

## MK2788S Wide VCC Range HF QR Controller with GaN Integrated

### 1. Description

The MK2788S is a high frequency QR controller optimized for PD/Fast Charge applications. Its wide VCC operating voltage range (9V-85V) allows it to cover PD/PPS output range of 3.3V-21V without the need of additional VCC windings or linear step-down circuits.

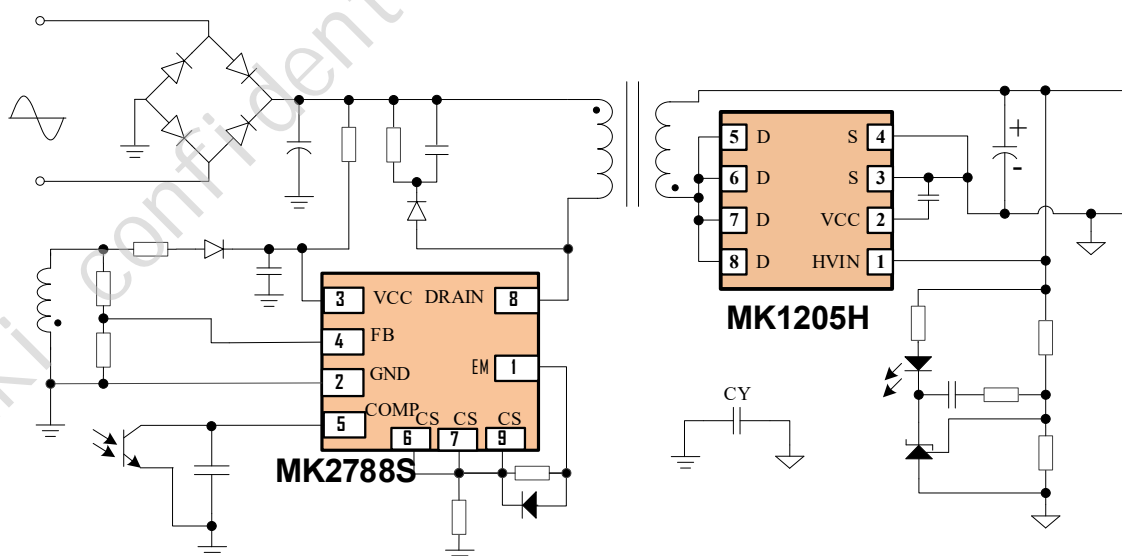
To achieve high efficiency across universal line and different load conditions, the MK2788S is self-adaptive to operate in DCM/QR mode. At light load, it works in Burst mode to improve efficiency.

The MK2788S offers various protection features including output over-voltage protection (OVP), output over power protection (OPP), VCC over-voltage protection, Brown-in/Brown-out, Secondary side SR short-circuit protection (SSCP), and CS short-circuit protection.

### 2. Typical Applications

- 45W AC/DC PD/Adapter
- High Power Density Power Supply

### 4. Simplified Application



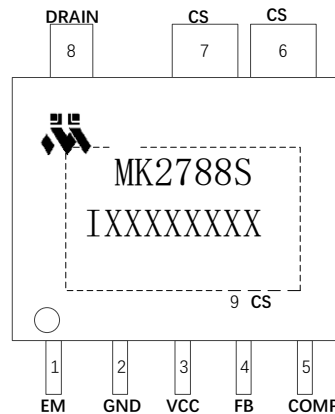
### 3. Features

- Built-in 700V 430mR GaN FET
- Wide VCC Operating Range (9V-85V)
- Operating Frequency up to 130kHz
- Proprietary Soft-Start Scheme to Achieve Low SR Vds Stress
- Optimized Efficiency to Easily Meet Energy Efficiency Standards
- CS Short-Circuit Protection
- OPP/SSCP Protection
- Brown-In/Brown-Out Function
- VCC OVP/VO OVP Protection
- Supports PPS Wide-Range Output
- Tiny ESOP-7 Package

## 5. Ordering Information

Ordering No.	Description
MK2788SIAU	ESOP-7, 5000 pcs/reel

## 6. Package Reference



XXXXXXXXX: Lot Code

ESOP-7 Top View

### 6.1 Absolute Maximum Ratings<sup>(1)</sup>

VCC.....	-0.3V to +100V
COMP, FB.....	-0.3V to +5.5V
CS.....	-0.7V to +5.5V
EM.....	-3V to +5.5V
DRAIN.....	-3V to +700V
I <sub>D</sub> .....	6A <sup>(2)</sup>
Junction Temperature .....	+155°C

### 6.2 Recommended Operation Conditions

VCC .....	9V to 85V
Maximum Junction Temp. (T <sub>J</sub> ).....	+125°C

### 6.3 Thermal Resistance<sup>(4)</sup>

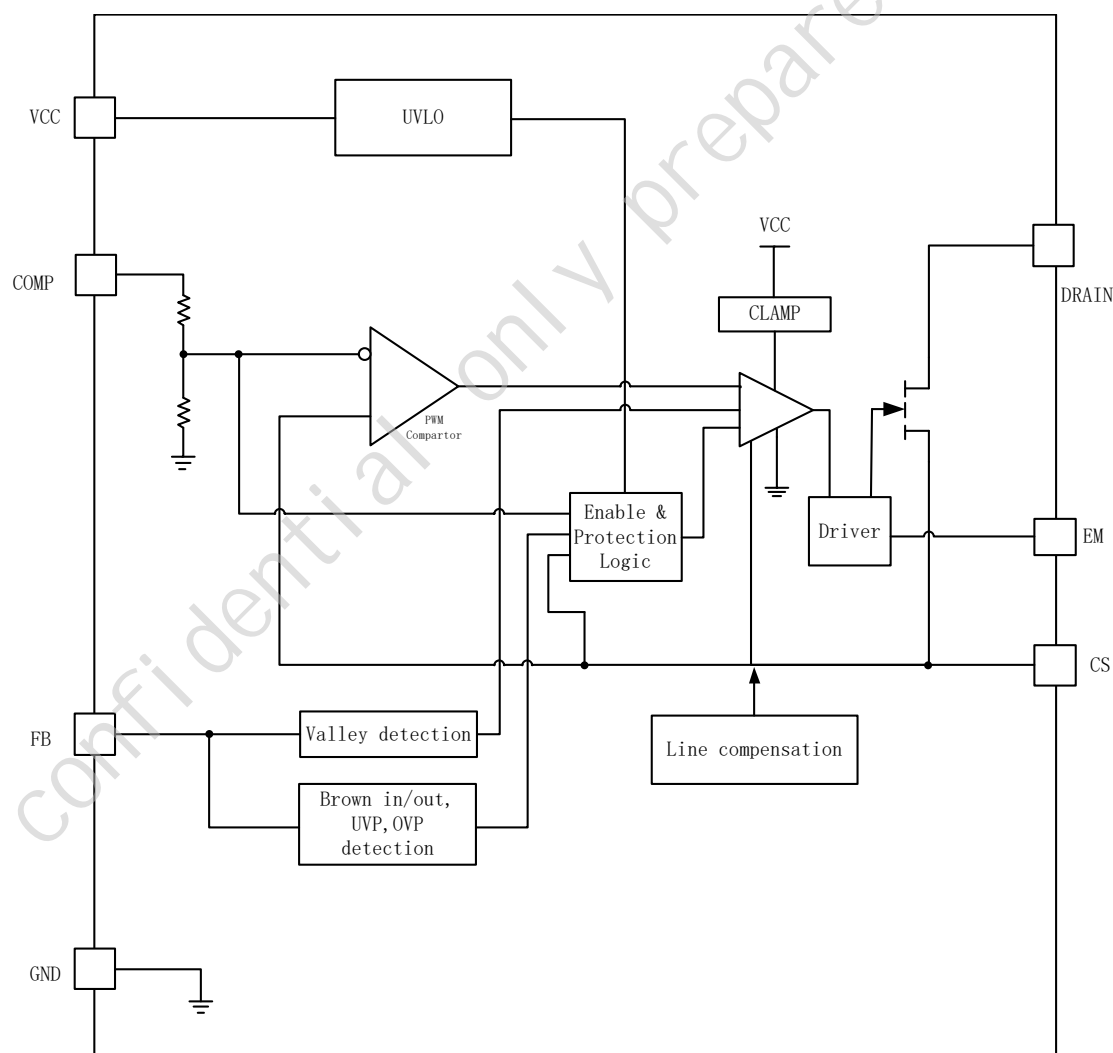
θ <sub>JA</sub> .....	45 °C/W
θ <sub>JC</sub> .....	2°C/W

#### Notes:

- (1) Exceeding these ratings may damage the device;
- (2) T<sub>c</sub> = 25 °C, T<sub>pulse</sub> = 10μs ; Limit was extracted from characterization test, not measured during production;
- (3) Measured on JESD51-7, 4 layers PCB.

## 8. Block Diagram

Pin #	Name	Description
1	EM	External driving modulating pin, connected to CS through a resistor and a diode
2	GND	Ground
3	VCC	Power Supply
4	FB	Auxiliary Voltage Sense
5	COMP	Voltage Feedback
6、7、9	CS	Current Sense Input
8	DRAIN	HV Power GaN Drain



### Figure 1. Functional Block Diagram

## 9. Electrical Characteristics

VCC=12V, T<sub>A</sub>=25°C, unless otherwise noted.

Parameter	Symbol	Conditions	Min	Typ	Max	Units
<b>GaN Section</b>						
Maximum Drain Voltage	V <sub>DS_max</sub>		700			V
Static Drain to Source on Resistance	R <sub>DS(on)</sub>	I <sub>D</sub> =1A		430		mΩ
<b>Supply Management Section</b>						
VCC UVLO Rising	V <sub>CC_ON</sub>		15.5	17.2	19.9	V
VCC UVLO Falling	V <sub>CC_OFF</sub>		6	7.3	8.4	V
VCC UVLO Hysteresis	V <sub>CC_HYST</sub>		8.5	10	11.2	V
VCC Startup Current	I <sub>STARTUP</sub>		2	5	8	uA
VCC Normal Operating Current	I <sub>OP</sub>	COMP=2V	0.3	0.6	1.5	mA
Burst Operating Current	I <sub>BURST</sub>	COMP=0V, GATE=1nF to GND	240	290	340	uA
VCC OVP Threshold	V <sub>CC_OVP</sub>		87	93	100	V
VCC Clamp Threshold	V <sub>CC_CLAMP</sub>		89	102	110	V
<b>Comp Input Section</b>						
COMP Open Voltage	V <sub>COMP_OP</sub>	COMP Pin Open-circuited	4	4.4	4.8	V
COMP Short-Circuit Current	I <sub>COMP_SHOR</sub> T	COMP=0V	130	160	190	uA
Burst Mode Entry Voltage	V <sub>BM_ET</sub>		0.27	0.30	0.33	V
Burst Mode Hysteresis	V <sub>BM_HY</sub>		0.02	0.05	0.09	V
OPP Protection Threshold	V <sub>OPP</sub>		2.8	3.0	3.2	V
OPP Deglitch Time*	T <sub>D_OPP</sub>			T <sub>SS</sub> *6		ms
<b>Current Sense Input Section</b>						
Soft Start Time of CS Threshold	T <sub>SS</sub>		4	7	10	ms
Secondary Rectifier Short-Circuit Trigger Voltage (OC FAULT)	V <sub>SR_SH</sub>		1.1	1.2	1.3	V
SR Short-Circuit Deglitch Cycles*				3		cycles
Cycle by Cycle Current Limit (low line)	V <sub>CS_CBCL</sub>	V <sub>FB</sub> <1V, I <sub>FB</sub> =100uA	0.77	0.83	0.89	V

Cycle by Cycle Current Limit (high line)	$V_{CS\_CBCH}$	$V_{FB} < 1V, I_{FB} = 300\mu A$	0.52	0.59	0.66	V
CS Short Protection Threshold	$V_{CS\_SH}$			0.05		V
CS Short Deglitch Cycles*	$T_{CS\_SH}$			3		cycles
<b>FB Input Section</b>						
Brown-in Detection Threshold	$I_{BNI}$		78	94	109	$\mu A$
Brown-out Detection Threshold	$I_{BNO}$		69	85	100	$\mu A$
Brown-out Deglitch Time*	$T_{BL\_BNO}$			$T_{SS} * 7$		ms
FB OVP Threshold	$V_{FB\_OVP}$		3.3	3.6	3.9	V
FB OVP Deglitch Time*	$T_{BL\_OVP}$			7		
FB UVP Threshold (Output Short)	$V_{FB\_ST}$		0.27	0.30	0.33	V
FB UVP Threshold (Output Short) Deglitch Time*	$T_{BL\_ST}$			7		cycles
UVP Blanking Time after SS*	$T_{D\_ST}$			$T_{SS} * 2$		ms
FB High Threshold	$V_{FB\_H}$		1.7	1.9	2.1	V
FB Middle Threshold	$V_{FB\_M}$		1	1.1	1.2	V
<b>Control Law</b>						
Normal Mode Frequency	$F_{SW\_max}$		110	130	150	kHz
Green Mode Frequency	$F_{SW\_green}$		21	25	29	kHz
Dithering Range*				$\pm 6$		%
Dithering Period*				8		ms
Maximum Toff Time	$T_{off\_MAX}$		80	110	140	$\mu s$
Thermal Shutdown Threshold*	$Th_{SD}$			155		$^{\circ}C$
Thermal Shutdown Hysteresis*	$Th_{SD\_hys}$			30		$^{\circ}C$

**Note:**

\* Guaranteed by design

## 10. Operation Descriptions

### VCC and Start-up

The MK2788S's start-up current  $I_{STARTUP}$  is only  $\sim 5\mu A$ , allowing the use of a high-value start-up resistor to charge up VCC while minimizing power loss during start-up. Once VCC reaches above the  $V_{CC\_ON}$  ( $\sim 17.2V$ ) threshold, the MK2788S starts switching.

### Soft Start

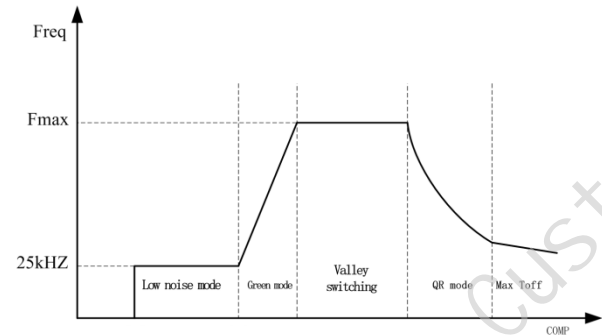
The MK2788S features an internal soft start with  $T_{SS}$  ( $\sim 7ms$ ) to reduce electrical stress in the power system during start-up. To further reduce voltage stresses caused by high peak currents and high frequency switching, the MK2788S operates at optimized frequencies and control modes accordingly to the output voltages and the start-up status of the synchronous rectifier controller.

### External Driving Modulating (EM)

The resistor and diode connected between the EM pin and CS pin are used to modulate the driving speed of the internal GaN. Specifically, the resistor affects the turn-on speed, while the diode ensures the turn-off speed as fast as possible. A common range for this resistor selection is 0 to 47 ohms.

### Operation Curve

The MK2788S has multiple working modes, which can be switched by monitoring the voltage change of the COMP pin. Since the voltage change of COMP is consistent with the load change, the MK2788S can automatically switch to the optimal operating mode according to different load conditions. The operation curve of the MK2788S operating mode is shown in Figure 2:



**Figure 2 Operation Curve**

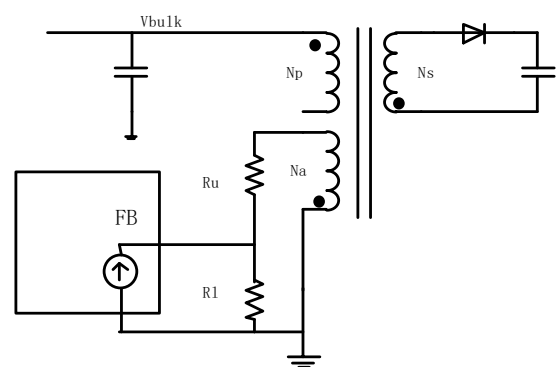
### Brown in/ Brown out

When the power GaN is turned on, the voltage at auxiliary windings is negative, which makes Brown-in/Brown-out protection feasible by detecting the current at FB pin. When the system starts up, and the power GaN is turned on, the current flowing out of FB pin is equal to:

$$\frac{V_{BULK} * N_a}{R_u * N_p}$$

If this current is larger than  $I_{BNI}$  for four switching cycles, the controller enables soft start. Otherwise, Brown-in restart protection is triggered.

During normal operation, if the current at FB is less than  $I_{BNO}$  for at least  $T_{BL\_BNO}$  ( $\sim 49ms$ ), the controller enters Brown-out restart protection.



**Figure 3 Brown in/Brown out**

## Current Sense

The MK2788S is current mode PWM controller. The voltage detected on CS pin is compared with the voltage loop feedback voltage inside the chip to determine the duty ratio. When COMP is at its maximum, the MK2788S also limits the peak current of the primary edge every switching cycle, and its maximum current limit value is  $V_{CS\_CBC}/R_{CS}$ .

Due to the voltage of the drive current on the CS resistance and the influence of the converted capacitor  $C_{SW}$  on the drain node, there will be a spike in the CS resistance at the moment when the driver is switched on. This spike could trigger PWM controller to falsely generate very narrow duty cycle pulse. Therefore, the leading-edge blanking time  $\sim 300\text{ns}$  was added to the CS sampling circuit inside the chip.

## Line Compensation

The MK2788S uses the detected input line voltage through the current at FB pin to generate the offset voltage added on internal current signal to compensate the output OPP power level. This mechanism helps to achieve flat OPP power level over different input voltage.

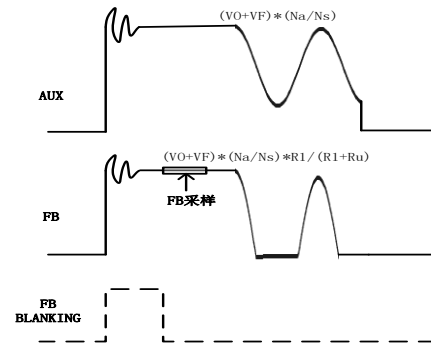
## Voltage Feedback Loop

COMP is the voltage loop feedback pin which is connected to TL431 output through opto-coupler. In order to support a wide COMP range, a ratio of 1/2.5 resistor divider is used before it goes into PWM comparator.

A ceramic capacitor is suggested to be placed parallel to the resistor which is in series with opto-coupler diode.

## FB Voltage Detection

The MK2788S detects the transformer core demagnetization by monitoring the signal at the auxiliary windings through FB pin.



**Figure 4 FB Detection**

After a period of demagnetization time ( $\sim 1.4\mu\text{s}$ ) of the transformer, the FB sampling voltage is compared with different thresholds. The MK2788S can complete the following functions:

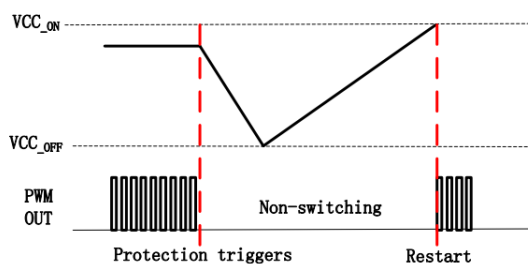
1. Output over voltage protection (OVP): FB is above  $V_{FB\_OVP}$  ( $\sim 3.6\text{V}$ ) for 7 switching cycles;
2. Output under voltage protection (output short circuit protection): FB is below  $V_{FB\_ST}$  ( $\sim 0.3\text{V}$ ) for 7 switching cycles;
3. Based on the detected output voltage, the operating control curve is determined.

## Valley Switching

After secondary side rectification is complete, the drain voltage starts oscillating with a frequency of approximately  $\frac{1}{2} \pi \sqrt{C_{OSS} \times L_p}$ , where  $L_p$  is the inductance of primary winding of the transformer and  $C_{OSS}$  is capacitance on the drain of primary GaN. When the oscillation ringing is below 0V at the auxiliary winding, the MK2788S clamps the FB pin to 0V, and senses the current at the FB pin. When the current out of FB reaches a designed value, a "possible" valley is locked and the MK2788S turns on after propagation delay.

## Protection Function

Reliable power supply system is achieved with restart protections including cycle-by-cycle current limit, over-power protection (OPP), output over-voltage protection, etc. Detailed protection features are described in the following sessions. Once the protection triggers, MK2788S will stop the drive, and the VCC discharge current makes the VCC capacitor voltage drop. When the VCC voltage drops to  $V_{CC\_OFF}$  ( $\sim 7.3V$ ), the VCC capacitor starts charging and reaches  $V_{CC\_ON}$  ( $\sim 17.2V$ ), restarting the drive and completing the restart.



**Figure 5 Restart Mode**

MK2788S Protection Features	MK2788S Protection Schemes
OPP	Restart
VO_OVP	Restart
VCC_OVP	Restart
CS_SHORT	Restart
SSCP	Restart
FB_UVP (VO_SCP)	Restart

## Over Power Protection

The OPP protection is achieved by monitoring COMP voltage. If COMP voltage is above  $V_{OPP}$  ( $\sim 3V$ ) for at least 6 times of soft-start time, i.e.  $T_{ss} \times 6$  ( $\sim 42ms$ ), the MK2788S enters restart mode.

## Cycle by Cycle Current Limiting

The current-mode controller compares the CS signal with the COMP signal cycle-by-cycle. However, during an output short circuit or an

open opto-coupler fault, the COMP voltage can rise excessively, leading to high peak currents and transformer saturation. To mitigate this, the MK2788S implements an additional protection scheme, which compares the CS voltage with  $V_{CS\_CBC}$  cycle-by-cycle. After the blanking time of approximately 300ns, if the CS voltage reaches  $V_{CS\_CBC}$ , the chip immediately halts the driver output.

## Secondary Side SR Short Circuit Protection

If the secondary side synchronous rectifier is short circuited, the peak current increases rapidly after the power GaN is turned on. Therefore, the protection is needed to react in much less wait time. The MK2788S reduces current sense blanking time to 90ns when the CS pin detects a voltage above  $V_{SR\_SH}$  ( $\sim 1.2V$ ) threshold. It immediately stops the driver output. If this condition persists for three consecutive cycles, the MK2788S determines that a secondary SR short circuit has occurred, and it stops the driver and enters the restart mode.

## CS Short Protection

If CS still fails to reach  $V_{CS\_SH}$  ( $\sim 0.05V$ ) after 5us of primary GaN turning on, the MK2788S will force drive shutdown. If this condition occurs for three consecutive periods, the MK2788S enters restart mode.

## VCC OVP

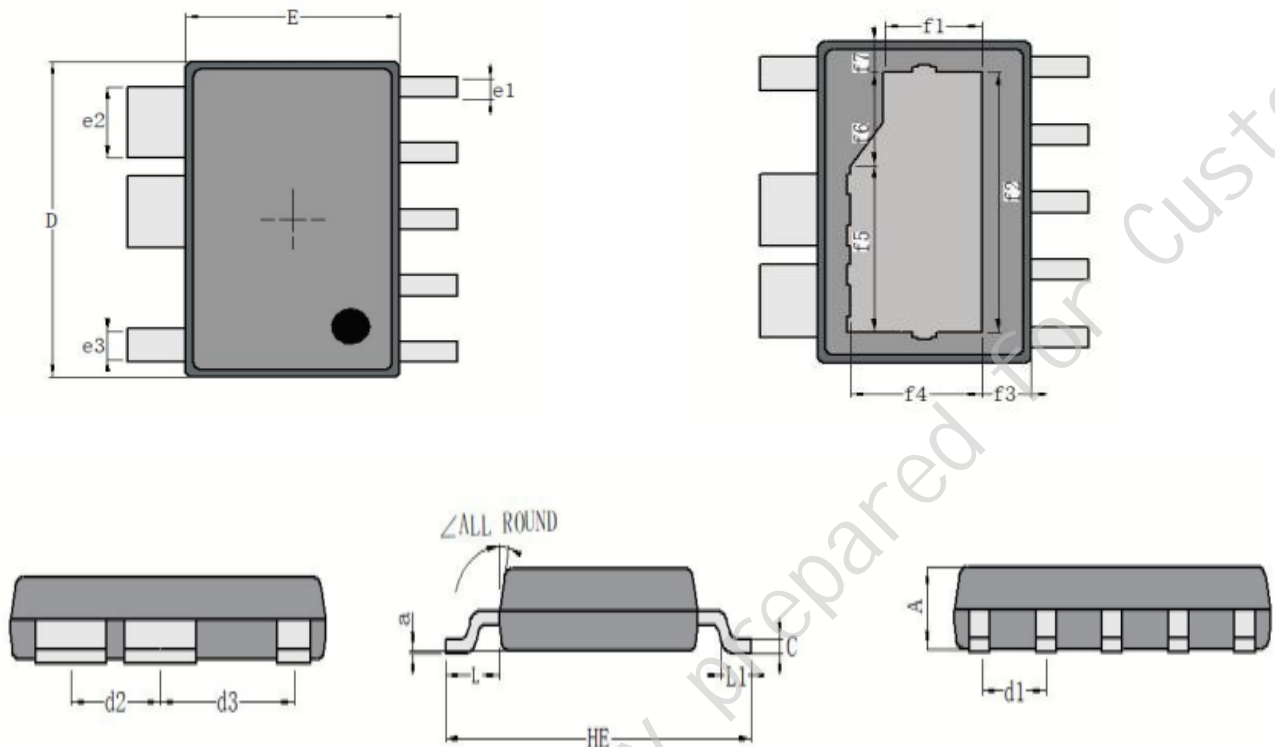
Whenever the VCC voltage is higher than the OVP threshold voltage  $V_{CC\_OVP}$  ( $\sim 93V$ ), the output gate drive circuit will be shut down to stop the switching of the power GaN, and the MK2788S enters the restart mode.

## OTP

The MK2788S provides internal over-temperature protection with a trigger point of  $\sim 155^{\circ}C$  and a hysteresis temperature of  $\sim 30^{\circ}C$ .



## 11. Package Information (ESOP-7)



Symbol	Dimensions In Millimeters		
	MIN	NOM	MAX
A	1.05	1.15	1.25
C	0.15	0.20	0.25
D	6.00	6.20	6.40
E	3.70	3.90	4.10
HE	5.90	6.00	6.10
d1	1.25	1.30	1.35
d2	1.70	1.75	1.80
e1	0.35	0.40	0.45
e2	1.35	1.40	1.45
L	0.95	1.05	1.15
L1	0.40	/	0.80
a	0.00	/	0.20
∠	12°		

**Note:**

Unit: Millimeter(mm)