c) Winding volume and mean length of turn has also reduced to about 85% - 90% (depends on the length (l) to width (w) ratio). This translates into a lower DC winding resistance and copper conduction loss.

d) AC winding resistance may have increased due to reduced skin depth which will depend on the wire thickness used.

Overall, this will result in a more efficient transformer as typically (a) > (b) and (c) > (d). The 'new' core area product as percentage would be roughly equal to the square root of the ratio of the lower frequency divided by the higher frequency, about 77% in this example, but would be dependent on core aspect ratio. The new core volume would also be reduced to a similar percentage.

In high enough volume, where material cost dominates the transformer cost, it would be fair to assume the cost of a transformer would decrease accordingly. Since the magnetic component tends to be the largest and most expensive single item, this savings can be substantial.

Additional benefits of increased switching frequency would be reduced output capacitance (inversely proportional to frequency), inductor size improved control bandwidth, and faster dynamic and transient response.

SUMMARY

This paper introduced the eGaN FET as a viable and efficient alternative to standard MOSFET solutions in a forward converter. The eGaN FETs enable higher operating frequencies that can be leveraged into reduced converter size and cost.

References:

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