Transformers to Drive SiC FETs

Properly driving and optimizing the use of wide band-gap devices like SiC FETs with off-the-shelf power transformers

Introduction

Silicon Carbide Metal Oxide Semiconductor Field Effect Transistors (SiC MOSFETs or SiC FETs) are wide bandgap (WBG) devices that operate at higher voltage and higher frequency than standard silicon (Si) and IGBTs. This translates to higher power density, meaning smaller size and lighter weight power supplies. SiC also has a much higher junction temperature rating than that of high-power IGBT's, and a higher thermal conductivity than Si, which cools the junction faster. This makes SiC FETs ideal for higher power applications.

Applications for SiC bias supplies include bi-directional chargers, industrial motor drives, solar and other renewable energy storage systems, grid-scale storage devices, and uninterruptible power supplies (UPS).

As SiC FETs become the switch of choice in high-power, and especially high-voltage, switching power supplies for electric vehicles (EV) and hybrid electric vehicles (HEV), the use of an accurate, high-performance, transformer-based bias supply is necessary, especially to switch working voltages in the range of 400 V to 1,000 V. Just like the high-power supplies themselves, the bias supply might use one of several switching topologies

Topologies and Transformers

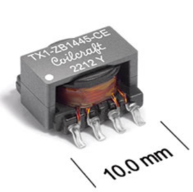
Flyback converters are a tried-and-true choice for generally reliable low-power converters. However, they are generally not able to operate at high switching frequency and the transformer is relatively large. In addition, flyback transformers are typically designed to have low leakage inductance to reduce current spikes. However, designing a transformer for low leakage inductance means primary-secondary capacitance is high, which in turn leads to common mode noise passing through through the transformer.

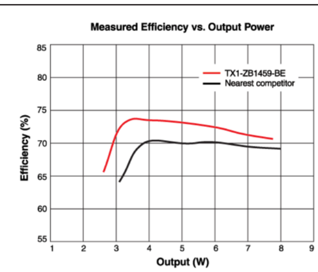
Push-pull is a popular topology in which switching frequency can typically be higher than flyback, and driving the transformer core back-and-forth enables the transformer to be small. The smaller size and turn count in push-pull transformers enable a nice combination of reduced leakage inductance and interwinding capacitance. Push-pull bias supplies are generally driven open-loop which also helps to achieve small size and low cost. Since output voltage regulation will not be as tight as an output-regulated configuration, it is necessary to select only high quality transformers from a dependable supplier to insure there will not be variation in key

Typical Application

Works with Texas Instruments SN6507

Part number	Primary voltage	Secondary voltage	Power [1]	Fsw
TX1-ZB1445-CED	12 V	15 V	7.5 W	1000 kHz
TX1-ZC1892-AED	12 V	30 V	15 W	1000 kHz
TX1-ZB1459-BED	24 V	15 V	7.5 W	1000 kHz
TX1-ZC1891-AED	24 V	30 V	15 W	1000 kHz





Specifications

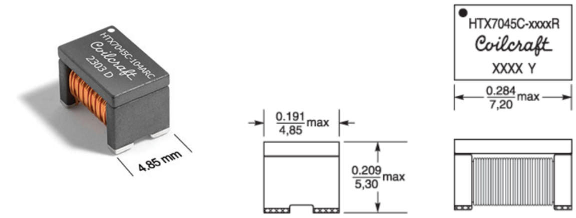
Electrical specifications at 25°C.

Part number (Hover for schematics)	Inductance at 0A (µH) [2]	DCR max (Ω) [3]		Leakage Inductance max (µH) [4]	Turns Ratio	Volt-time product (V-µs) [5]	Isolation Voltage (Vrms) [6]	Schematic
		Pri	Sec		Pri : Sec			
TX1-ZB1445-CED	99.7	0.087	0.135	0.25	1 : 1.4	22	2500	tx1s
TX1-ZC1892-AED	99.7	0.102	0.240	1.0	1 : 2.8	22	2500	tx1s
TX1-ZB1459-BED	196.0	0.115	0.098	1.0	1 : 0.71	30	2500	tx1s
TX1-ZC1891-AED	196.0	0.134	0.163	1.0	1 : 1.43	30	2500	tx1s

Figure 1: Push-Pull Transformer Family[1]

Typical Application

Input Voltage
9 V — 34 V



Specifications

Electrical specifications at 25°C.

Part number 1 (Hover for schematics)	Inductance at 0A (µH) 2 *(Tolerance: ±30%)*	DCR max (Ω) 3		Leakage Inductance ±20% (µH) 4		Turns Ratio	Capacitance max (pF) 5	Volt-time product (V-µs)	Irms (mA) 6	Isolation Voltage (Vdc) 7
		Pri	Sec	Pri	Sec	Pri : Sec				
HTX7045C-753ARC	75	0.35	0.35	8.5	8.5	1 : 1	0.75	33.9	730	4000
HTX7045C-104ARC	100	0.40	0.40	9.5	9.5	1 : 1	0.9	38.8	680	4000
HTX7045C-124DRC	120	0.42	0.28	12.5	5.5	1 : 0.67	0.7	38.8	660	4000
HTX7045C-124ERC	120	0.42	0.32	12.0	6.5	1 : 0.75	0.7	45.3	660	4000
HTX7045C-124FRC	120	0.42	0.35	11.0	7.5	1 : 0.83	0.75	38.8	660	4000
HTX7045C-134BRC	130	0.44	0.17	15.0	2.5	1 : 0.4	0.7	45.3	660	4000
HTX7045C-144CRC	140	0.45	0.23	15.0	3.5	1 : 0.5	0.75	45.3	640	4000

Figure 2: Miniature Transformers Optimized for LLC[2]

parameters from transformer to transformer. Push-pull is a very popular configuration for which controller ICs and off-the-shelf transformers have been developed. For example, Coilcraft TX-1 family of transformers was specifically designed to operate efficiently up to 1 MHz with a good balance of leakage inductance and interwinding capacitance while minimizing transformer size.

Another open-loop configuration growing in popularity is the LLC converter. The LLC takes the balancing of leakage inductance and interwinding capacitance in a whole new direction. Because the leakage inductance can be usefully incorporated into the converter resonant operation, the transformer can be designed with the lowest possible interwinding capacitance. The resonant nature of the converter, along with minimum interwinding capacitance, make the LLC converter the new circuit of choice for low-conducted common mode noise (CMTI). Like push-pull converters, LLC bias supplies are being driven open-loop, placing high emphasis on the consistency and quality of properly-designed transformers. This new transformer design paradigm now enables miniature, chip-style transformers with high part-to-part consistency and high isolation. Note the interwinding capacitance is now less than 1 pF, whereas non-LLC transformers typically might have up to 10 pF or more.

Transformers for Direct Gate Drive

In addition to bias supplies, gate drive transformers are often used to supply the pulsed gate drive voltage that turns the drain-source current on and off. For SiC switches, a negative bias at the time of turn-off is often used to assure fast turn-off and to avoid faulty turn-on.

Gate drive transformers are used to deliver the controlling on/off voltage pulses while providing isolation between the FET and the controlling drive circuit.

Gate driver circuits need an electrically-isolated (floating) bias supply to maintain the required turn-on bias as the FET source rises toward the input voltage. Isolation assures that there are no direct conduction paths between circuits and is very important to both insure noise immunity and provide safety protection. Gate drive transformers isolate the controlling gate drive circuit from the switch node when driving the gate.

In some lower-power applications, digital isolators or opto-couplers may provide the means to drive FETs directly, however, gate drive transformers are preferred for higher-voltage requirements and have the advantage of much lower turn-on and turn-off delay times. Gate drive transformers also provide the ability to scale the voltage up or down by the selected turns ratio. Therefore, gate drive transformers are often the best-performing solution for high-voltage, high-frequency applications where fast and accurate signal timing is critical, as when driving SiC FETs.

Topologies for driving SiC FET gates

Figure 3 on the next page shows a simplified single-output, transformer-coupled (AC-coupled), high-side gate drive circuit for lower-power applications. Depending on duty cycle and other circuit conditions, additional components (capacitors, diodes and resistors) may be used to prevent the development of a DC voltage across the transformer (to prevent core saturation) and to prevent the magnetizing inductance and coupling capacitance from resonating with sudden changes in duty cycle.

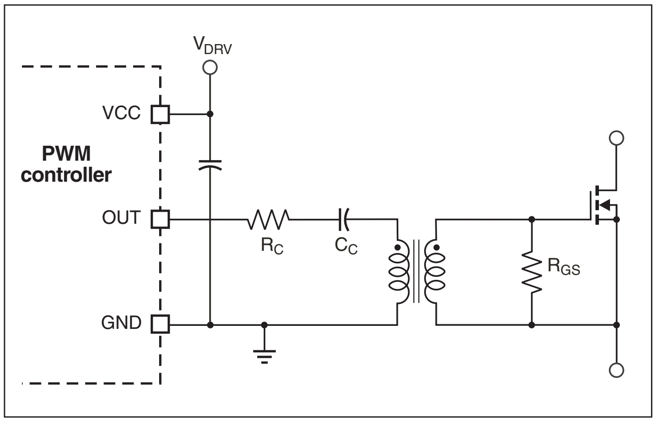


Figure 3: Simplified transformer-coupled single-ended gate drive circuit

Half-bridge and full-bridge configurations, such as the transformer-coupled, push-pull half-bridge gate drive circuit shown in Figure 4, are typically used for higher-power applications, such as those using SiC FETs.

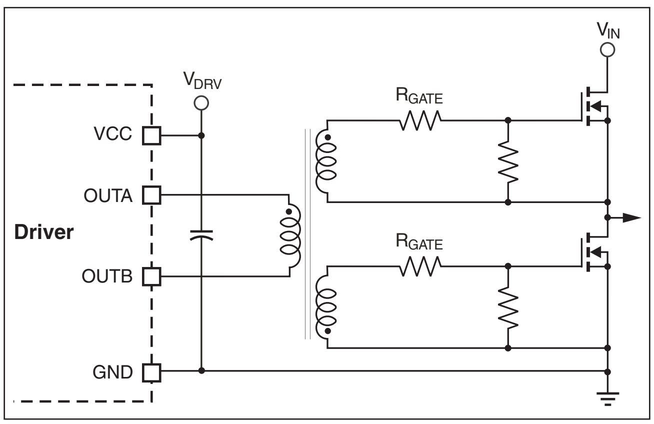


Figure 4: Transformer-coupled push-pull half-bridge gate drive circuit

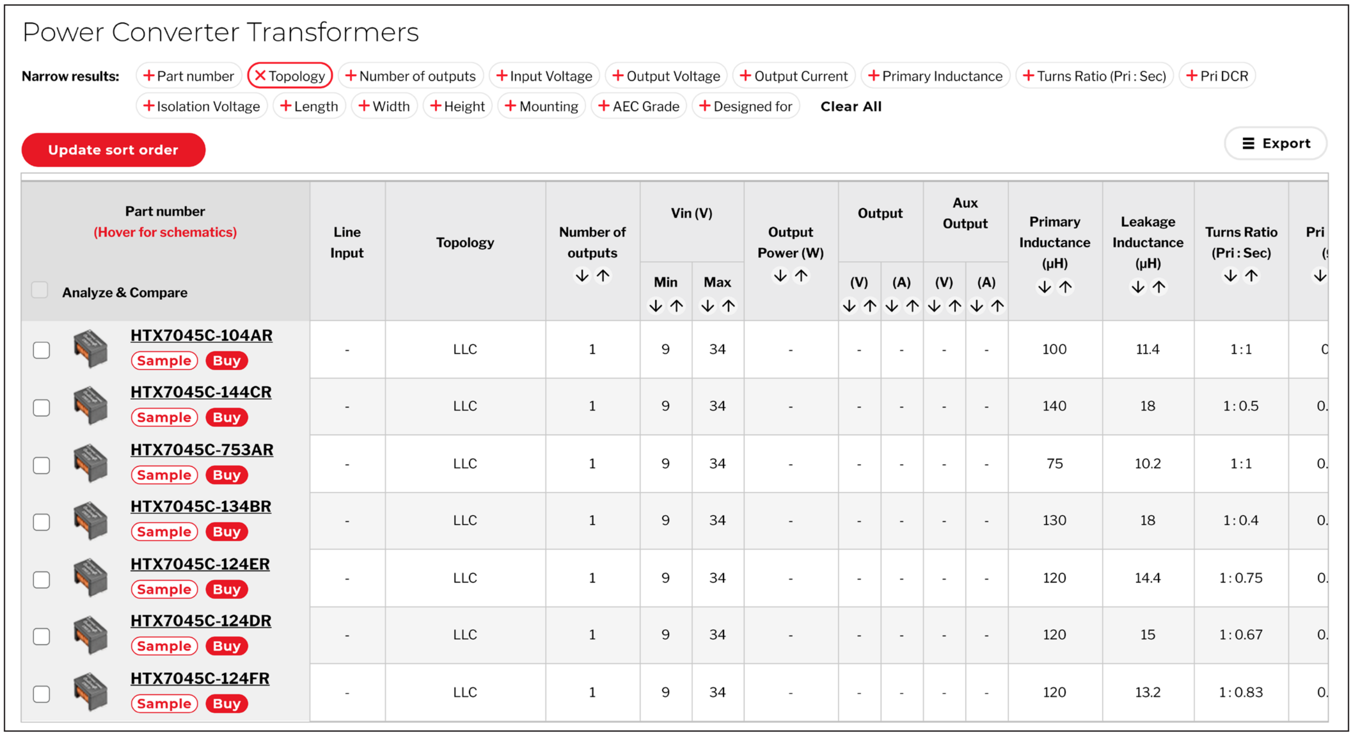
Finding a Transformer

For isolated bias supplies and for direct gate drive transformers, finding the transformer that best fits the application can be a challenge due to the wide variety of transformers available. Proper tools can be very helpful to get this process started.

One starting point is to find transformers designed for a specific application or for use with a specific IC controller. For example, Coilcraft TX1 transformer family is specially designed for optimized performance with the SN6507 push-pull transformer driver from Texas Instruments. Coilcraft's ZA9668-AE isolated Buck Transformer is optimized for STMicroelectronics' A6986i and L6986i. Standard transformers are available for Analog Device's MAX17690 no-opto flyback controller, and Coilcraft HTX7045C family is designed specifically for LLC converters.

Figure 5: Purpose-designed off-the shelf transformers[3]

Applications are not always based on a reference design, or a specific device, but transformers can still be found to match most applications. Coilcraft has collected specifications for hundreds of off-the-shelf transformers into a Parametric Search tool and designers can find what they need based on the specifications needed for their application. Figure 6 shows that LLC transformers can simply be found by filtering for LLC topology.



Power Converter Transformers

Narrow results: +Part number ✕Topology +Number of outputs +Input Voltage +Output Voltage +Output Current +Primary Inductance +Turns Ratio (Pri : Sec) +Pri DCR +Isolation Voltage +Length +Width +Height +Mounting +AEC Grade +Designed for Clear All

Update sort order

Export

Part number (Hover for schematics) Analyze & Compare	Line Input	Topology	Number of outputs	Vin (V) Min	Vin (V) Max	Output Power (W)	Output (V)	Output (A)	Aux Output (V)	Aux Output (A)	Primary Inductance (µH)	Leakage Inductance (µH)	Turns Ratio (Pri : Sec)	Pri
HTX7045C-104AR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	100	11.4	1 : 1	C
HTX7045C-144CR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	140	18	1 : 0.5	0.
HTX7045C-753AR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	75	10.2	1 : 1	0.
HTX7045C-134BR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	130	18	1 : 0.4	0.
HTX7045C-124ER Sample Buy	-	LLC	1	9	34	-	-	-	-	-	120	14.4	1 : 0.75	0.
HTX7045C-124DR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	120	15	1 : 0.67	0.
HTX7045C-124FR Sample Buy	-	LLC	1	9	34	-	-	-	-	-	120	13.2	1 : 0.83	0.

Figure 6: Coilcraft Transformer Parametric Search Tool filtered for LLC topology[4]

Conclusion

Transformers are an essential component for properly driving and optimizing the use of wide band-gap devices like SiC FETs. A wide variety of off-the-shelf transformers optimized for specific use cases are readily available for prototype and volume production needs.

Sources

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