Asymmetric Half-Bridge AC-DC Power Converter with HB GaN FET Integrated

General Description

The DK87xxAD is an AC-DC power converter based on asymmetric half-bridge topology, which integrates half bridge GaN devices. The DK87xxAD recycles leakage inductance energy to enable primary side ZVS and secondary side ZCS. Therefore, system overall efficiency is improved. Soft switches also can reduce power FET stress, reduce switching losses and reduced EMI interference (EMI).

The DK87xxAD greatly simplifies system design and manufacture of AC-DC converters, especially those requiring high efficiency and high power density. The DK87xxAD has comprehensive protection functions such as: overload protection(OCP), output over voltage protection(output OVP), output short circuit protection(output SCP), VCC over and under voltage protection(VCC UVLO and VCC OVP), VS abnormal protection, cycle-by-cycle current limit protection, over temperature protection(OTP), etc.

The DK87xxAD adopts DFN8*8 packaging.

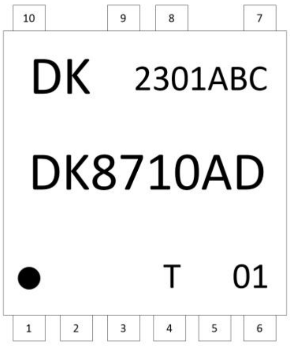
Features

- HB GaN FETs integrated
- AHB control circuit and half-bridge driver integrated
- Up to 800KHz switching frequency
- Standby power consumption less than 50mW
- Self adaptive dead time
- Very few peripheral components
- Less voltage stress over secondary side FET
- Built-in frequency jittering
- Built-in HV start-up and X-capacitor discharge
- Halogen-free and ROHs-compliant
- DFN8*8 packaging

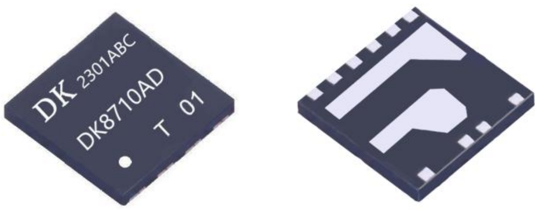
Applications

- High power density SMPS power adapter/charger
- Laptop adapter, tablet adapters, TV power supply, electrical cycle charger
- Communication power supply
- LED power supply

■ *Order Information*



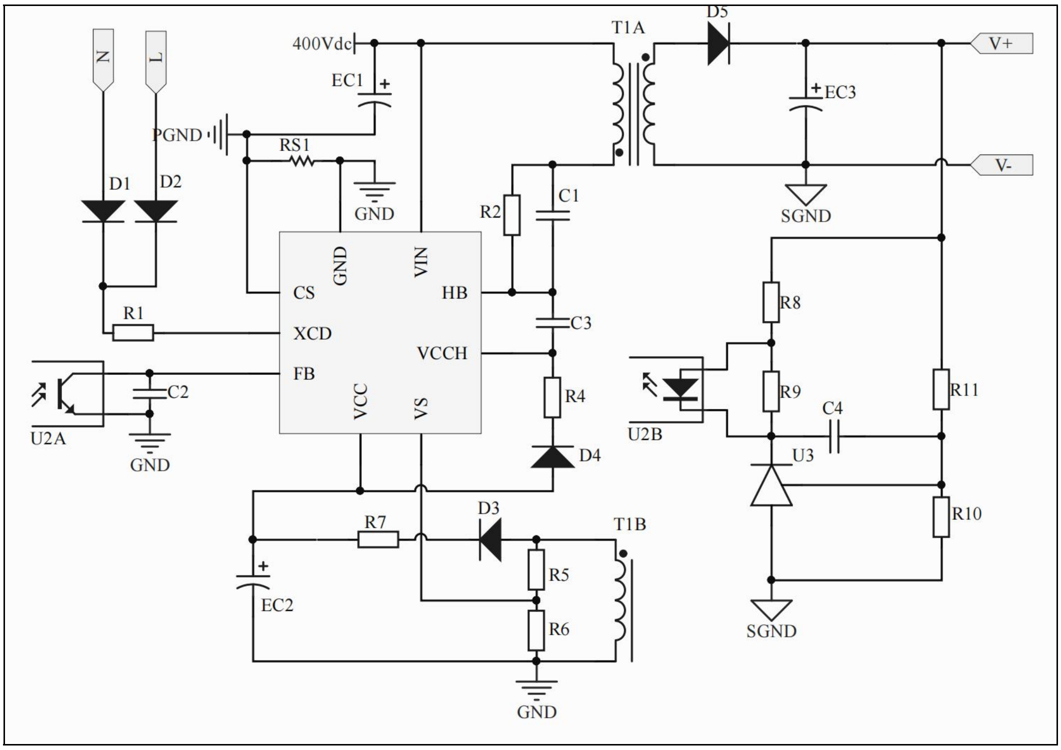
Marking	Note
DK	DK Semiconductor
2301	2023 1^{th} Batch of Production
A	Internal Code
B	Internal Code
C	Internal Code
8710	Product No.
A	Internal Code
D	Encapsulated Code
T 01	Testing Code



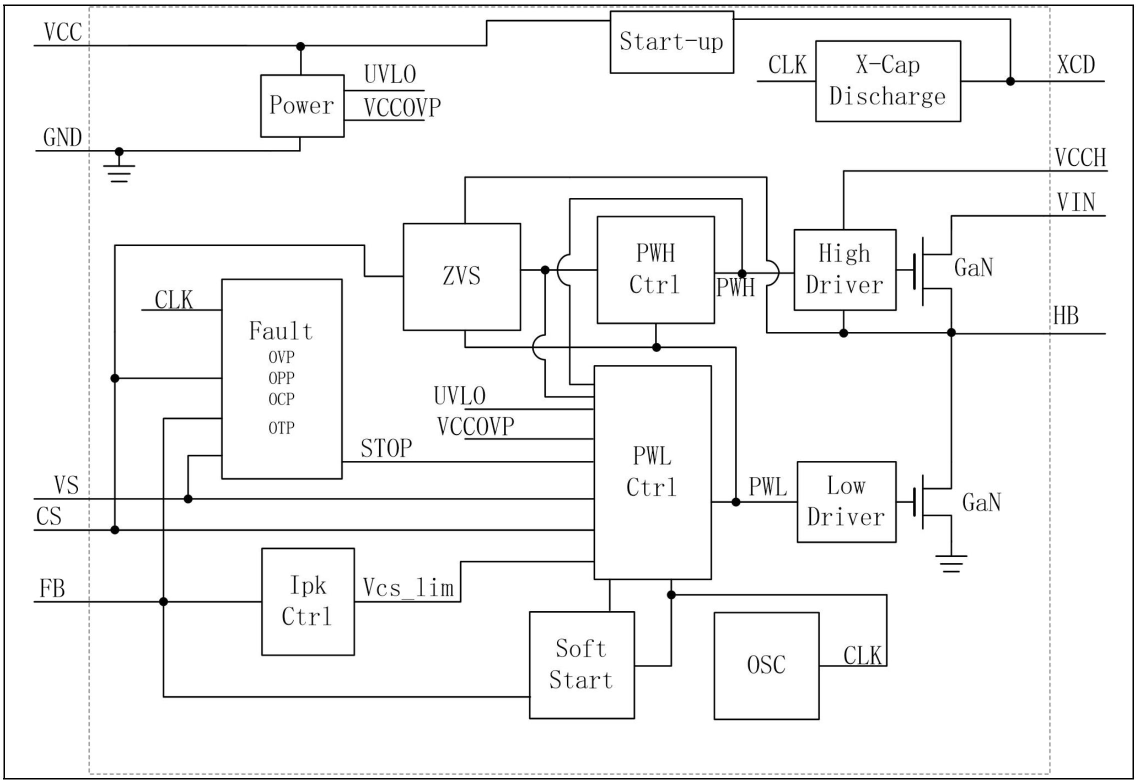
■ *Product Information*

Order Codes	Package	Typical Power With PFC-DC380V
DK8710AD	DFN8*8	100W
DK8712AD	DFN8*8	120W
DK8715AD	DFN8*8	150W
DK8718AD	DFN8*8	180W

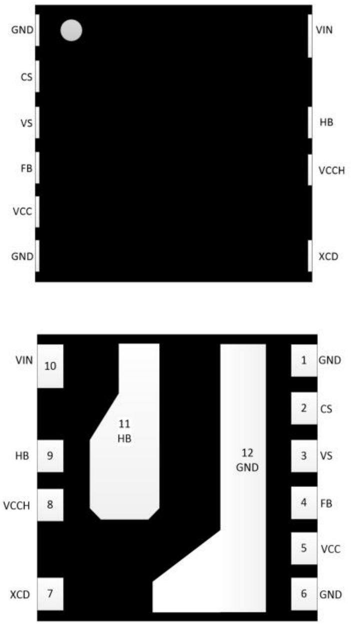
Typical Application



Block Diagram



■ *Pin Configuration*



Pin No.	Pin Name	Description
1 ， 6， 12	GND	Ground reference.
2	CS	Current sense.
3	VS	Multi-function pin for de-magnetization detection, output OVP, etc.
4	FB	Input of error amplifier receiving feedback signal from opto-coupler.
5	VCC	IC power supply input.
7	XCD	X capacitor discharge, HV start-up.
8	VCCH	Power supply input for the HS FET driver.
9， 11	HB	Half-bridge output.
10	VIN	HV power input, also drain of HS FET.

■ *Absolute Maximum Ratings (TA=25℃ Unless otherwise noted)*

Description	Symbol	Value	Unit
VIN maximum voltage (HS FET drain-source voltage)	$V_{VIN(MAX)}$	650	V
HB maximum voltage (LS FET drain-source voltage)	$V_{HB(MAX)}$	650	V
XCD Maximum Voltage	$V_{XCD(MAX)}$	600	V
V_{CC} Maximum voltage	V_{CC}	27	V
V_{CC} current	I_{CC}	2	mA
FB Maximum Voltage	$V_{FB(MAX)}$	5.5	V
VS Maximum Voltage	$V_{VS(MAX)}$	5.5	V
CS Maximum Voltage	$V_{CS(MAX)}$	-1~1	V
VCCH Maximum Voltage (HB point voltage as reference point)	$V_{VCCH(MAX)}$	26	V
Total dissipation power	$P_{D(MAX)}$	3	W
Thermal resistance	θ_{JC}	4	℃/W
Maximum junction temperature	$T_{J(MAX)}$	150	℃
Storage temperature range	T_{STG}	-40~150	℃
Maximum soldering temperature	T_W	260	℃/10s

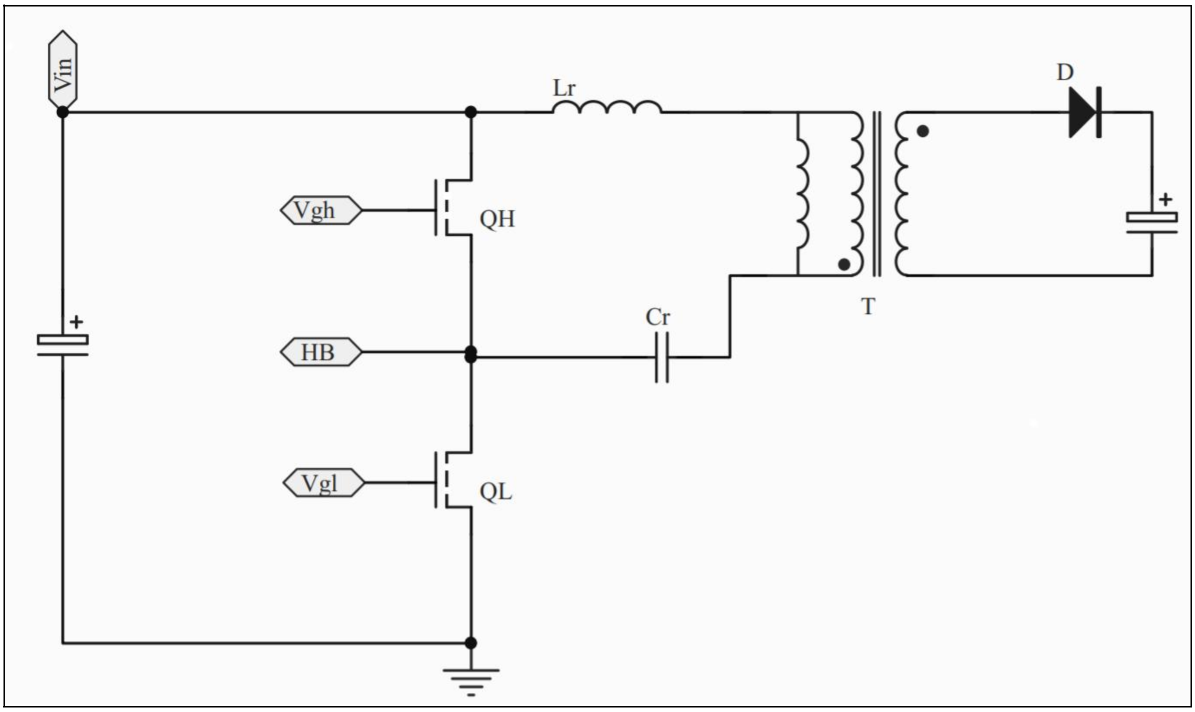
Note: Absolute maximum ratings are those values beyond which the device could be permanently damaged.

■ ***Electronic Characteristics** (T_A=25℃ Unless otherwise noted)*

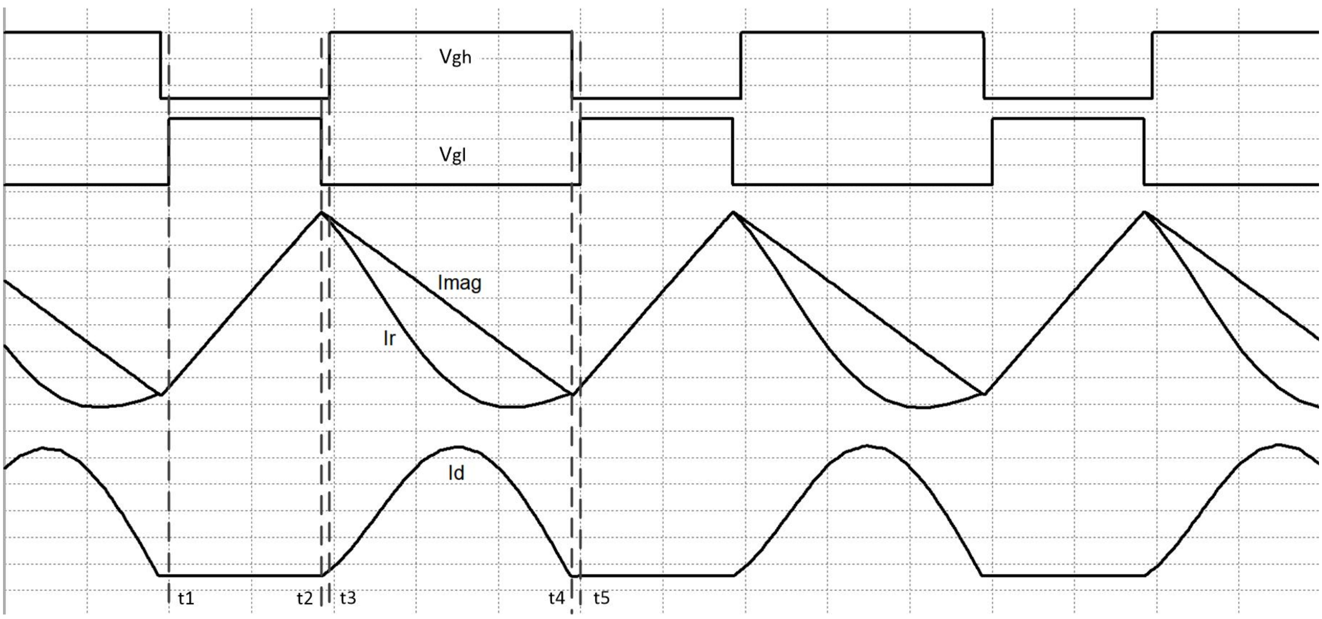
Parameter	Symbol	Conditions	Min	Typ	Max	Unit
V_{CC} Power Supply						
V_{CC} Start-up Voltage	$V_{CC(start)}$	Input 90Vac-----265Vac	16.2	18	19.8	Vdc
V_{CC} Restart Voltage	$V_{CC(reset)}$		5.6	6.1	6.7	V
V_{CC} Operating Current	$I_{CC(on)}$	V_{CC}=10V		0.60		mA
V_{CC} Overvoltage Protection Point	$V_{CC(OVP)}$		24	25.5	27	V
XCD provides current						
VCC Start-up Current	I_{start}	V_{CC}=12V，XCD=32V,R1=2K	2.8	3.4	4.8	mA
X capacitor discharge current	I_{XCD}		2.8	4	5.2	mA
Brown In and Brown Out Detection						
Brown-in Start-up Current	$I_{Brownin}$		300	345	380	μA
Brown-out Dropout Current	$I_{Brownout}$		128	148	163	μA
Brownin Detection Interval	$t_{Brownin}$			128		ms
Brownout Detection Time	$t_{Brownout}$		0.75		2.5	ms
Feedback						
FB Open Circuit Voltage	$V_{FB(open)}$		4.7	5.1	5.6	V
FB Short Circuit Current	$I_{FB(short)}$	FB pin shorted to GND, measuring FB current	155	170	187	μA
CS Sampling						
Over power detection CS reference	$V_{CS(OPP)}$		-385	-400	-415	mV
Primary over current protection CS reference	$V_{CS(OCP)}$	Abnormal protection time limit		-700		mV
Adaptive control mode current limit voltage	$V_{CS(BUR))}$			-300		mV

Minimum CS voltage reference	$V_{CS(MIN)}$			-160		mV
Leading edge blanking time	t_{LEB1}			165		ns
Primary Overcurrent Detection Fade Time	t_{LEB2}			80		ns
VS Demagnetization Detection						
Demagnetization Threshold Voltage	V_{TH_VS}			40		mV
VS Over voltage Protection	V_{VS_OVP}		3.85	4.2	4.55	V
VS short circuit protection value	V_{VS_OSP}			0.2		V
Timer Section						
Maximum On-time	T_{on_MAX}			10.6		μs
Maximum Switching Cycle	$T_{\_MAX}$			96		μs
Power Section						
dead time	T_{dead1}	LS FET off, HS FET on	150	200	250	ns
dead time	T_{dead2}	GS FET off, LS FET on (120ns + adaptive time)	120			ns
Power FET (HS FET) on-resistance	$R_{DS(on)}$	DK8710AD		365	480	mΩ
		DK8712AD		270	350	mΩ
		DK8715AD		200	260	mΩ
		DK8718AD		115	150	mΩ
Power FET (LS FET) on-resistance	$R_{DS(on)}$	DK8710AD		365	480	mΩ
		DK8712AD		270	350	mΩ
		DK8715AD		200	260	mΩ
		DK8718AD		115	150	mΩ
Protection						
Overload protection detection time	t_{OPP}			160		ms
Protection restart time	t_{STOP}			2000		ms
OTP	T_{SD}	Junction Temperature	130		150	℃

■ *Asymmetric Half Bridge Topology Overview*



Asymmetric Half Bridge Topology Application Schematic



Typical waveforms of asymmetric half bridge

Operating stages of AHB

t1-t2: During this stage, LS FET turns on while the HS FET turns off. The main inductor stores energy and the magnetizing current rises linearly. When V_{CS} triggers to V_{CS_LIMIT}, LS FET turns off. In this stage, secondary rectifier is turned off because of reversely biased voltage.

t2-t3: After LS FET turns off, system enters dead time T_{dead1}. In this duration, both HS and LS power FETs are turned off to ensure system safety. LS FET C_{DS} is charged to V_{IN} while the HS FET C_{DS} discharges to zero voltage.

t3-t4: During this stage, HS FET ZVS turns on and secondary rectifier turns on. Transformer transfers energy to the secondary side. The primary winding voltage of the transformer is clamped by the output voltage and the magnetizing current I_{MAG} decreases linearly. L_R resonates with C_R in the resonant tank, which introduces resonant current I_R. The difference between the resonant current I_R and the magnetizing current I_{MAG} transfers to the secondary side;

t4-t5: During this stage, HS FET turns off and C_{DS} of HS FET charges to V_{IN} after deadtime T_{DEAD2}, while LS FET C_{DS} discharges to zero. Therefore, LS FET can be ZVS turned on in the next circle. T_{DEAD2} also ensures system safety and avoids LS and HS FETs conducting at the same time.

Functional Description

The DK87xxAD is an AC-DC power converter based on asymmetric half-bridge topology, which integrates two GaN FETs. The DK87xxAD features peak current control mode. The DK87xxAD recycles leakage inductance energy which involves L_R and C_R resonant to realize primary side ZVS and secondary side ZCS, therefore system overall efficiency is improved. Meanwhile, voltage stress over primary and secondary FETs on are reduced compared to traditional flyback topology.

◆ Start-up

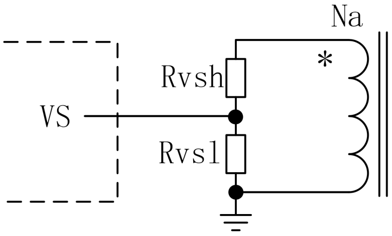
The DK87xxAD features HV start-up. HV start-up circuit charges the external VCC capacitor through XCD pin after system powered on. As VCC voltage exceeds $V_{CC(START)}$, the DK87xxAD starts to work. Auxiliary winding begins to power the IC after output voltage is built up. HV start-up circuit turns off afterwards to reduce standby power consumption.

◆ Soft Start

After powered on, the DK87xxAD enters soft start. During soft start, the DK87xxAD gradually increases V_{CS_LIMIT} (absolute value) to prevent output overshoot during startup. Soft start ends when the V_{CS_LIMIT} (absolute value) increases to $|V_{CS(OPP)}|$. With soft start, The DK87xxAD can avoid output voltage overshoot and transformer core saturation, also can avoid voltage over stress of the primary MOSFET and secondary rectifier.

◆ Input Voltage Brown-in Detection

After powered on, the DK87xxAD will detect I_{VS} current in real time. When $I_{VS}>I_{Brownin}$, it means system powered on successfully and the DK87xxAD enters soft start. If $I_{VS}<I_{Brownin}$, the DK8715xxAD will stop PWM output and after $T_{Brownin}$, it will restart. As soon as VCC reaches $V_{CC(start)}$, the DK87xxAD will enter input voltage detection again.



Pull-up resistance calculation formula:

$$Rvsh = \frac{Vin(start) \times Na}{I_{Brownin} \times Np}$$

Vin(start) is the starting voltage, Np is the number of turns of the transformer primary winding, and Na is the number of turns of the transformer auxiliary winding.

◆ Input Voltage Brown-out Detection

During normal operation, the DK87xxAD s will detect input voltage in real time: If $I_{VS}<I_{Brownout}$ is detected during the $t_{Brownout}$ time, the DK87xxAD will stop PWM output and will restart after $t_{Brownin}$. As soon as VCC is charged to $V_{CC(start)}$, the DK87xxAD will restart again.

Brown-out voltage Vin(stop) can be calculated by the following equation:

$$Vin(stop) = \frac{Rvsh \times I_{Brownout} \times Np}{Na} + VOR$$

Note: V_{OR} is reflected voltage.

◆ Zero Voltage Switch

The DK87xxAD will acquire ZVS condition by detecting VS pin voltage. When VS voltage falls below V_{TH_VS}, the DK87xxAD turns on the LS GaN HEMT to achieve ZVS(zero voltage switching).

After LS GaN HEMT turns off, the DK87xxAD enters Tdead1, in this duration, the voltage over the HB point will rising to V_{IN} rapidly, which will charge the C_{OSS} of the LS GaN HEMT while discharge the C_{OSS} of the HS GaN HEMT. In this way, the HS GaN HEMT can be zero voltage switched on.

◆ X-CAP Discharge

In order to meet the requirements of the safety standard, when powered off, the voltage over the X-cap must be discharged below the safety voltage within a certain time.

The DK87xxAD series has an integrated X-cap discharge circuit. The X-cap discharge circuit will be activated when powered off. The X-cap voltage will be reduced to safe voltage within 1 or 2s.

◆ Frequency Jittering

The DK87xxAD has frequency jittering function which can disperse the energy level of the electro-magnetic interference effectively. Hence the EMI filter can be easily designed.

◆ Leading Edge Blanking

Due to the distributed capacitance of the power supply system, the CS voltage will have a voltage spike during system power on, which will trigger system protection if not handled properly. To avoid such problem, the DK87xxAD will sample CS voltage after a blanking time t_{LEB1}. During $t_{LEB1,}$ the DK87xxAD will not sample CS voltage to filter the spike out.

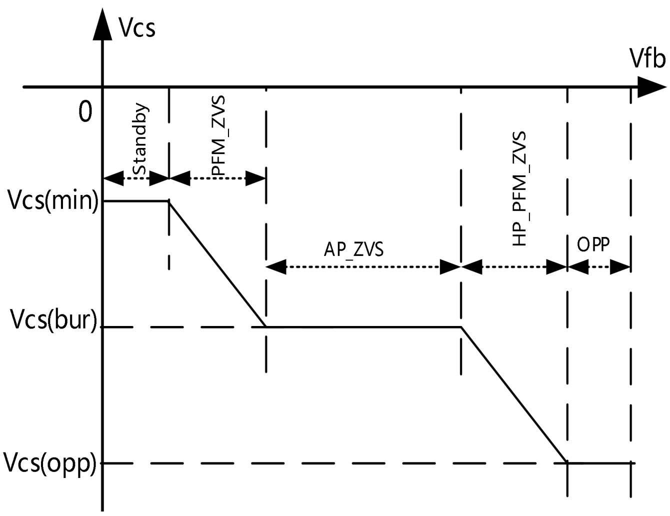
◆ Negative Voltage Sampling

The DK87xxAD detects CS voltage to determine the primary current, i.e. $Ipk=V_{CS}/R_{CS}$. The DK87xxAD uses negative CS voltage sampling to diminish the interference of V_{CS} over the GaN driver voltage V_{GS}. System reliability can be improved and GaN driver can be stabilized in this way.

◆ Feedback Control

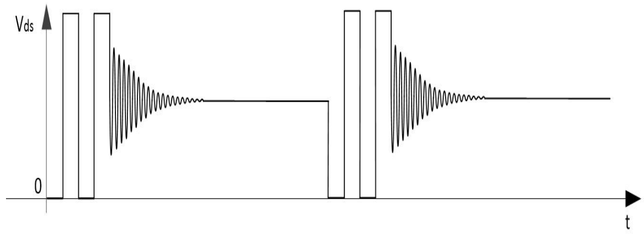
The DK87xxAD uses cycle by cycle primary peak current limit PWM control algorithm to adjust output power. By detecting the feedback voltage, it can precisely control the output power.

The DK87xxAD have four operation modes when having different load conditions. The relation between VCS_{LIMIT} and FB voltage as the picture below. During full load or heavy load condition, the DK87xxAD enters HP_PFM_ZVS mode. As load reduces, VCS_{LIMIT} reduces linearly. When VCS_{LIMIT} hits $VCS_{(BUR)}$, the DK87xxAD enters AP_ZVS mode. In this mode, the DK87xxAD remains VCS_{LIMIT} at a certain level and PWM will have 2~10 output according to load level. After these PWM output, system will enter free oscillation. During this mode, the fewest PWM output number is 2. If load continues to decrease, the DK87xxAD will enter PFM_ZVS mode, during which VCS_{LIMIT} will continuously decrease. When VCS_{LIMIT} hits $VCS_{(MIN)}$, the DK87xxAD enters standby mode. These four modes will be discussed in detail.



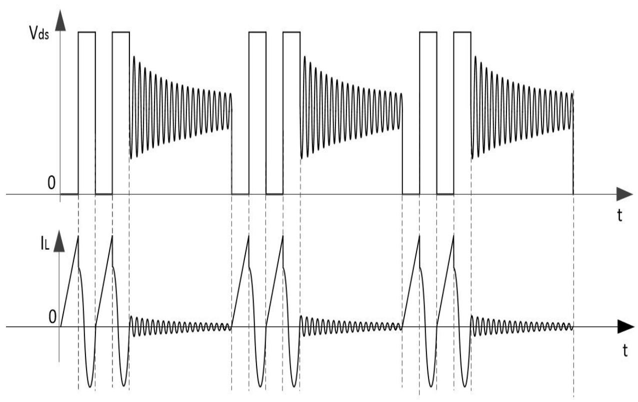
Standby Mode:

In order to meet the efficiency requirement of Energy Star, the DK87xxAD detects the load status automatically through FB voltage which is has a linear relation with load status. When system load is at 0~10%, the DK87xxAD enters standby mode. In this mode, VCS_{LIMIT} is $VCS_{(MIN)}$ and will have 2 PWM output to minimize the standby power consumption.



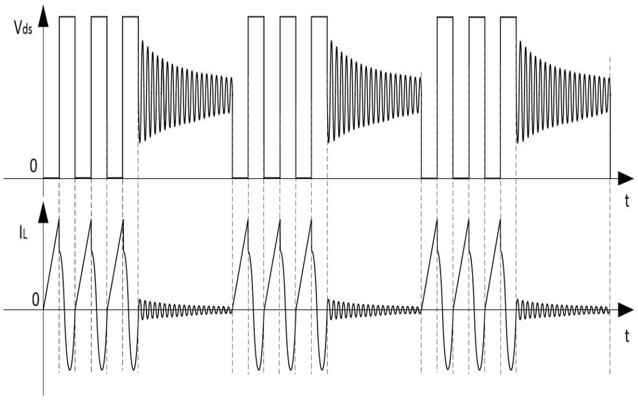
PFM_ZVS Mode:

When system load increases to 10~20%, the DK87xxAD exits standby mode and enters PFM_ZVS mode. In this mode, VCS_{LIMIT} gradually increases from 160mV to 300mV as load increases and system frequency decreases accordingly to improve light load efficiency. Although system in light load mode, the DK87xxAD can still achieve zero voltage switching(ZVS) which will increase light load efficiency further more.



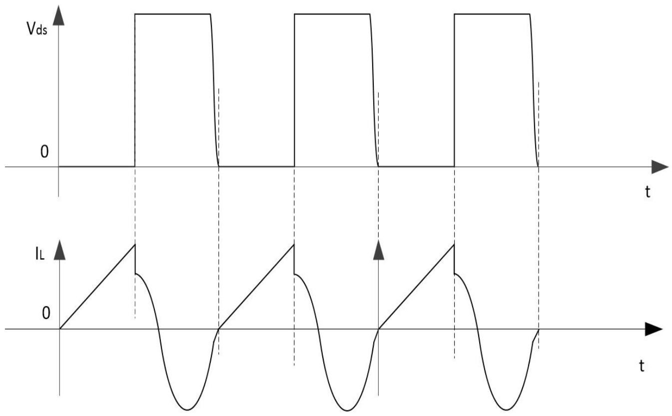
Adaptive Control Mode (AP_ZVS)

When system load increases to 20~70%, the DK87xxAD enters adaptive control (AP_ZVS) mode. During this mode, VCS_{LIMIT} is fixed at 300mV and the DK87xxAD outputs 2~10 PWMs to optimize the system overall efficiency. As load increases, the DK87xxAD will output more PWMs as system demand.



High Power PFM ZVS (HP_PFM_ZVS)

The DK87xxAD enters HP_PFM_ZVS mode as load increases above 70%. During this mode VCS_{LIMIT} varies from $V_{CS(BUR)}$ to $V_{CS(OPP)}$ as load increases. As VCS_{LIMIT} varies, system frequency decreases accordingly. Both LS and HS GaN HEMTs can realize zero voltage switching(ZVS) during this mode to ensure maximum conversion efficiency.



■ *Protections*

◆ Over Power Protection (OPP)

Once the DK87xxAD detects a continuous 160mS $VCS>VCS_{(OPP)}$, system enters over power protection(OPP), both LS and HS driver output will stop immediately.

◆ Output Over Voltage Protection (OVP)

The DK87xxAD can accurately detect the output voltage through the VS voltage. During open loop condition, VS voltage will increase as system output voltage increases. When the VS voltage reaches V_{VS_OVP}, the DK87xxAD will stop PWM output.

When output protection voltage is determined, R_{VSL} can be calculated using the following equation:

$$V_{VS\_OVP} = \frac{Vout(ovp) \times Na \times Rvsl}{Ns \times (Rvsl + Rvsh)}$$

Where Ns is the number of turns of the transformer secondary winding and voltage drop over the rectifier diode is neglected.

◆ Output Short Circuit Protection (OSP)

Once the DK87xxAD detects VS<V_{VS_OSP}, it will trigger output short circuit protection(OSP). The DK87xxAD will stop PWM output.

◆ VCC Over/Under Voltage Protection

The DK87xxAD features VCC over/under voltage protection, which turns off the PWM outputs when the VCC voltage rises above $V_{CC(OVP)}$ or falls below $V_{CC(reset)}$.

◆ VS Abnormal Protection (VSP)

The DK87xxAD features VS abnormal protection, which will trigger when detects pull-up resistor open connected or pull-down resistor short connected. DK87xxAD will stop PWM outputs when enters VS abnormal protection.

◆ Output Rectifier Abnormal Protection

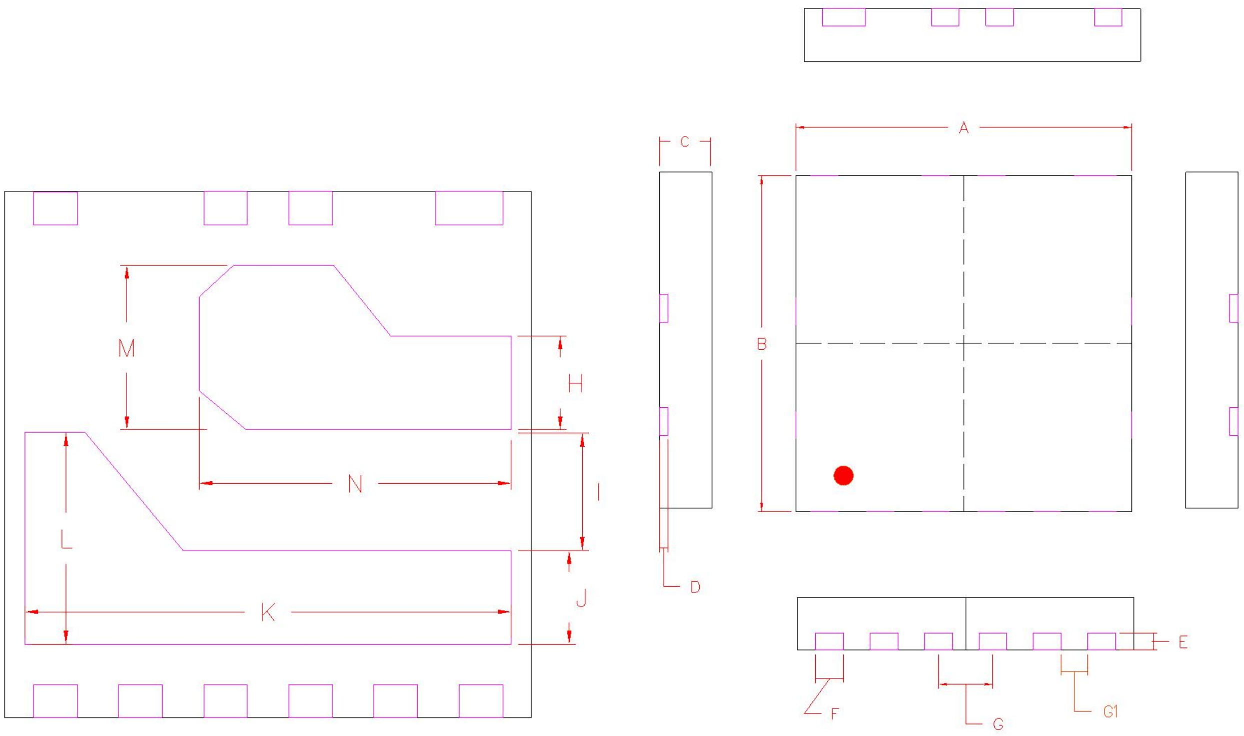
When the secondary rectifier diode is opened or shorted, or the primary inductor is shorted, the V_{CS} will reach $V_{CS(OCP)}$ rapidly, this will trigger over current protection of the DK87xxAD.

◆ Over Temperature Protection (OTP)

The DK87xxAD features over temperature protection which monitors the junction temperature of the primary Gan HEMTs in real time. As long as the junction temperature exceeds the over temperature protection threshold T_{SD}, the DK87xxAD will stop PWM output.

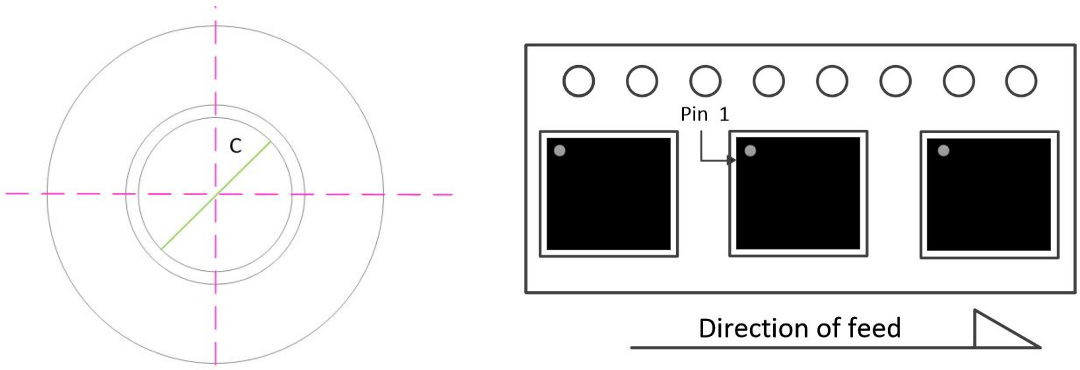
■ *PACKAGE OUTLINE DIMENSIONS*

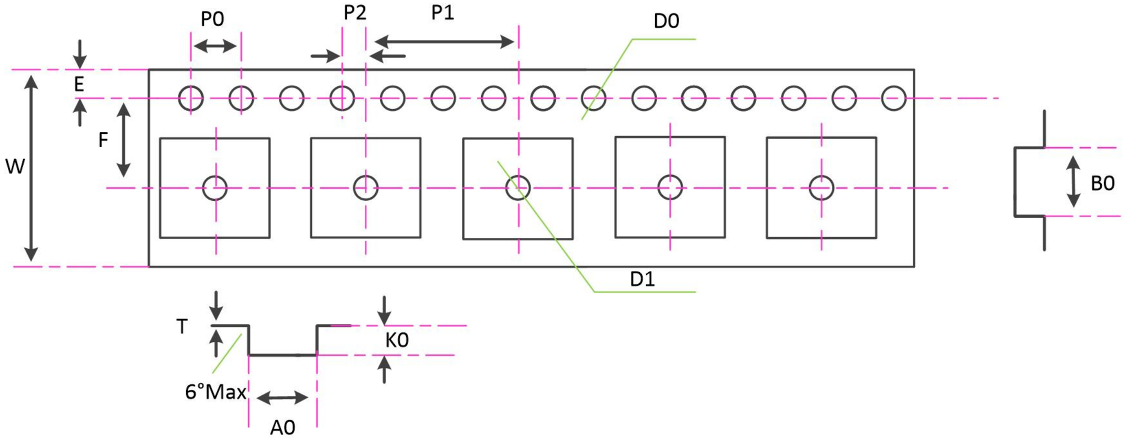
1. DFN8*8



Symbol	Dimensions In Millimeters		
	Min	NOM	Max
A	7.80	7.88	8.00
B	7.80	7.88	8.00
C	1.18	1.23	1.25
D	0.18	0.20	0.25
E	0.35	0.40	0.45
F	0.65 BSC		
G	1.27 BSC		
G1	0.60	0.62	0.65
H	1.40	1.50	1.60
I	1.60	1.70	1.80
J	1.40	1.50	1.60
K	7.10	7.25	7.40
L	3.05	3.15	3.25
M	2.35	2.45	2.55
N	4.55	4.65	4.75

2. Taping and Reeling Information





Symbol	SPEC(mm)
A0	8.30 ± 0.10
B0	8.30 ± 0.10
C	76.5± 0.50
K0	1.50 ± 0.10
P0	4.00 ± 0.10
P1	12.00 ± 0.10
P2	2.00 ± 0.10
T	0.30 ± 0.05
E	1.75 ± 0.10
F	7.50 ± 0.05
D0	1.50 + 0.1/-0
D1	1.50 + 0.25/-0.4
W	16.00+0.3/-0.1