Outline

- Introduction
- Pin Configuration & Functions
- Bench Test Result
  - Over Voltage Protection (OVP) / Short Circuit Protection (SCP)
  - Soft Start / Hot Switch / Jitter / OTP
  - PWM & Linear Dimming
  - EMI Performance
- Typical Applications
  - Boost
  - Buck-Boost
  - SEPIC
**Introduction**

**General Description**

TS19501CB10H is a single channel LED driver with Low-Side current sensing. The output current regulation is based on average-current-mode-control supervised by a control loop.

This controller supports typical topologies including Boost, Buck-Boost, and SEPIC, and could also be operated in DCM, BCM, and CCM mode. A new control method is adopted for low pin count and BOM cost while it has applied for patent.

To enhance the safety and reliability of the system, the controller provides multiple advanced protection, including over-voltage protection (OVP), short-circuit protection (SCP), cycle-by-cycle current limit (OCP), MOS current protection (MCP), and over-temperature protection (OTP).

Additional features include soft-start (SS), under voltage lock-out (UVLO), PWM & Linear dimming, jitter function for effective spread spectrum, and FLT output for fault diagnosis.

**Feature Summary**

- Low-Side Current Sensing Control
- Applied Topology: Boost, Buck-Boost, and SEPIC
- Operation in CCM, BCM, and DCM Mode
- Low Pin Count & Simple BOM Structure (Patented)
- Input Voltage Range: 4.5V ~ 38V (42V Abs. Max.)
- Internal Voltage Reference: 150mV ±3.3%
- Adjustable Switching Frequency: 70k ~ 700kHz
- PWM & Linear Dimming
- Over Voltage Protection (OVP)
- Short-Circuit Protection (SCP)
- Cycle-by-Cycle Over Current Protection (OCP)
- Over Temperature Protection (OTP)
- Under Voltage Lockout (UVLO)
- MOS Current Protection (MCP)
- Gate Drive Voltage Clamping
- Open Drain Fault Status Flag (FLT)
- Soft-Start to Avoid Inrush Current
- Jitter Function for Better EMI Performance
## Package & Pin Definition

### MSOP-10EP

<table>
<thead>
<tr>
<th>PIN #</th>
<th>Name</th>
<th>Function Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EN</td>
<td>Enable and shut-down pin</td>
</tr>
<tr>
<td>2</td>
<td>DIM</td>
<td>PWM/Linear dimming voltage input</td>
</tr>
<tr>
<td>3</td>
<td>FLT</td>
<td>Open drain output pin for fault status flag</td>
</tr>
<tr>
<td>4</td>
<td>CS</td>
<td>Input current sense pin</td>
</tr>
<tr>
<td>5</td>
<td>COM</td>
<td>Compensation output pin of error amplifier</td>
</tr>
<tr>
<td>6</td>
<td>OVP</td>
<td>Over voltage sensing pin</td>
</tr>
<tr>
<td>7</td>
<td>RT</td>
<td>Connect ext. resistor to GND to set frequency</td>
</tr>
<tr>
<td>8</td>
<td>GND</td>
<td>Ground return for all internal circuitry</td>
</tr>
<tr>
<td>9</td>
<td>VIN</td>
<td>Battery power input pin</td>
</tr>
<tr>
<td>10</td>
<td>OUT</td>
<td>Power MOS output pin</td>
</tr>
</tbody>
</table>

### Application Circuit

**ex. Buck-Boost Regulator**

![Application Circuit Diagram](image-url)
Functional Block Diagram
Outline

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Pin1 (EN)

The EN pin can sense $V_{IN}$ information by voltage divider resister. A 20uA current source, $I_{HYS\_EN}$, provides hysteresis voltage with $R_{ENL}$ or $R_{HYS\_EN}$ resistor when the divider voltage over $V_{EN\_ON}$ (see Figure 1.)

$$V_{IN\_EN} = V_{EN\_ON} \times \left( \frac{R_{ENH} + R_{ENL}}{R_{ENL}} \right)$$

The hysteresis voltage is defined as:

$$V_{HYS\_EN} = I_{HYS\_EN} \times R_{ENH}$$

Pin2 (DIM)

A PWM and linear dimming function is applied in TS19501CB10H. The linear dimming range is an DC voltage 0V~1.6V (Figure 2.) A built-in source current ($I_{DIM}$~10uA) of low temperature coefficient is used for easy voltage setting or linear OTP setting with NTC resistor by the design (Figure 3.). PWM dimming works with the same pin of linear dimming. The current regulation is decided by the duty cycle of the external PWM signal.

$$I_{LED} = \left( \frac{150m}{R_{CS}} \right) \times \left( \frac{I_{DIM} \times R_{DIM}}{1.6} \right)$$

Figure 1. Enable circuit
Pin 3 (FLT)

The device includes an open-drain output to indicate the fault conditions as:

- Over voltage across the LED string \( (V_{OVP} > 3.2 \text{ V}) \)
- Short circuit across the LED string \( (V_{OVP} < 1.5 \text{ V}) \)

As triggered, this pin goes low after 2048 clock cycles while it goes high when the fault condition ends. (Figure 4.)
Pin Configuration & Functions (3/8)

- **Pin 4 (CS)**

The CS pin senses the main MOSFET current to implement average current mode control (ACMC) as long as the cycle-by-cycle current limit for Soft-Start and OCP (Figure 5.). In addition, Leading Edge Blanking (LEB) is built-in for noise immunity as well (Figure 6.). This pin integrates the current signal feedback stable to equal the internal reference voltage (150mV) by the $G_M$ amplifier of $T_{ON}$ and $T_{OFF}$ signal.

The easiest method of generating this signal is to use a current sense resistor between the MOSFET source and ground. The sensing resistor should be selected as:

$$I_{CS(LIMIT)} = \frac{0.8}{R_{CS}} \quad I_{LED_{avg}} = \frac{V_{REF}}{R_{CS}}$$

- $I_{CS(LIMIT)}$ is the input current limit
- $R_{CS}$ is the sensing resistor between the MOSFET source and GND

![Figure 5. Soft-Start & OCP](image1)
![Figure 6. Leading Edge Blanking (LEB) Circuit](image2)
Pin Configuration & Functions  

- **Pin5 (COM)**
  This is the output of the $G_m$ amplifier. Connect with a suitable RC network to the ground.

- **Pin6 (OVP)**
  The output voltage is reflected by inductor voltage. The OVP pin can sense the output information by voltage divider resister to depart from the start-up voltage ($V_{SCP}$) and the protect voltage ($V_{OVP}$) (Figure 7.).

  When the OVP sense voltage gets under $V_{SCP}$ for 8 clock cycles, the short circuit protection (SCP) is triggered (Figure 8.). When the OVP sense voltage is over $V_{OVP}$ for 8 clock cycles, the over voltage protection (OVP) is triggered (Figure 9.). Both of the protections trigger the sustained fault condition, and then the FLT pin goes low for 2048 clock cycles. The device operates in Hiccup-up mode, attempting to recover after every 32768 clock cycles. The output voltage is defined as:

  \[
  V_{O,\text{OVP}} = 3.2 \times \frac{R_{OVPH} + R_{OVPL}}{R_{OVPL}}
  \]

  \[
  V_{O,\text{SCP}} = \left(3.2 \times \frac{R_{OVPH} + R_{OVPL}}{R_{OVPL}}\right) - V_{\text{BAT}}
  \]

  \[
  V_{O,\text{SCP}} = \left(1.5 \times \frac{R_{OVPH} + R_{OVPL}}{R_{OVPL}}\right) - V_{\text{BAT}}
  \]

![Figure 7. Application Circuit of OVP](image_url)
Pin Configuration & Functions

Figure 8. Short circuit protection timing diagram

Figure 9. Over voltage protection timing diagram
The device can operate in DCM, BCM, and CCM mode by the hysteresis comparator design of OVP pin. Figure 10. shows the hysteresis comparator circuit for accuracy sense the $T_{OFF}$.

Sense the voltage of OVP Pin and produce the shift $\Delta V$ for next step reference voltage (S/H) to make sure the switch time of $T_{OFF}$ precisely in wide operation output condition; DCM and BCM mode can follow the current formula (Figure 11.).
Pin Configuration & Functions (7/8)

- **Pin7 (RT)**
  This pin is to program the operation frequency by connecting a resistor to the ground. The reference formula is listed as:

\[
F_S = \frac{I}{0.1n \times R_T}
\]

This formula typical define by the 50KΩ (200KHz), but the operation frequency can not align with the formal in high frequency by the OP bandwidth (Figure 12.).

- **Pin8 (GND)**
  GND is the reference node of internal circuit.

- **Pin9 (VIN)**
  Power supply input for the controller during normal operation. The controller will start up when \(V_{\text{IN}}\) reaches 4.2V (typ.) and will shut-down when \(V_{\text{IN}}\) is below 4.0V (typ.) as \(V_{\text{EN}}\) is over 1.2V. A decoupling capacitor should be connected between the pins of \(V_{\text{IN}}\) and GND as close as possible.

- **Pin10 (OUT)**
  Gate drive for external MOSFET switch. It’s built-in with the gate clamp function (~12V) for the protection of MOSFET gate.

![Figure 12. Frequency vs. Rₚ resistor](image)
Pin Configuration & Functions  (8/8)

Line regulation compensation via the pins of CS and RT

The LEB function can eliminate the noise, but the blanking time (~300nSec) (Figure 6.) decreases the accuracy of LED current as the low duty cycle and high frequency conditions that cause the line regulation worse. Two methods can improve the line regulation as:

1. Compensation by the CS Pin ($R_{LC}$)
   Add a resistor $R_{LC}$ between the pins of VIN and CS to generate the variation current $I_{LC}$ from VIN. The voltage $\Delta V_{LC}$ is the compensation.

   ![Figure 13. Compensation by the CS Pin ($R_{LC}$)](image)

2. Compensation by the RT Pin ($R_{TC}$)
   Add a $R_{TC}$ resistor between the pins of VIN and RT to generate the variation current $I_{TC}$ from VIN. It reduces the operation frequency to minimize the impact by LEB blanking time.

   ![Figure 14. Compensation by the RT Pin ($R_{TC}$)](image)
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- Characteristics of Typical Applications
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  - SEPIC
Bench Test Result (OVP/SCP)

**Over Voltage Protection (V_{OVP}=3.29V)**

- **Duration**: 1ms, 120,000μs
- **Stop**: 1/1

**Short Circuit Protection (Initial short)**

- **Duration**: 50ms, -157, 000ms
- **Stop**: 1/1

**Over Voltage Protection (T=98mSec)**

- **Duration**: 50ms, -120, 000ms
- **Stop**: 3/3

**Short Circuit Protection (Active short)**

- **Duration**: 50ms, -131, 000ms
- **Stop**: 1/1
Bench Test Result (Soft Start / Hot Switch / Jitter / OTP)

**Soft Start**

- Jitter (330KHz ±7.92%) (3.03μS ±240nS)

**Hot Switch**

**Over Temperature Protection**

I<sub>OUT</sub>, OVP, CS

Parameters:
- Soft Start
- Frequency: [221.7ms, 338.3ms, 2.57V]
- Jitter: 330KHz ±7.92%, 3.03μS ±240nS
- Over Temperature Protection (OVP): OUT, CS
Bench Test Result (Dimming)

Dimming Characteristics

**PWM Dimming**

Minimum Dimming = 3% ; IO = 6.4%

**Linear Dimming**

Minimum Dimming = 0% ; IO = 7.6%
EMI Performance – ECE R10 (EMARK) (1/2)

Input: 12V
Output: 18V/1A
30MHz ~ 200MHz

Input: 12V
Output: 18V/1A
200MHz ~ 1000MHz
EMI Performance – ECE R10 (EMARK) (2/2)

Input: 24V
Output: 18V/1A
30MHz ~ 200MHz

Input: 24V
Output: 18V/1A
200MHz ~ 1000MHz
EMI Performance – CISPER25

CISPER25 RE
150kHz ~ 28MHz
Class 3

CISPER25 RE
30MHz ~ 200MHz
Class 3
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Typical Application – Boost

APPLICATION CIRCUIT

TS19501CB10H

IO & Efficiency vs. VIN (20W-36V/0.6A)

On-Time Limit
## System Characteristics – Boost

<table>
<thead>
<tr>
<th>V&lt;sub&gt;IN&lt;/sub&gt;</th>
<th>I&lt;sub&gt;IN&lt;/sub&gt;</th>
<th>V&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>I&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>P&lt;sub&gt;IN&lt;/sub&gt;</th>
<th>P&lt;sub&gt;OUT&lt;/sub&gt;</th>
<th>Efficiency</th>
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<td>1.49</td>
<td>23.13</td>
<td>0.572</td>
<td>14.90</td>
<td>13.230</td>
<td>88.79%</td>
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<tr>
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<td>1.84</td>
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<tr>
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<td>2.26</td>
<td>34.36</td>
<td>0.559</td>
<td>22.60</td>
<td>19.207</td>
<td>84.99%</td>
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<tr>
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<td>2.68</td>
<td>40.20</td>
<td>0.550</td>
<td>26.80</td>
<td>22.110</td>
<td>82.50%</td>
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<td>1.21</td>
<td>23.07</td>
<td>0.573</td>
<td>14.52</td>
<td>13.219</td>
<td>91.04%</td>
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<td>1.50</td>
<td>28.65</td>
<td>0.568</td>
<td>18.00</td>
<td>16.273</td>
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<td>1.81</td>
<td>34.40</td>
<td>0.562</td>
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<td>89.01%</td>
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<td>2.13</td>
<td>39.80</td>
<td>0.556</td>
<td>25.56</td>
<td>22.129</td>
<td>86.58%</td>
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<td>14</td>
<td>1.02</td>
<td>23.00</td>
<td>0.572</td>
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<td>13.156</td>
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<tr>
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<td>1.26</td>
<td>28.60</td>
<td>0.567</td>
<td>17.64</td>
<td>16.216</td>
<td>91.93%</td>
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<tr>
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<td>1.51</td>
<td>34.20</td>
<td>0.563</td>
<td>21.14</td>
<td>19.255</td>
<td>91.08%</td>
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<tr>
<td>14</td>
<td>1.77</td>
<td>39.80</td>
<td>0.558</td>
<td>24.78</td>
<td>22.208</td>
<td>89.62%</td>
</tr>
</tbody>
</table>

### Test Condition
- R<sub>CC</sub> : 1KΩ  
- R<sub>S</sub> : 0.125Ω  
- R<sub>ENH</sub> : 160KΩ  
- R<sub>ENL</sub> : 20KΩ  
- R<sub>OVPH</sub> : 56KΩ  
- R<sub>OVPL</sub> : 4.3KΩ  
- R<sub>DMY</sub> : 50KΩ  
- L<sub>1</sub> : 100µH  
- C<sub>O</sub> : 30µF  
- R<sub>T</sub> : 27KΩ (340kHz)

### Diagram
- Boost (13W~22W, 0.6A)
- Efficiency vs. V<sub>OUT</sub> (V)

- I<sub>OUT</sub> max.: 0.573, 2.05%
- I<sub>OUT</sub> min.: 0.550, -2.05%
Reference Schematics – Boost
<table>
<thead>
<tr>
<th>Item</th>
<th>Designator</th>
<th>Component Description</th>
<th>TSC Product</th>
<th>Package</th>
<th>Quantity</th>
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<tbody>
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<td>U1</td>
<td>TS19501CB10H</td>
<td>TS19501CB10H</td>
<td>MSOP-10</td>
<td>1</td>
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<td>2</td>
<td>Q1</td>
<td>60V, 35A, Single N-Channel Power MOSFET</td>
<td>TSM220NB06LCR</td>
<td>PDFN56</td>
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<td>3, 4</td>
<td>D1, D4</td>
<td>Diode, Schottky Rectifier, 5A, 100V</td>
<td>SK510B</td>
<td>DO-214AA (SMB)</td>
<td>2</td>
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<tr>
<td>5</td>
<td>D2</td>
<td>Diode, TVS, Uni, 24 V</td>
<td>1.5SMC24A</td>
<td>DO-214AB (SMC)</td>
<td>1</td>
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<tr>
<td>6</td>
<td>D3</td>
<td>Fast Recovery Rectifier 1A, 1000V</td>
<td>RS1M</td>
<td>DO-214AA (SMB)</td>
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</tr>
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<td>7</td>
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<td>SMD RES 10R, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<tr>
<td>8</td>
<td>R2</td>
<td>SMD RES 10R, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<td>9</td>
<td>R_{ENH}</td>
<td>SMD RES 160k, 1%, 0.25 W</td>
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<td>0805</td>
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<td>R_{ENL}</td>
<td>SMD RES 20k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<td>11</td>
<td>R_{OVPH}</td>
<td>SMD RES 33k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<td>12</td>
<td>R_{OVPL}</td>
<td>SMD RES 2.4k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<tr>
<td>13</td>
<td>R_{DMY}</td>
<td>SMD RES 50k, 1%, 0.25 W</td>
<td>-</td>
<td>1206</td>
<td>1</td>
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<td>14</td>
<td>R_s</td>
<td>SMD RES 0.167R, 1%, 0.25 W</td>
<td>-</td>
<td>1210</td>
<td>1</td>
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<tr>
<td>15</td>
<td>R_T</td>
<td>SMD RES 20k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
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<tr>
<td>18</td>
<td>C_{COM}</td>
<td>CAP, 1.0μF, 50V, +/- 5%, X7R</td>
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<td>1</td>
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<td>20</td>
<td>L1</td>
<td>Inductor, Shielded Drum Core, Powdered Iron, 100μH, 4A, 200mΩ, AEC-Q200 Grade 0, SMD</td>
<td>-</td>
<td>13.5x12.5x5.7mm</td>
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</table>
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Typical Application – Buck-Boost

APPLICATION CIRCUIT

IO & Efficiency vs. VIN

- (6W-9V/0.6A)
- (15W-25V/0.6A)

IO (A)

VIN (V)

Efficiency

IO

EFF

0.8

0.7

0.6

0.5

0.4

0.3

0.2

0.1

0

10

15

20

25

30

60%

70%

80%

90%

100%
## System Characteristics – Buck-Boost

<table>
<thead>
<tr>
<th>$V_{IN}$</th>
<th>$I_{IN}$</th>
<th>$V_{OUT}$</th>
<th>$I_{OUT}$</th>
<th>$P_{IN}$</th>
<th>$P_{OUT}$</th>
<th>Efficiency</th>
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<tr>
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<td>0.92</td>
<td>10.05</td>
<td>0.905</td>
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<td>9.095</td>
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<td>1.18</td>
<td>13.18</td>
<td>0.894</td>
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<td>11.783</td>
<td>83.21%</td>
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<td>1.44</td>
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<td>0.887</td>
<td>17.28</td>
<td>14.502</td>
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<td>1.72</td>
<td>19.53</td>
<td>0.881</td>
<td>20.64</td>
<td>17.206</td>
<td>83.36%</td>
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<td>2.01</td>
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<td>19.990</td>
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<td>2.12</td>
<td>24.11</td>
<td>0.872</td>
<td>25.44</td>
<td>21.024</td>
<td>82.64%</td>
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<td>2.40</td>
<td>27.12</td>
<td>0.868</td>
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<td>81.74%</td>
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<td>2.68</td>
<td>30.08</td>
<td>0.866</td>
<td>32.16</td>
<td>26.049</td>
<td>81.00%</td>
</tr>
</tbody>
</table>

### Test Condition

- $R_{ENH}$ : 160$\Omega$
- $R_{ENL}$ : 20$\Omega$
- $R_{OVPH}$ : 33$\Omega$
- $R_{OVPL}$ : 2.4K$\Omega$
- $R_{DMY}$ : 50K$\Omega$
- $L_1$ : 100$\mu$H
- $C_O$ : 30$\mu$F
- $R_T$ : 27K$\Omega$ (340kHz)
- $R_S$ : 0.167Ω

### Buck-Boost (9W~26W, 0.9A)

- $V_{OUT}$ (V): 55% to 90%
- Efficiency: 55% to 90%

- $I_{OUT}$ max.: 0.905 A, 2.20%
- $I_{OUT}$ min.: 0.866 A, -2.20%

![efficiency graph](image)
<table>
<thead>
<tr>
<th>Item</th>
<th>Designator</th>
<th>Component Description</th>
<th>TSC Product</th>
<th>Package</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1</td>
<td>TS19501CB10H</td>
<td>TS19501CB10H</td>
<td>MSOP-10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Q1</td>
<td>60V, 35A, Single N-Channel Power MOSFET</td>
<td>TSM220NB06LCR</td>
<td>PDFN56</td>
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</tr>
<tr>
<td>3, 4</td>
<td>D1, D4</td>
<td>Diode, Schottky Rectifier, 5A, 100V</td>
<td>SK510B</td>
<td>DO-214AA (SMB)</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>D2</td>
<td>Diode, TVS, Uni, 24 V</td>
<td>1.5SMC24A</td>
<td>DO-214AB (SMC)</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>D3</td>
<td>Fast Recovery Rectifier 1A, 1000V</td>
<td>RS1M</td>
<td>DO-214AA (SMB)</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>R1</td>
<td>SMD RES 10R, 1%, 0.25 W</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>R2</td>
<td>SMD RES 10R, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>R_{ENH}</td>
<td>SMD RES 160k, 1%, 0.25 W</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>R_{ENL}</td>
<td>SMD RES 20k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>R_{OVPH}</td>
<td>SMD RES 33k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>R_{OVPL}</td>
<td>SMD RES 2.4k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>R_{DMY}</td>
<td>SMD RES 50k, 1%, 0.25 W</td>
<td>-</td>
<td>1206</td>
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<tr>
<td>14</td>
<td>R_{S}</td>
<td>SMD RES 0.167R, 1%, 0.25 W</td>
<td>-</td>
<td>1210</td>
<td>1</td>
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<tr>
<td>15</td>
<td>R_{T}</td>
<td>SMD RES 20k, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>18</td>
<td>C_{COM}</td>
<td>CAP, 1.0μF ,50V, +/- 5%, X7R</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>L1</td>
<td>Inductor, Shielded Drum Core, Powdered Iron, 100μH, 4A, 200mΩ, AEC-Q200 Grade 0, SMD</td>
<td>-</td>
<td>13.5x12.5x5.7mm</td>
<td>1</td>
</tr>
</tbody>
</table>
Outline

- Introduction
- Pin Configuration & Functions
  - Over Voltage Protection (OVP) / Short Circuit Protection (SCP)
  - Soft Start / Hot Switch / Jitter / OTP
  - PWM & Linear Dimming
  - EMI Performance
- Bench Test Result
- Typical Applications
  - Boost
  - Buck-Boost
  - SEPIC
Typical Application – SEPIC

**APPLICATION CIRCUIT**

- **LED**
- **R_DNY**
- **C_D**
- **L_2**
- **D_1**
- **C_S**

Components:

- **VIN**
- **OVP**
- **FLT**
- **DIM**
- **EN**
- **OUT**
- **CS**
- **COM**

Components Placement:

- TS19501CB10H

- **RT**
- **GND**
- **VIN**
- **EN**
- **DIM**
- **FLT**
- **CS**
- **OUT**

**MOSFET Turn-On**

Heavy current path

- **Vin**
- **R_OVPH**
- **Q_1**
- **R_S**

**MOSFET Turn-Off**

Heavy current path

- **TS19501CB10**
- **OVP**
- **COM**
- **VIN**
- **EN**
- **DIM**
- **FLT**
- **GND**
- **CS**
- **RT**

**Definitions**

- **RT**: Refers to a specific terminal on the device.
- **GND**: Ground reference.
- **CS**: Channel source.
- **OUT**: Output terminal.
- **VIN**: Input voltage.
- **EN**: Enable signal.
- **DIM**: Dimming control.
- **FLT**: Fault protection.
- **OVP**: Overvoltage protection.
Design Example

12 V to 24 V

SEPIC Calculation Form:

Requirements:

\[ V_{IN} = 12V \]
\[ V_{OUT} = 24V \]
\[ I_{OUT} = 1A \]
\[ F_{SW} = 330kHz \]

\[ V_{IN,MAX} = 26 \text{ V} \]
\[ V_{IN,MIN} = 10 \text{ V} \]
\[ V_{IN,EN} = 12 \text{ V} \]
\[ N = 8 \text{ pcs} \]
\[ V_{LED} = 3 \text{ V} \]
\[ I_{LED,OUT} = 1 \text{ A} \]
\[ F_{SW} = 330 \text{ KHz} \]
\[ V_{D1} = 0.5 \text{ V} \]

Output Voltage
\[ V_{OUT} = 24 \text{ V} \]

High-Side Resistor of \( V_{IN,EN} \)
\[ R_{ENH} = 900.00 \text{ K}\Omega \]

Duty Cycle (Maximum)
\[ D_{MAX} = 71.01 \% \]

Duty Cycle (Minimum)
\[ D_{MIN} = 48.51 \% \]
# Design Example (Inductor Selection)

## Inductor Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>SEPIC</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ripple Current of $L_1$ and $L_2$</td>
<td>$\Delta I_L$</td>
<td>0.960</td>
<td>A</td>
</tr>
<tr>
<td>Inductor for $L_1, L_2$</td>
<td>$L_1, L_2$</td>
<td>22.42</td>
<td>uH</td>
</tr>
<tr>
<td>Peak Current of $L_1$</td>
<td>$I_{L1,\text{Peak}}$</td>
<td>2.94</td>
<td>A</td>
</tr>
<tr>
<td>Peak Current of $L_2$</td>
<td>$I_{L2,\text{Peak}}$</td>
<td>1.2</td>
<td>A</td>
</tr>
<tr>
<td>Resistance for Average Output Current</td>
<td>$R_{Cs}$</td>
<td>150</td>
<td>mΩ</td>
</tr>
</tbody>
</table>

- $\Delta I_L$ represents the ripple current of $L_1$ and $L_2$.
- $I_{L1,\text{Peak}}$ and $I_{L2,\text{Peak}}$ are the peak currents of $L_1$ and $L_2$ respectively.
- $R_{Cs}$ is the resistance for the average output current.

### Diagram

- **Vin** is the input voltage.
- **$L_1$** and **$L_2$** are the inductors.
- The circuit diagram shows the connections and components of the SEPIC (Single-Ended Primary Inductor Converters) circuit, including input, output, and control signals.

---

**Note:** The diagram and table are provided to illustrate the design example of inductor selection for the SEPIC converter.
Design Example (Output Diode/$C_S$/R$_{CS}$ Selection)

### Output Diode Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>SEPIC</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode Reverse Voltage</td>
<td>$V_{D1}$</td>
<td>50</td>
<td>V</td>
</tr>
</tbody>
</table>

### SEPIC Coupling Capacitor ($C_S$) Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Current of $C_S$</td>
<td>$I_{Cs_{\text{RMS}}}$</td>
<td>1.57 A</td>
</tr>
</tbody>
</table>

### $R_{CS}$ Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance for Average Output Current</td>
<td>150.00 mΩ</td>
</tr>
</tbody>
</table>
## Design Example (Protection Selection)

<table>
<thead>
<tr>
<th>Protection Selection</th>
<th>R_{OVPH}</th>
<th>240.00 kΩ</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-Side Resistor of $V_{OVP}$, $V_{SCP}$</td>
<td>R_{OVPL}</td>
<td>15.00 kΩ</td>
</tr>
<tr>
<td>Low-Side Resistor of $V_{OVP}$, $V_{SCP}$</td>
<td>V_{OVP}</td>
<td>28.40 V</td>
</tr>
<tr>
<td>Open Protection Voltage</td>
<td>V_{SCP}</td>
<td>13.31 V</td>
</tr>
</tbody>
</table>

- Key In the requirements
- Output for the design suggestion
System Characteristics – SEPIC

Efficiency vs. $V_{IN}$

- $F_{sw} = 100$ kHz
- $F_{sw} = 330$ kHz

Line Regulation

- $F_{sw} = 100$ kHz
- $F_{sw} = 330$ kHz

SEPIC vs. Buck-Boost

Line Regulation
### Test Raw Data

**SEPIC @ 100kHz/330kHz**

<table>
<thead>
<tr>
<th>$V_{IN}$ (V)</th>
<th>$I_{IN}$ (A)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ (V)</th>
<th>$I_{OUT}$ (A)</th>
<th>$P_{OUT}$ (W)</th>
<th>$\eta$ (%)</th>
<th>$I_{OUT}$ Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.090</td>
<td>30.900</td>
<td>23.816</td>
<td>0.969</td>
<td>23.078</td>
<td>74.685</td>
<td>-1.52%</td>
</tr>
<tr>
<td>12</td>
<td>2.425</td>
<td>29.100</td>
<td>23.867</td>
<td>0.984</td>
<td>23.485</td>
<td>80.705</td>
<td>0.00%</td>
</tr>
<tr>
<td>14</td>
<td>2.023</td>
<td>28.322</td>
<td>23.9</td>
<td>0.993</td>
<td>23.733</td>
<td>83.796</td>
<td>0.91%</td>
</tr>
<tr>
<td>16</td>
<td>1.744</td>
<td>27.904</td>
<td>23.911</td>
<td>1.003</td>
<td>23.983</td>
<td>85.947</td>
<td>1.93%</td>
</tr>
<tr>
<td>18</td>
<td>1.538</td>
<td>27.684</td>
<td>23.931</td>
<td>1.009</td>
<td>24.146</td>
<td>87.221</td>
<td>2.54%</td>
</tr>
<tr>
<td>20</td>
<td>1.376</td>
<td>27.520</td>
<td>23.952</td>
<td>1.014</td>
<td>24.287</td>
<td>88.253</td>
<td>3.05%</td>
</tr>
<tr>
<td>22</td>
<td>1.250</td>
<td>27.500</td>
<td>23.974</td>
<td>1.019</td>
<td>24.430</td>
<td>88.835</td>
<td>3.56%</td>
</tr>
<tr>
<td>24</td>
<td>1.150</td>
<td>27.600</td>
<td>23.996</td>
<td>1.024</td>
<td>24.572</td>
<td>89.029</td>
<td>4.07%</td>
</tr>
<tr>
<td>26</td>
<td>1.065</td>
<td>27.690</td>
<td>24.019</td>
<td>1.029</td>
<td>24.716</td>
<td>89.258</td>
<td>4.57%</td>
</tr>
</tbody>
</table>

**SEPIC, L1 = L2 = 33uH, R_T= 30kΩ @ 330kHz**

<table>
<thead>
<tr>
<th>$V_{IN}$ (V)</th>
<th>$I_{IN}$ (A)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ (V)</th>
<th>$I_{OUT}$ (A)</th>
<th>$P_{OUT}$ (W)</th>
<th>$\eta$ (%)</th>
<th>$I_{OUT}$ Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.091</td>
<td>30.910</td>
<td>23.866</td>
<td>0.998</td>
<td>23.818</td>
<td>77.057</td>
<td>-2.06%</td>
</tr>
<tr>
<td>12</td>
<td>2.478</td>
<td>29.736</td>
<td>23.951</td>
<td>1.019</td>
<td>24.406</td>
<td>82.076</td>
<td>0.00%</td>
</tr>
<tr>
<td>14</td>
<td>2.094</td>
<td>29.316</td>
<td>24.023</td>
<td>1.031</td>
<td>24.768</td>
<td>84.485</td>
<td>1.18%</td>
</tr>
<tr>
<td>16</td>
<td>1.822</td>
<td>29.152</td>
<td>24.081</td>
<td>1.045</td>
<td>25.165</td>
<td>86.322</td>
<td>2.55%</td>
</tr>
<tr>
<td>18</td>
<td>1.621</td>
<td>29.178</td>
<td>24.122</td>
<td>1.055</td>
<td>25.449</td>
<td>87.219</td>
<td>3.53%</td>
</tr>
<tr>
<td>20</td>
<td>1.460</td>
<td>29.200</td>
<td>24.153</td>
<td>1.063</td>
<td>25.675</td>
<td>87.927</td>
<td>4.32%</td>
</tr>
<tr>
<td>22</td>
<td>1.331</td>
<td>29.282</td>
<td>24.181</td>
<td>1.070</td>
<td>25.874</td>
<td>88.360</td>
<td>5.00%</td>
</tr>
<tr>
<td>24</td>
<td>1.230</td>
<td>29.520</td>
<td>24.22</td>
<td>1.080</td>
<td>26.158</td>
<td>88.610</td>
<td>5.99%</td>
</tr>
<tr>
<td>26</td>
<td>1.142</td>
<td>29.692</td>
<td>24.251</td>
<td>1.088</td>
<td>26.385</td>
<td>88.863</td>
<td>6.77%</td>
</tr>
</tbody>
</table>
## Test Raw Data

(SEPIC & Buck-Boost @ 100kHz)

### SEPIC, L1 = L2 = 100uH, R_T = 100kΩ @ 100kHz

<table>
<thead>
<tr>
<th>V_IN (V)</th>
<th>I_IN (A)</th>
<th>P_IN (W)</th>
<th>V_OUT (V)</th>
<th>I_OUT (A)</th>
<th>P_OUT (W)</th>
<th>η (%)</th>
<th>I_OUT Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.090</td>
<td>30.900</td>
<td>23.816</td>
<td>0.969</td>
<td>23.078</td>
<td>74.685</td>
<td>-1.52%</td>
</tr>
<tr>
<td>12</td>
<td>2.425</td>
<td>29.100</td>
<td>23.867</td>
<td>0.984</td>
<td>23.485</td>
<td>80.705</td>
<td>0.00%</td>
</tr>
<tr>
<td>14</td>
<td>2.023</td>
<td>28.322</td>
<td>23.9</td>
<td>0.993</td>
<td>23.733</td>
<td>83.796</td>
<td>0.91%</td>
</tr>
<tr>
<td>16</td>
<td>1.744</td>
<td>27.904</td>
<td>23.911</td>
<td>1.003</td>
<td>23.983</td>
<td>85.947</td>
<td>1.93%</td>
</tr>
<tr>
<td>18</td>
<td>1.538</td>
<td>27.684</td>
<td>23.931</td>
<td>1.009</td>
<td>24.146</td>
<td>87.221</td>
<td>2.54%</td>
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<tr>
<td>20</td>
<td>1.376</td>
<td>27.520</td>
<td>23.952</td>
<td>1.014</td>
<td>24.287</td>
<td>88.253</td>
<td>3.05%</td>
</tr>
<tr>
<td>22</td>
<td>1.250</td>
<td>27.500</td>
<td>23.974</td>
<td>1.019</td>
<td>24.430</td>
<td>88.835</td>
<td>3.56%</td>
</tr>
<tr>
<td>24</td>
<td>1.150</td>
<td>27.600</td>
<td>23.996</td>
<td>1.024</td>
<td>24.572</td>
<td>89.029</td>
<td>4.07%</td>
</tr>
<tr>
<td>26</td>
<td>1.065</td>
<td>27.690</td>
<td>24.019</td>
<td>1.029</td>
<td>24.716</td>
<td>89.258</td>
<td>4.57%</td>
</tr>
</tbody>
</table>

### Buck-Boost, L1 = L2 = 100uH, R_T = 100kΩ @ 100kHz

<table>
<thead>
<tr>
<th>V_IN (V)</th>
<th>I_IN (A)</th>
<th>P_IN (W)</th>
<th>V_OUT (V)</th>
<th>I_OUT (A)</th>
<th>P_OUT (W)</th>
<th>η (%)</th>
<th>I_OUT Variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>3.346</td>
<td>33.460</td>
<td>23.3</td>
<td>0.996</td>
<td>23.207</td>
<td>69.357</td>
<td>-0.70%</td>
</tr>
<tr>
<td>12</td>
<td>2.552</td>
<td>30.624</td>
<td>23.29</td>
<td>1.003</td>
<td>23.360</td>
<td>76.280</td>
<td>0.00%</td>
</tr>
<tr>
<td>14</td>
<td>2.095</td>
<td>29.330</td>
<td>23.25</td>
<td>1.009</td>
<td>23.459</td>
<td>79.984</td>
<td>0.60%</td>
</tr>
<tr>
<td>16</td>
<td>1.784</td>
<td>28.544</td>
<td>23.24</td>
<td>1.015</td>
<td>23.589</td>
<td>82.639</td>
<td>1.20%</td>
</tr>
<tr>
<td>18</td>
<td>1.563</td>
<td>28.134</td>
<td>23.24</td>
<td>1.022</td>
<td>23.751</td>
<td>84.422</td>
<td>1.89%</td>
</tr>
<tr>
<td>20</td>
<td>1.396</td>
<td>27.920</td>
<td>23.25</td>
<td>1.029</td>
<td>23.924</td>
<td>85.689</td>
<td>2.59%</td>
</tr>
<tr>
<td>22</td>
<td>1.265</td>
<td>27.830</td>
<td>23.26</td>
<td>1.037</td>
<td>24.121</td>
<td>86.671</td>
<td>3.39%</td>
</tr>
<tr>
<td>24</td>
<td>1.159</td>
<td>27.816</td>
<td>23.26</td>
<td>1.044</td>
<td>24.283</td>
<td>87.300</td>
<td>4.09%</td>
</tr>
<tr>
<td>26</td>
<td>1.072</td>
<td>27.872</td>
<td>23.29</td>
<td>1.052</td>
<td>24.501</td>
<td>87.906</td>
<td>4.89%</td>
</tr>
</tbody>
</table>
### Reference BOM – SEPIC

<table>
<thead>
<tr>
<th>Item</th>
<th>Designator</th>
<th>Component Description</th>
<th>TSC Product</th>
<th>Package</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>U1</td>
<td>TS19501CB10H</td>
<td>TS19501CB10H</td>
<td>MSOP-10</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Q1</td>
<td>60V, 25A, Single N-Channel Power MOSFET</td>
<td>TSM340N06CP</td>
<td>TO-252 (DPAK)</td>
<td>1</td>
</tr>
<tr>
<td>3, 4</td>
<td>D1, D5</td>
<td>Diode, Schottky Rectifier, 5A, 100V</td>
<td>SK510B</td>
<td>DO-214AA (SMB)</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>R2</td>
<td>SMD RES 820K, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>R3</td>
<td>SMD RES 100K, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>R7</td>
<td>SMD RES 10R, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
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<tr>
<td>8</td>
<td>R10, R13</td>
<td>SMD RES 0R, 1%, 0.25 W</td>
<td>-</td>
<td>0805</td>
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<tr>
<td>9</td>
<td>R12</td>
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<td>-</td>
<td>0805</td>
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<tr>
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<td>R14</td>
<td>SMD RES 240k, 1%, 0.25 W</td>
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<td>11</td>
<td>R15</td>
<td>SMD RES 15k, 1%, 0.25 W</td>
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<td>0805</td>
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<tr>
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<td>R19</td>
<td>SMD RES 330k, 1%, 0.25 W</td>
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<td>13</td>
<td>C6, C7, C8, C14, C16, C17</td>
<td>CAP, 10μF, 50V, +/- 5%, X7R</td>
<td>-</td>
<td>1206</td>
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<td>L2, L3</td>
<td>Inductor, Shielded, Ferrite, 33μH, 6A, 65mΩ, SMD</td>
<td>-</td>
<td>13.5x12.5x5.7mm</td>
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</table>
Thank You

Taiwan Semiconductor Co., Ltd.

Headquarters

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