

## Single-Stage Power Factor Correction Dimmable LED Driver with 3.3V Voltage Regulator Output

### DESCRIPTION

The TS19820 is a single-stage active power factor correction (PFC) switch-mode power supply IC supporting high PF over a wide AC input voltage range. Output current modulation dimming is controlled from a dedicated pin capable of either PWM or linear analog signal input. The TS19820 achieves high accuracy line- and load-regulation in discontinuous conduction mode (DCM) architecture. Output switching regulation is controlled with pulse frequency modulation (PFM) which is particularly suited for high conversion efficiency and high PF even at low output power levels. The TS19820 also features a 3.3V LDO output for MCU applications. Integrated protection features such as an external switching MOSFET gate drive voltage clamp,  $V_{CC}$  over-voltage protection, and system output open/short circuit protection increase system reliability.

### FEATURES

- Supports PWM & Linear dimming
- Embedded 3.3V LDO output for MCU
- Low cost BOM
- High Power Factor >0.9
- Pulse Frequency Modulation (PFM) Control
- Discontinuous Conduction Mode Control
- No Opto-Coupler Required
- Gate output voltage clamp
- LED open and short protection
- Over Current Protection (OCP)
- Internal Over Temperature Protection (OTP)
- Low start-Up current
- Compliant to RoHS Directive 2011/65/EU and in accordance to WEEE 2002/96/EC.
- Halogen-Free according to IEC 61249-2-21

### APPLICATION

- Smart LED lighting
- Infrared remote control light
- Motion sensing LED light

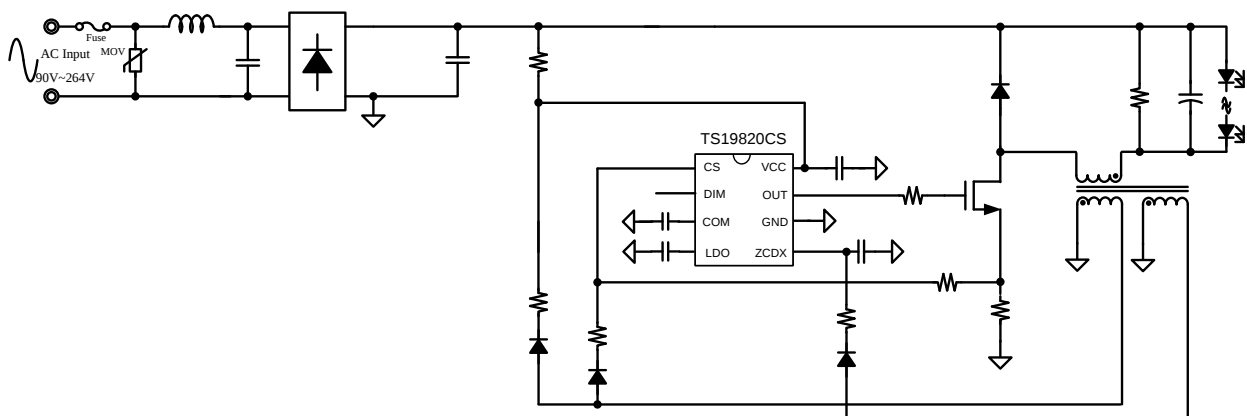


#### Pin Definition:

- |        |             |
|--------|-------------|
| 1. CS  | 8. $V_{CC}$ |
| 2. DIM | 7. OUT      |
| 3. COM | 6. GND      |
| 4. LDO | 5. ZCDX     |

**Notes:** MSL 3 (Moisture Sensitivity Level) per J-STD-020

### TYPICAL APPLICATION CIRCUIT



| <b>ABSOLUTE MAXIMUM RATINGS</b> ( $T_A = 25^\circ\text{C}$ unless otherwise specified) (Note 1) |            |             |                  |
|-------------------------------------------------------------------------------------------------|------------|-------------|------------------|
| PARAMETER                                                                                       | SYMBOL     | LIMIT       | UNIT             |
| Power Supply Pin                                                                                | $V_{CC}$   | 40          | V                |
| DIM Voltage to GND                                                                              | $V_{RT}$   | -0.3 to 5.5 | V                |
| OUT Voltage to GND                                                                              | $V_{OUT}$  | -0.3 to 40  | V                |
| CS Voltage to GND                                                                               | $V_{CS}$   | -0.3 to 5.5 | V                |
| ZCDX Voltage to GND                                                                             | $V_{ZCDX}$ | -0.3 to 40  | V                |
| LDO Voltage to GND                                                                              | $V_{LDO}$  | -0.3 to 5.5 | V                |
| COM Voltage to GND                                                                              | $V_{COM}$  | -0.3 to 5.5 | V                |
| Operating Temperature Range                                                                     | $T_{OPR}$  | -40 to 105  | $^\circ\text{C}$ |
| Junction Temperature Range                                                                      | $T_J$      | -40 to +150 | $^\circ\text{C}$ |
| Storage Temperature Range                                                                       | $T_{STG}$  | -65 to +150 | $^\circ\text{C}$ |
| Lead Temperature (Soldering 10 sec)                                                             | $T_{LEAD}$ | 260         | $^\circ\text{C}$ |
| Power Dissipation @ $T_A = 25^\circ\text{C}$                                                    | $P_D$      | 0.6         | W                |
| ESD Rating (Human Body Mode) (Note 2)                                                           | HBM        | 2           | kV               |
| ESD Rating (Machine Mode)                                                                       | MM         | 200         | V                |

| <b>THERMAL PERFORMANCE</b>               |                 |       |                    |
|------------------------------------------|-----------------|-------|--------------------|
| PARAMETER                                | SYMBOL          | LIMIT | UNIT               |
| Thermal Resistance - Junction to Case    | $R_{\theta JC}$ | 50    | $^\circ\text{C/W}$ |
| Thermal Resistance - Junction to Ambient | $R_{\theta JA}$ | 208   | $^\circ\text{C/W}$ |

| <b>RECOMMENDED OPERATING CONDITIONS</b> (Note 3) |            |             |                  |
|--------------------------------------------------|------------|-------------|------------------|
| PARAMETER                                        | SYMBOL     | LIMIT       | UNIT             |
| Power Supply Pin                                 | $V_{CC}$   | 20          | V                |
| DIM Voltage to GND                               | $V_{OTP}$  | -0.3 to 5   | V                |
| OUT Voltage to GND                               | $V_{OUT}$  | -0.3 to 19  | V                |
| CS Voltage to GND                                | $V_{CS}$   | -0.3 to 5   | V                |
| COM Voltage to GND                               | $V_{COM}$  | -0.3 to 5   | V                |
| ZCDX Voltage to GND (Note 3)                     | $V_{ZCDX}$ | 3.5 to 20   | V                |
| Operating Junction Temperature Range             | $T_J$      | -40 to +125 | $^\circ\text{C}$ |
| Operating Ambient Temperature Range              | $T_{OPA}$  | -40 to +85  | $^\circ\text{C}$ |

**ELECTRICAL SPECIFICATIONS** ( $V_{CC} = 18V$ ,  $T_A = 25^\circ C$  unless otherwise noted)

| PARAMETER                                            | CONDITIONS                                       | SYMBOL          | MIN  | TYP  | MAX  | UNIT       |
|------------------------------------------------------|--------------------------------------------------|-----------------|------|------|------|------------|
| <b>Supply Voltage</b>                                |                                                  |                 |      |      |      |            |
| Start-up Current                                     | $V_{CC} = V_{UVLO(ON)} - 1V$                     | $V_{CC(ST)}$    | --   | 57   | --   | $\mu A$    |
| Operating Current                                    | With 1nF load on out pin                         | $I_{OPA}$       | --   | 2    | 2.6  | mA         |
| Under Voltage Lock Out (off)                         |                                                  | $V_{UVLO(off)}$ | 6.5  | 8    | 9.5  | V          |
| Under Voltage Lock Out (on)                          |                                                  | $V_{UVLO(ON)}$  | 16   | 17.5 | 19   | V          |
| OVP Level on $V_{CC}$ Pin                            |                                                  | $V_{OVP}$       | 30.5 | 32   | 33.5 | V          |
| <b>Voltage Feedback</b>                              |                                                  |                 |      |      |      |            |
| Feedback Reference Voltage                           |                                                  | $V_{FB}$        | 0.19 | 0.2  | 0.21 | V          |
| <b>Current Sensing</b>                               |                                                  |                 |      |      |      |            |
| CS Limit Voltage                                     |                                                  | $V_{OCP}$       | --   | 1.0  | --   | V          |
| Leading-Edge Blanking Time                           |                                                  | $LEB_t$         | --   | 280  | --   | Ns         |
| <b>Switching Frequency</b>                           |                                                  |                 |      |      |      |            |
| Start Frequency                                      |                                                  | $f_{STR}$       | 3    | 4.5  | 6    | kHz        |
| <b>Low Drop Out regulator</b>                        |                                                  |                 |      |      |      |            |
| Reference Voltage                                    | $V_{ZCDX} = 10V$ , $I_o = 30mA$                  | $V_{LDO}$       | 3.1  | 3.3  | 3.5  | V          |
| Load Regulation                                      | $V_{ZCD} = V_o + 6.7V$<br>$I_o = 10mA \sim 30mA$ | $REG_{LOAD}$    | --   | 0.6  | --   | %          |
| Line Regulation                                      | $V_o + 2.7V < V_{ZCDX} < 40V$<br>$I_o = 10mA$    | $REG_{LINE}$    | --   | 0.3  | --   | %          |
| <b>Gate Driver Output</b>                            |                                                  |                 |      |      |      |            |
| Rising Time                                          | Load Capacitance = 1nF                           | $t_{RISE}$      | --   | 240  | --   | ns         |
| Falling Time                                         | Load Capacitance = 1nF                           | $t_{FALL}$      | --   | 120  | --   | ns         |
| VGATE-Clamp                                          |                                                  | $V_{GATE}$      | --   | 12.5 | --   | V          |
| <b>DIM Function (PWM-D/Linear-D)</b>                 |                                                  |                 |      |      |      |            |
| PWM Dimming Input High Voltage Threshold             |                                                  | $V_{OH}$        | 2.5  | --   | --   | V          |
| Linear Dimming Threshold for 100% Current Regulation |                                                  | $V_{MAX}$       | --   | --   | 1.6  | V          |
| <b>Thermal Section</b>                               |                                                  |                 |      |      |      |            |
| Thermal Shutdown (Note 4)                            |                                                  |                 | --   | 165  | --   | $^\circ C$ |
| Thermal Shutdown Release (Note 5)                    |                                                  |                 | --   | 120  | --   | $^\circ C$ |

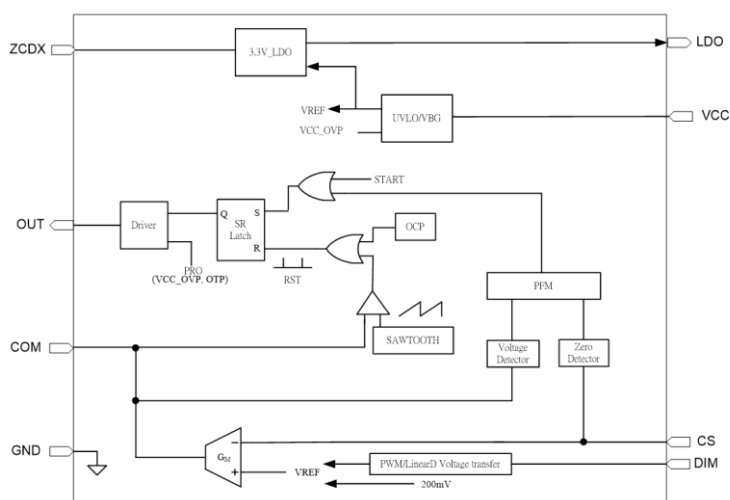
**Note:**

- Stresses listed as the above "Absolute Maximum Ratings" may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.
- Devices are ESD sensitive. Handling precaution recommended.
- The product dropout voltage and output current should not exceed the maximum power dissipation
- The device is not guaranteed to function outside its operating conditions.
- Guaranteed by design.
- Auto Recovery Type.

## ORDERING INFORMATION

| ORDERING CODE | PACKAGE | PACKING            |
|---------------|---------|--------------------|
| TS19820CS RLG | SOP-8   | 2,500pcs / 13"Reel |

## FUNCTION BLOCK



## PIN DESCRIPTION

| PIN NO. | NAME            | FUNCTION                                     |
|---------|-----------------|----------------------------------------------|
| 1       | CS              | Input current sense pin                      |
| 2       | DIM             | PWM/Linear DIMMING voltage input             |
| 3       | COM             | Output pin of error amplifier                |
| 4       | LDO             | 3.3V LDO output                              |
| 5       | ZCDX            | Auxiliary Winding input for LDO power supply |
| 6       | GND             | Ground return for all internal circuitry     |
| 7       | OUT             | Gate driver output                           |
| 8       | V <sub>CC</sub> | Power supply pin for all internal circuitry  |

## PIN FUNCTION DESCRIPTION

### CS pin:

CS pin provides the LED current feedback function,  $I_{OUT}$  and  $R_S$  formula as below

$$R_S = \frac{0.2V}{I_{OUT}}$$

Where :

- $R_S$  is the resistance
- 0.2 is a V reference for electric potential
- $I_{OUT}$  is the current output

Also, CS pin provides over-current protection (OCP), over-current  $I_{CS}$  (Limit) and  $R_S$  formula as below:

$$I_{CS(limit)} = \frac{1}{R_S}$$

Where :

- $I_{CS(Limit)}$  is a current sense
- 1 is a voltage value for OCP
- $R_S$  is the resistance

### DIM pin:

Output current modulation dimming can be controlled from either PWM or linear analog signal input on a dedicated pin. The linear dimming range is an analog voltage from 0V to 1.6V. The PWM dimming range is larger than 2.5V . PWM dimming control is a function of the duty cycle of external PWM signal.

### COM pin:

The most important design is compensation circuit for PFC control loop. It achieves high PFC and low total harmonic distortion (THD) function. In order to remain  $V_{COM}$  is a constant value in every cycle we usually set the bandwidth under 10Hz. We recommend using 1 $\mu$ F capacitor in typ. design. If the system specification comes with higher output voltage or large output capacitor, ensure the  $V_{CC}$  voltage above  $UVL_{(off)}$ . If not the system will fail to start or blinking or flickering.  $V_{COM}$  level determine Switch-on time ( $t_{ON}$ ). In order to avoid malfunction that recommend operating range between 1 $\mu$ s ~ 14 $\mu$ s.

### LDO pin:

Provide 3.3V to MCU power supply.

### ZCDX pin:

Auxiliary Winding input for LDO power supply.

### GND pin:

GND is the reference node of internal circuit.

### OUTPUT pin:

OUT pin has internal built-in a voltage clamp circuit. 12.5V is the maximum clamping voltage, when  $V_{CC}$  is over 12.5V which OUT pin will be clamped under 12.5V. This function is avoided the output voltage too high and damaged the MOSFET gate

### $V_{CC}$ pin:

$V_{CC}$  pin has built-in three levels. Such as :

Start voltage level ( $V_{CC\_ON}$ ), Cutoff voltage level ( $V_{CC\_OFF}$ ), Over-voltage protection level ( $V_{OVP}$ ).

When  $V_{CC}$  voltage over  $V_{CC\_ON}$  level, IC will work in the system. When  $V_{CC}$  voltage over OVP level (31.5V Typ.), IC will shut down and goes into "Hiccup" mode. The IC operating between  $UVLO_{(ON)}$  and  $UVLO_{(OFF)}$ , 8 times per cycle until the OVP condition is removed.

## APPLICATION INFORMATION

### Functional Description

The TS19820 is a single stage Buck PFC controller. It adopts the proprietary control architecture to achieve an accurate regulation of LED current, unity power factor, and quasi-resonant valley plus time delay adjust turn-on operation. High power factor is achieved by constant on-time operation mode, which the control scheme and the circuit structure are both simple.

According to the following formula, assume Switch-on time ( $t_{ON}$ ) is a constant, inductor peak current ( $I_{L_{pk}}$ ) and the AC input voltage will become a linear relationship in half sine wave shape. Thus we can estimate " $I_{IN_{pk}}$ " will also be a sine wave shape to achieve high power factor and reduce inductance in DCM mode.

$$V = L \frac{di}{dt} \Rightarrow \frac{V}{L} = \frac{I_{L_{pk}}}{t_{on}} \Rightarrow I_{L_{pk}} = \frac{V}{L} t_{on}$$

Where :

- V : Voltage
- L : Inductor
- di : Differential to current
- dt : Differential to time
- $I_{L_{pk}}$  : Peak of current and inductance
- $t_{ON}$  : Constant On-time

TS19820 operates in discontinues conduction mode (DCM) as shown in Figure 1. Switching point is controlled by CS voltage, and the frequency is changing with the input instantaneous line voltage. General suggestion is used 40kHz ~150kHz by switching frequency in system that obtain better performances. The max on time is 13 $\mu$ s ~ 14 $\mu$ s .CS pin detect MOSFET current from CS resister. TS19820 can control the output average current accurately regardless of any changes about AC input voltage and output voltage (LED  $V_F$ ).

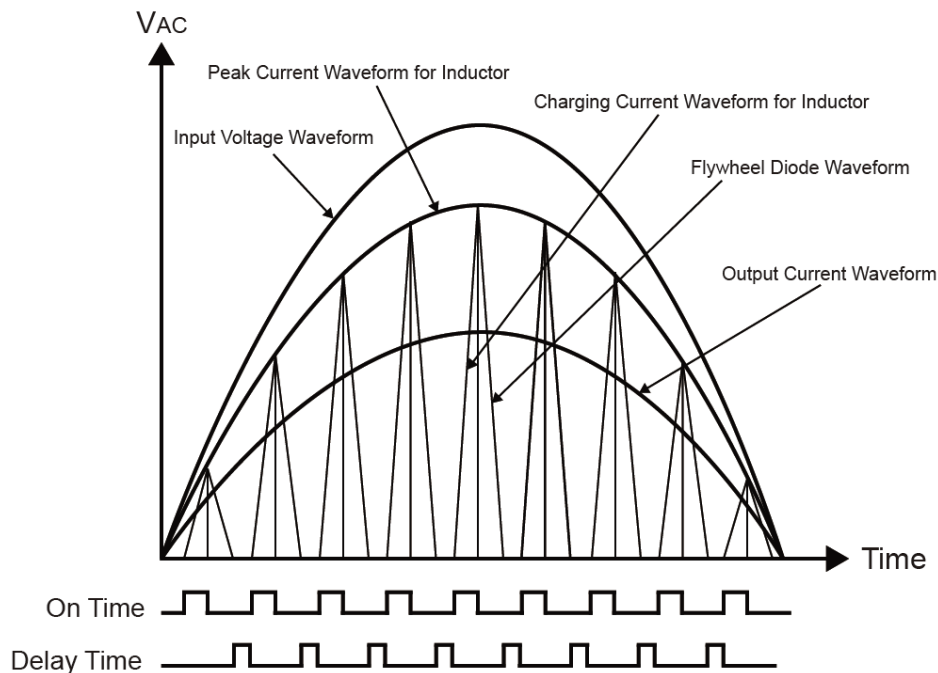
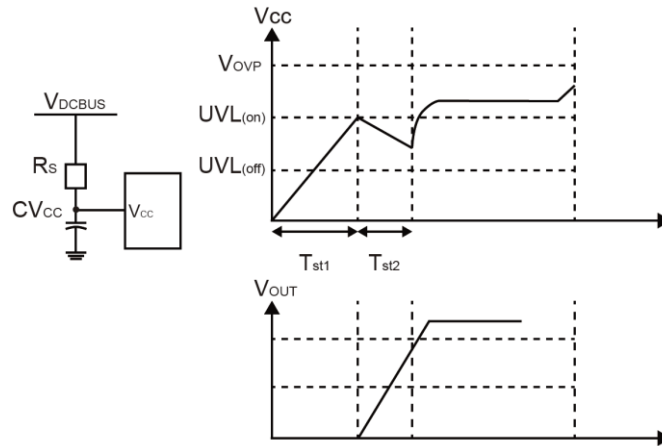


Figure 1: Constant on-time diagram

## APPLICATION INFORMATION (CONTINUE)

### Start-up

After AC supply or DC BUS is powered on, the capacitor  $CV_{CC}$  across  $V_{CC}$  and GND pin is charged up by DC BUS voltage through a start-up resistor  $R_S$ . Once  $V_{CC}$  rises up to  $UVLO_{(ON)}$ , the internal blocks start to work. The whole start up procedure is divided into two sections shown in Fig.2.  $T_{st1}$  is the  $CV_{CC}$  charged up section, and  $T_{st2}$  is the output voltage built-up section. The start-up time  $T_{st}$  composes of  $T_{st1}$  and  $T_{st2}$ , and usually  $T_{st1}$  is much larger than  $T_{st2}$ .



The start-up resistor  $R_S$  and  $CV_{CC}$  are designed by rules below:

- (a) Preset start-up resistor  $R_S$ , make sure that the current through  $R_S$  is larger than  $I_{ST}$   
Where  $I_{ST}$  is the Start-up Current.

$$\frac{V_{DcBus}}{I_{vcc\_ovp}} < R_S < \frac{V_{DcBus}}{I_{st}}$$

- (b) Select  $CV_{CC}$  to obtain an ideal start up time  $T_{st}$ , and ensure the output voltage is built up.

$$UVLO_{(ON)} = V_{DCBUS} * (1 - e^{-T_{st1} / (R_S * CV_{CC})})$$

- (c) If the  $CV_{CC}$  is not big enough to build up the output Increase  $CV_{CC}$  and decrease  $R_S$ , go back to step (a) and redo such design flow until the ideal start up procedure is obtained.

### Constant current control

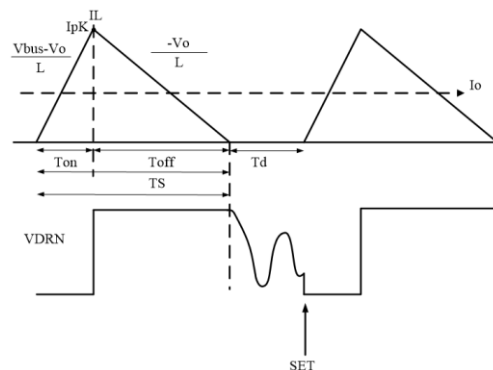


Figure 2

The switching waveforms are shown in Fig.2. The output current  $I_{OUT}$  can be represented by:

$$\frac{1}{2} * I_{pk} * (T_{on} + T_{off}) = I_{out} \quad (1)$$

## APPLICATION INFORMATION (CONTINUE)

Where  $I_{PK}$  is the peak current of the inductor;  $T_s$  is the effective time of inductor current rising and falling;  $T_s + T_d$  is the switching period.

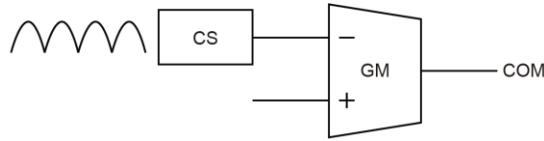


Figure 3

In static state, the positive and negative inputs are equal.

$$\frac{1}{2} * \frac{1}{2} * I_{pk} * (T_{on} + T_{off}) * R_{cs} = V_{ref}$$

According to (1)

Where  $V_{REF}$  is the internal reference voltage,  $R_{CS}$  is the current sense resistor;  $I_{OUT}$  can be programmed by  $R_{CS}$ .

### Over Voltage Protection (OVP) on $V_{CC}$

When the  $V_{CC}$  voltage higher than OVP voltage (31.5V Typ.), the output gate driver circuit will shut down immediately. Then switching is shut down and  $V_{CC}$  goes into “Hiccup” mode,  $V_{CC}$  voltage will gradually be released to  $V_{CC\_OFF}$  (8V Typ.). In this condition the IC operating between  $UVLO_{(ON)}$  and  $UVLO_{(OFF)}$  with eight times per cycle until the OVP condition is removed. The TS19820 is working in an auto-recovery mode as shown in Fig.4

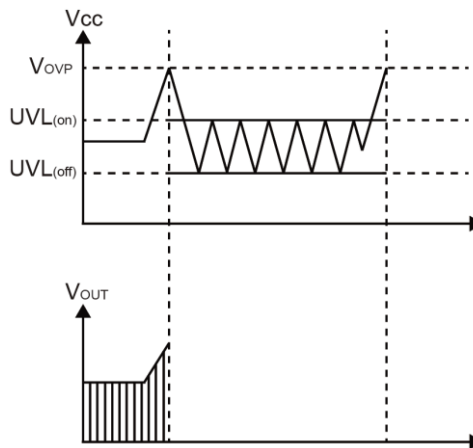


Figure 4

### Over Current Protection (OCP)

TS19820 detects the MOSFET current from CS pin, which is for the cycle-by-cycle current limit and output feedback. The current limit threshold of CS pin is set at 1.0V (Typ.).

### Over Temperature Protection (OTP)

When the IC internal temperature is over 150°C (Thermal Shutdown Typ.), the IC will stop and shut-down output signal which means into OTP status. While the IC internal temperature drops until to 120°C (Thermal Shutdown Release Typ.), the IC will be re-set automatically.

### Short Circuit Protection (SCP)

When the output is shorted, the IC will be automatically shut down. Because of the  $V_{CC}$  power is lost from power supply.

## TYPICAL PERFORMANCE CURVES

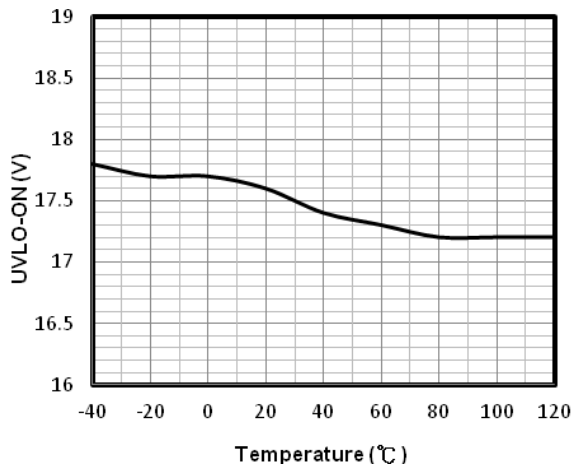


Figure 1. UVLO-ON vs. Ambient Temperature

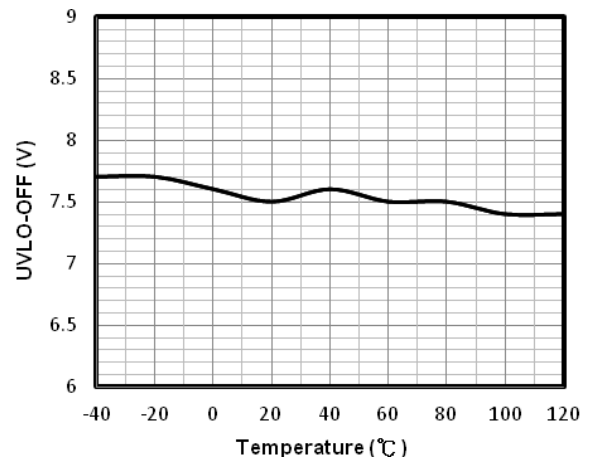


Figure 2 – UVLO-OFF vs. Ambient Temperature

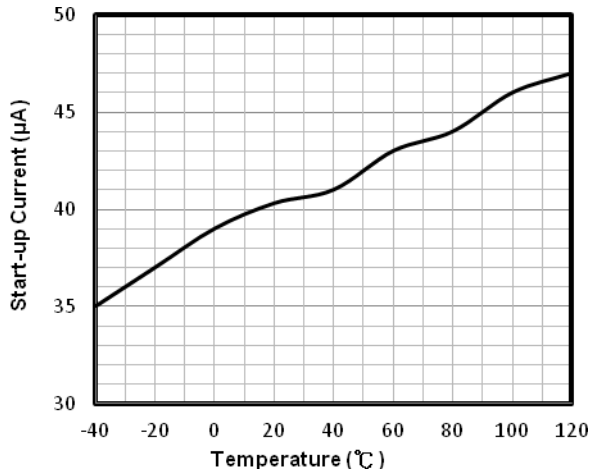


Figure 3 – Start-up Current vs. Ambient Temperature

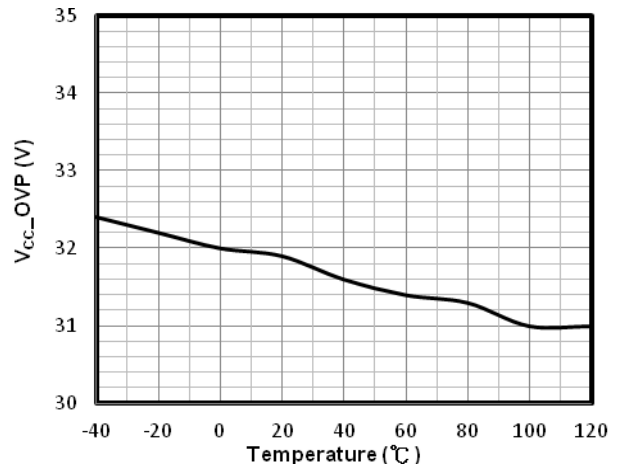


Figure 4 – OVP vs. Ambient Temperature

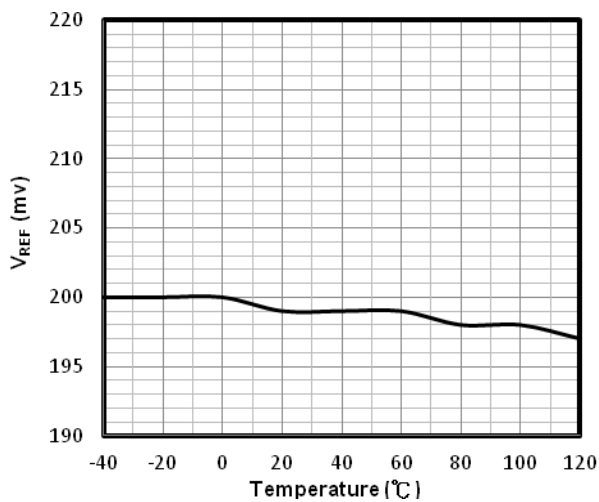


Figure 5– VREF vs. Ambient Temperature

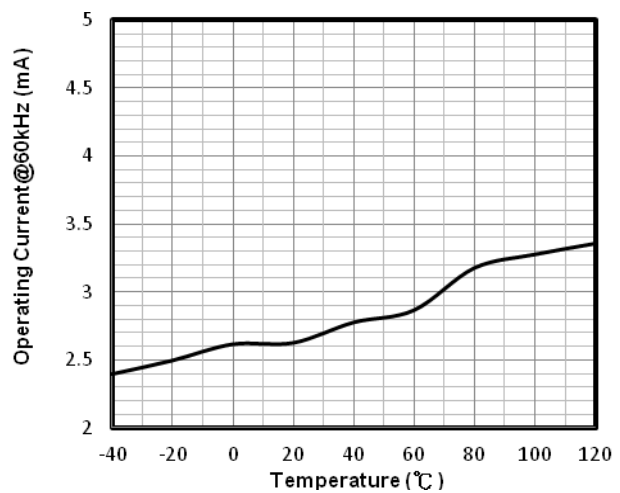


Figure 6 – Operating Current vs. Ambient Temperature

## TYPICAL PERFORMANCE CURVES

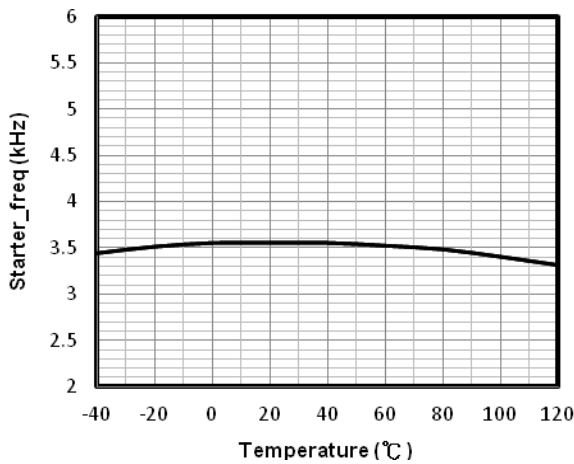


Figure 7– Starter Frequency vs. Ambient Temperature

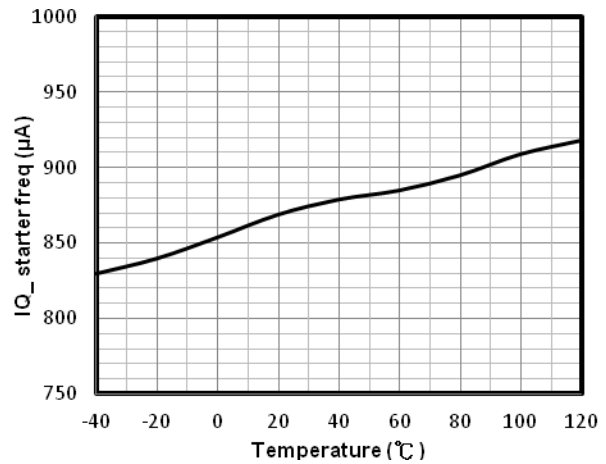


Figure 8 – Operating Current at starter vs. Ambient Temperature

## POWER DEVICE DESIGN

### MOSFET & Diodes

When the operation condition is with maximum input voltage and full load, the voltage stress of MOSFET and output power diode is maximized;

$V_{MOS\_dsmax} = \sqrt{2} V_{ac\_max}$  ,  $V_{diode\_rmax} = \sqrt{2} V_{ac\_max}$  Where  $V_{AC\_max}$  is maximum input AC RMS voltage.

When the operation condition is with minimum input voltage and full load, the current stress of MOSFET and power diode is maximized.

### Inductor (L)

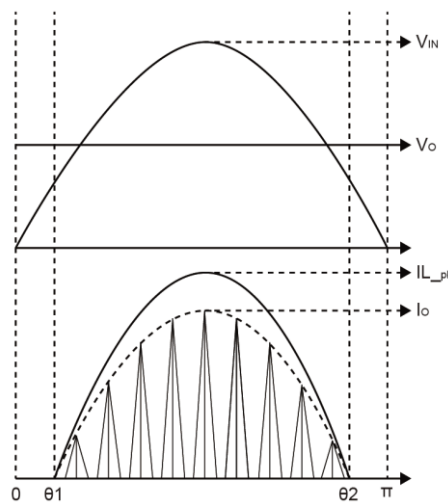


Figure.5

## POWER DEVICE DESIGN (CONTINUE)

In Buck converter when the input voltage is larger than output voltage, the power is transferred from AC input to output. The input voltage and inductor current waveforms are shown in Fig. 5, where  $\theta_1$  and  $\theta_2$  are the time that input voltage is equal to output. In discontinues mode, each switching period cycle  $T_s$  consists of three parts : current rising time  $T_{ON}$ , falling time  $T_{OFF}$  and delay time  $T_d$  shown in Fig.5.

The system operates in the constant on time mode to achieve high power factor. The on time increases with the input AC rms voltage decreasing and the load increasing. When the operation condition is with minimum input AC rms voltage and full load, the on time and CS voltage are maximized. On the other hand when the input voltage is at the peak value, the off time is maximized. IC base on CS voltage adjust  $T_d$  CS voltage high  $T_d$  increase low  $T_d$  decrease. Thus, the minimum switching frequency  $F_{S\_min}$  happens at the peak value of input voltage once the minimum frequency  $F_{S\_min}$  is set, the inductance of the transformer could be calculated. The design flow is shown as below:

(a) Preset minimum frequency  $F_{S\_min}$

(b) Compute relative  $T_c$ ,  $T_{on}$

$$T_c = \frac{1}{F_{S\_min}}, T_{on} = \frac{V_{out} + V_d}{\sqrt{2}V_{AC\_min}} * T_c, T_{off} = T_c - T_{on} - T_d$$

$$\theta_1 = \arcsin\left(\frac{V_{out}}{\sqrt{2}V_{AC\_min}}\right), \theta_2 = \pi - \theta_1$$

(c) Compute inductor maximum peak current

Where  $\eta$  is the efficiency;

$$I_{L\_pk} = 2 * I_{LED} * \pi * \frac{\sqrt{2}V_{AC\_min} - V_o}{\sqrt{2}V_{AC\_min} * (2\cos\theta - \frac{V_o(\pi - 2\theta)}{\sqrt{2}V_{AC\_min}})} * \frac{1}{\eta}$$

(d) Design inductance  $L$

$$L = \frac{(V_{out} + V_D) * T_{off}}{I_{L\_pk}}$$

(e) Compute RMS current of the inductor

$I$  is Inductor RMS current of whole AC period with minimum input AC RMS voltage and maximum load condition meanwhile, the maximum peak current through MOSFET and the transformer happens.

$$I_{L\_RMS} = \frac{T_{on}}{\sqrt{3} * L} * \sqrt{V_{AC\_min}^2 + V_{out}^2 - \frac{4\sqrt{2}V_{AC\_min} * V_{out}}{\pi}}$$

(f) compute RMS current of the MOSFET

$$I_{L\_RMS} = \sqrt{\frac{T_{on}}{3T_s} * \frac{T_{on}}{L} * \sqrt{V_{AC\_min}^2 + V_{out}^2 - \frac{4\sqrt{2}V_{AC\_min} * V_{out}}{\pi}}}$$

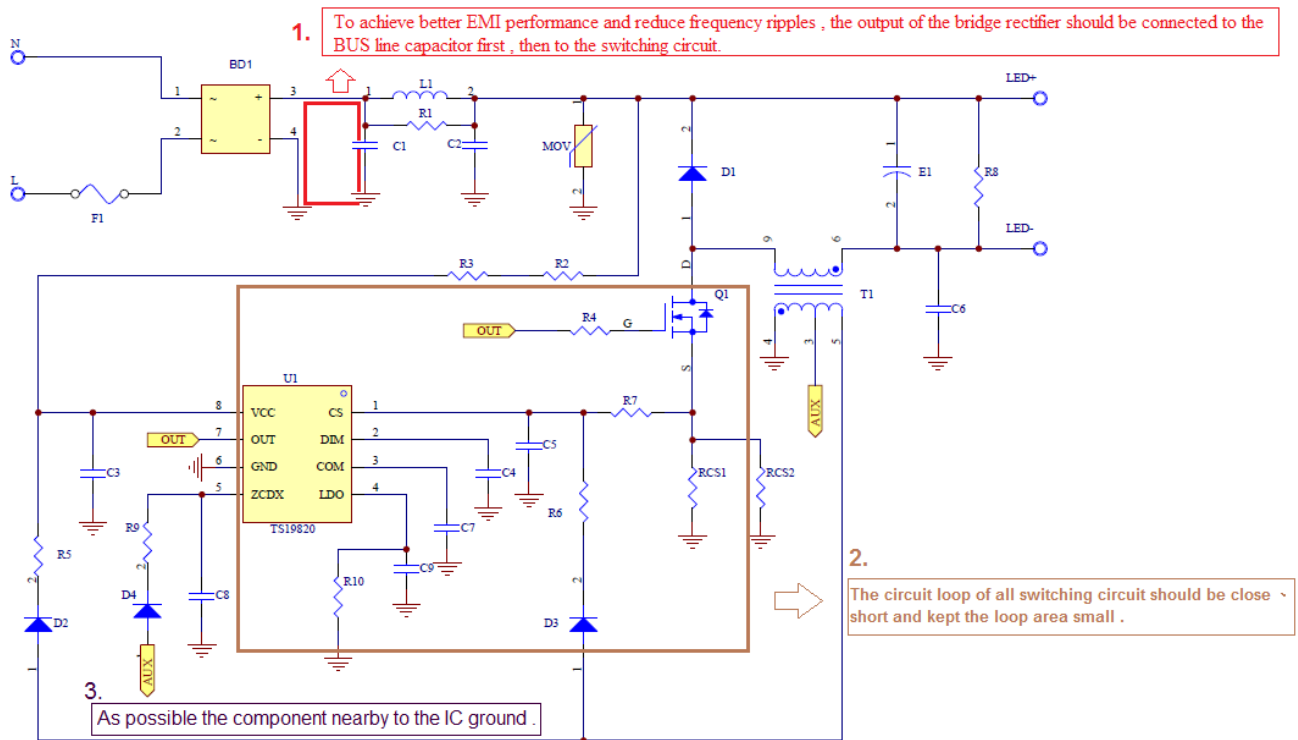
## Output capacitor

Preset the output current ripple  $\Delta I_{OUT}$ ,  $C_{OUT}$  is induced by

$$C_{OUT} = \frac{\sqrt{\left(\frac{2I_{out}}{\Delta I_{out}}\right)^2 - 1}}{4\pi f_{AC} R_{LED}}$$

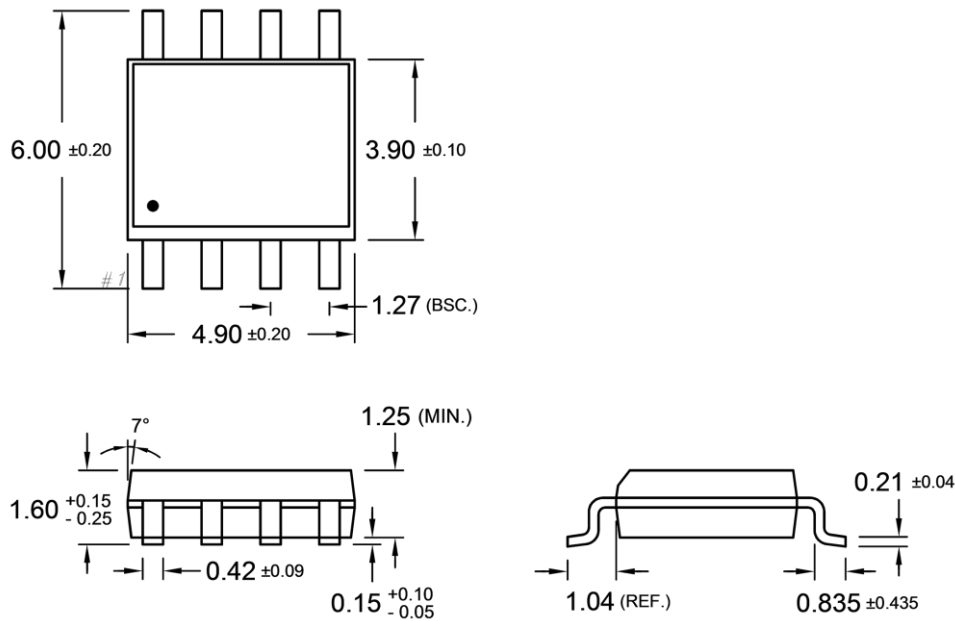
Where  $I_{OUT}$  is the rated output current;  $\Delta I_{OUT}$  is the demanded current ripple;  $f_{AC}$  is the input AC supply frequency;  $R_{LED}$  is the equivalent series resistor of the LED load.

## LAYOUT GUIDE

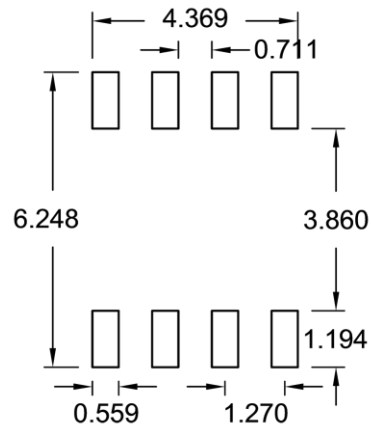


**PACKAGE OUTLINE DIMENSIONS** (Unit: Millimeters)

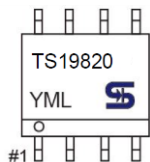
**SOP-8**



**SUGGESTED PAD LAYOUT** (Unit: Millimeters)



**MARKING DIAGRAM**



**Y** = Year Code

**M** = Month Code for Halogen Free Product

**O** =Jan **P** =Feb **Q** =Mar **R** =Apr

**S** =May **T** =Jun **U** =Jul **V** =Aug

**W** =Sep **X** =Oct **Y** =Nov **Z** =Dec

**L** = Lot Code (1~9, A~Z)

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