XLSEMI

上海芯龙半导体技术股份有限公司

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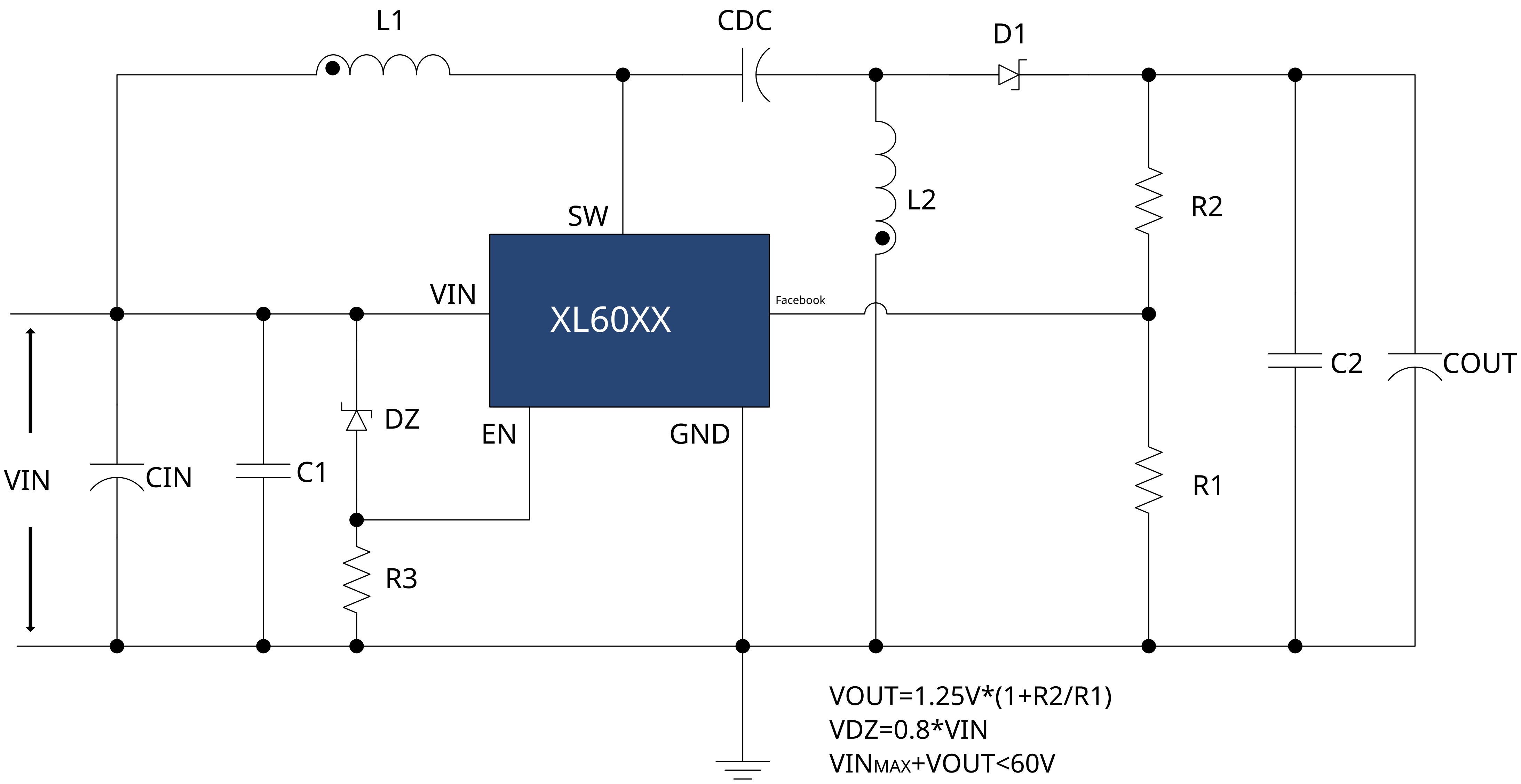
XL60XX Series SEPIC Constant Voltage Product Design Guide

V1.3

XL60XX Series Quick Selection Table

product model	input power pressure range	switch electric current	switch frequency	output Voltage	typical application	efficiency (Max)	encapsulation type	power
XL6007	3.6V-24V	2A	400KHz	5V~30V	12V/0.3A	85%	SOP8	≤8W
XL6008	3.6V-32V	3A	400KHz	5V~30V	12V/0.7A	85%	TO252-5L	≤20W
XL6012	5.0V-40V	5A	180KHz	5V~30V	12V/1.5A	87%	TO220-5L	≤100W
XL6019	5.0V-40V	5A	180KHz	5V~30V	12V/1.2A	87%	TO263-5L	≤100W



VOUT=1.25V*(1+R2/R1)
VDZ=0.8*VIN
VIN_{MAX}+VOUT<60V

Inductor selection

➢The two inductors in the SEPIC converter can use two independent inductors or a coupled inductor with a coaxial magnetic core. Using a coupled inductor can achieve higher conversion efficiency and better performance.

$$IL1_{MAX} = IIN_{MAX} = IOUT_{MAX} * \frac{D._{MAX}}{1 - D._{MAX}} \quad IL2_{MAX} = Iout_{MAX} \quad D. = \frac{VOUT + VD}{VIN + VOUT + VD}$$

VD is the voltage drop of the output freewheeling diode under the condition of maximum output current.

➢The switch current is equal to IL1+IL2, and the average value of the maximum switch current is calculated as follows:

$$ISW_{MAX} = IL1_{MAX} + IL2_{MAX} = IOUT_{MAX} * \left(1 + \frac{D._{MAX}}{1 - D._{MAX}}\right) = IOUT_{MAX} * \frac{1}{1 - D._{MAX}}$$

➢The maximum peak switch current is calculated as:

$$ILSW_{PEAK} = 1.2 * IOUT_{MAX} * \frac{1}{1 - D._{MAX}}$$

➢Switching Ripple Current:

$$\underline{\Delta IS}\, W = 0.4 * ISW_{MAX} = 0.4 * IOUT_{MAX} * \frac{1}{1 - D._{MAX}}$$

- Inductor ripple current:

$$\Delta IL1=\Delta IL2=0.5*\Delta ISW=0.5*0.4*IOUT_{MAX}*\frac{1}{1-D_{MAX}}$$

- The formula for calculating the minimum inductance in continuous mode is as follows:

- When using split inductors: $L1=L2=\frac{VIN_{MIN}}{0.5*\Delta ISW*FSW}*D_{MAX}$

- When using coupled inductors: $L1=L2=\frac{VIN_{MIN}}{\Delta ISW*FSW}*D_{MAX}$

- Inductor peak current:

$$IL1_{PEAK}=IL1_{MAX}+0.5*\Delta IL1=IOUT_{MAX}*\frac{D_{MAX}}{1-D_{MAX}}+0.5*0.5*0.4*IOUT_{MAX}*\frac{1}{1-D_{MAX}}$$

$$IL2_{PEAK}=IL2_{MAX}+0.5*\Delta IL2=IOUT_{MAX}+0.5*0.5*0.4*IOUT_{MAX}*\frac{1}{1-D_{MAX}}$$

- Selecting an inductor with low DC resistance can achieve higher conversion efficiency.

input capacitance

- Under normal conditions, the input capacitor capacity is selected between 10uF~100uF, and only the RMS current is required. The RMS current of the input capacitor is calculated as follows:

$$IRMS = 0.3 * \Delta IL$$

- Input capacitor withstand voltage according to 1.5*VIN_{MAX}make a choice;

- When ceramic capacitors are not used, it is recommended to connect a 0.1uF~1uF high-frequency chip ceramic capacitor in parallel with the input capacitor for high-frequency decoupling.

Calculate the maximum output current

- The internal current limit of the SEPIC converter is the peak current ΔIL on the power tube and the inductor. The maximum output current depends on the output voltage, minimum input voltage, ΔIL and efficiency. The calculation is as follows (more than 10% margin is reserved):

$$IOUT_{MAX} - \frac{I_{LIM} \Delta IL}{\frac{VOUT}{VIN_{MIN} * \eta} + 1} = \frac{I_{LIM} - 0.5 * \Delta ISW}{\frac{VOUT}{VIN_{MIN} * \eta} + 1} = \frac{I_{LIM} - 0.5 * 0.2 * IOUT_{MAX} * \frac{1}{1 - D_{.MAX}}}{\frac{VOUT}{VIN_{MIN} * \eta} + 1}$$

Output Voltage Design

- FB is the input terminal of the internal reference error amplifier of the chip, and the internal reference is stable at 1.25V;
- FB adjusts the output voltage by detecting the output voltage through an external resistor divider network. The formula for calculating the output voltage is:

$$out = 1.25 * \left(1 + \frac{R2}{R1}\right)$$

The value range of R1 is 1 KΩ~10KΩ;

- The accuracy of the output voltage depends on the accuracy of the chip VFB, R1 and R2. Selecting a resistor with higher precision can obtain a higher precision output voltage. The accuracy of R1 and R2 needs to be controlled within ±1%.

Freewheeling Diode Selection

- The freewheeling diode needs to choose a Schottky diode, the lower the VF value of the Schottky diode, the higher the conversion efficiency;
- The rated current value of the freewheeling diode is greater than 1.5 times the maximum output current;
- The reverse withstand voltage of the freewheeling diode is greater than the sum of the maximum input voltage and output voltage, and it is recommended to reserve more than 30% margin.

Coupling capacitor selection

- The withstand voltage of the coupling capacitor CDC is greater than the sum of the maximum input voltage and output voltage, it is recommended to reserve more than 30% margin;
- The coupling capacitor capacity is calculated as follows:

$$CDC - \frac{IOUT_{MA} * D_{MAX}}{0.05 * FSW}$$

- The coupling capacitor RMS current is calculated as follows:

$$IRMS_{CDC}-IOUT* \sqrt{\frac{VOUT+VD}{VIN_{MIN}}}$$

Output Capacitor Selection

- Low ESR capacitors should be selected at the output to reduce output ripple voltage.
- The output capacitor capacity and output voltage ripple are calculated as follows:

$$COUT- \frac{IOUT_{MAX}}{VOUT_{RIPPLE} * FSW}$$

$$out_{RIPPLE} = \frac{(1- \frac{VIN}{VOUT}) * IOUT}{COUT * FSW}$$

$$ESR- \frac{VOUT_{RIPPLE}}{ID}$$

$$COUT- 1.5*VOUT$$

- The output capacitor minimum RMS current is calculated as follows:

$$IRMS-IOUT* \sqrt{\frac{D_{MAX}}{1-D_{MAX}}}$$

PCB Design Considerations

- VIN, GND, SW, VOUT+, VOUT- are high-current paths, pay attention to the trace width, and reduce the impact of parasitic parameters on system performance;
- The input capacitor is placed close to the VIN and GND of the chip, and the electrolytic capacitor + chip ceramic capacitor is used in combination;
- The FB trace is far away from places with switching signals such as inductors and Schottky, and feedback is needed wherever stability is required. It is better to surround the FB trace with a ground wire;
- Chips, inductors, and Schottky are the main heat-generating components. Pay attention to the even distribution of PCB heat to avoid local temperature rise.

System input and output specifications

- Input voltage: VIN=10V~30V, the typical value is 1 2 V;
- Output voltage: VOUT=12V;
- Output current: IOUT=1.5A;
- Conversion efficiency: η=87%;
- Output voltage ripple: 1 %*VOUT;
- Chip selection XL6019;
- Switching frequency: F_{SW}=180KHz.

Choose an inductor:

$$D = \frac{V_{OUT} + V_D}{V_{IN} + V_{OUT} + V_D} = \frac{12 + 0.45}{12 + 12 + 0.45} = 0.509$$

$$D_{MAX} = \frac{V_{OUT} + V_D}{V_{INMIN} + V_{OUT} + V_D} = \frac{12 + 0.45}{10 + 12 + 0.45} = 0.555$$

$$I_{L1MAX} = I_{INMAX} = I_{OUTMAX} * \frac{D_{MAX}}{1 - D_{MAX}} = 1.5 * \frac{0.555}{1 - 0.555} = 1.87A$$

$$I_{L2MAX} = I_{OUTMAX} = 1.5A$$

$$I_{SWMAX} = I_{L1MAX} + I_{L2MAX} = I_{OUTMAX} * \left(1 + \frac{D_{MAX}}{1 - D_{MAX}}\right) = I_{OUTMAX} * \frac{1}{1 - D_{MAX}} = 1.5 * \frac{1}{1 - 0.555} = 3.37A$$

$$I_{LSWPEAK} = 1.2 * I_{OUTMAX} * \frac{1}{1 - D_{MAX}} = 1.2 * 1.5 * \frac{1}{1 - 0.555} = 4.04A$$

$$\Delta I_{SW} = 0.4 * I_{SWMAX} = 0.4 * I_{OUTMAX} * \frac{1}{1 - D_{MAX}} = 0.4 * 1.5 * \frac{1}{1 - 0.555} = 1.348A$$

$$\Delta I_{L1} = \Delta I_{L2} = 0.5 * \Delta I_{SW} = 0.5 * 0.4 * I_{OUTMAX} * \frac{1}{1 - D_{MAX}} = 0.5 * 0.4 * 1.5 * \frac{1}{1 - 0.555} = 0.674A$$

Choose an inductor:

When using split inductors:

$$L1=L2=\frac{VINMIN}{0.5*\Delta ISW*FSW}*DMAX=\frac{10}{0.5*1.348*180*1000}*0.555=45.75uH$$

When using coupled inductors:

$$L1=L2=\frac{VIN_{MIN}}{\Delta ISW*FSW}*D_{MAX}=\frac{10}{1.348*180*1000}*0.555=22.85uH$$

$$IL1_{PEAK}=IL1_{MAX}+0.5*\Delta IL1=IOUT_{MAX}*\frac{D_{MAX}}{1-D_{MAX}}+0.5*0.5*0.4*IOUT_{MAX}*\frac{1}{1-D_{MAX}}=2.544A$$

$$IL2_{PEAK}=IL2_{MAX}+0.5*\Delta IL2=IOUT_{MAX}+0.5*0.5*0.4*IOUT_{MAX}*\frac{1}{1-D_{MAX}}=1.837A$$

When split inductor is selected, the inductance of L1 and L2 is 47 uH, and the saturation current is 4 A;

when coupled inductor is selected, the inductance of L1 and L2 is 33 uH, and the saturation current is 4 A.

Calculate the input capacitance:

$$\Delta IL = \Delta IL1 = \Delta IL2 = 674\,mA$$

$IRMS = 0.3 * \Delta IL = 0.3*674mA = 202.2mA$ VCIN=1.5*VIN$_{MAX}$=1.5*30=45V Select CIN capacity 100uF, RMS current greater than 202mA, withstand voltage greater than or equal to 45V.

Calculate the divider resistance:

Suppose R1=2.7K;

$$out = 1.25*(1+\frac{R2}{R1}) - R2 = \frac{(VOUT-1.25)*R1}{1.25} = \frac{(12-1.25)*2.7}{1.25} = 23.22K$$

Choose R1=2.7K, R2=24K, 1% accuracy. The calculated center value of the output voltage is 12.36V.

Freewheeling diode selection:

➢Diode rated current:

$ID=1.5*IOUT=1.5*1.5=2.25A$

➢Reverse withstand voltage: $VIN_{MAX}+VOUT=30+12=42V$

➢Choose 3 A, 60 V Schottky.

Select the output capacitor:

➢Output capacitor capacity:

$$COUT-\frac{IOUT_{MAX}}{VOUT_{RIPPLE} * F_{SW}}=\frac{1.5}{0.01*VOUT*180K}=69.44uF$$

➢Output capacitor ESR:

$$ESR-\frac{VOUT_{RIPPLE}}{ID}=\frac{0.01*12}{1.5}=80m\Omega$$

Select the output capacitor:

- VCOUT≥1.5*VOUT=1.5*12V=18V

- The output capacitor minimum RMS current is calculated as follows:

$$IRMS\text{-}IOUT*\sqrt{\frac{D_{MAX}}{1-D_{MAX}}}=1*\sqrt{\frac{0.5546}{1-0.5546}}=1674mA$$

- Choose a 25V, 220uF, RMS current greater than 1674mA electrolytic capacitor. Choose a coupling capacitor:

- Coupling capacitance withstand voltage

- VCDC≥VIN$_{MAX}$+VOUT=30+12=42V

$$CDC\text{-}\frac{IOUT_{MAX}*D_{MAX}}{0.05*FSW}=\frac{1.5*0.5546}{0.05*180*1000}=92.43uF$$

$$IRMSCDC\text{-}IOUT*\sqrt{\frac{VOUT+VD}{VINMIN}}=1.5*\sqrt{\frac{12-0.5}{10}}=1677mA$$

- Select 50V, 100uF, RMS current greater than 1677mA electrolytic capacitor.

Q1. The input positive and negative poles are reversed and the chip is damaged

Solution: Add an anti-reverse connection circuit (blue dashed in the right picture)

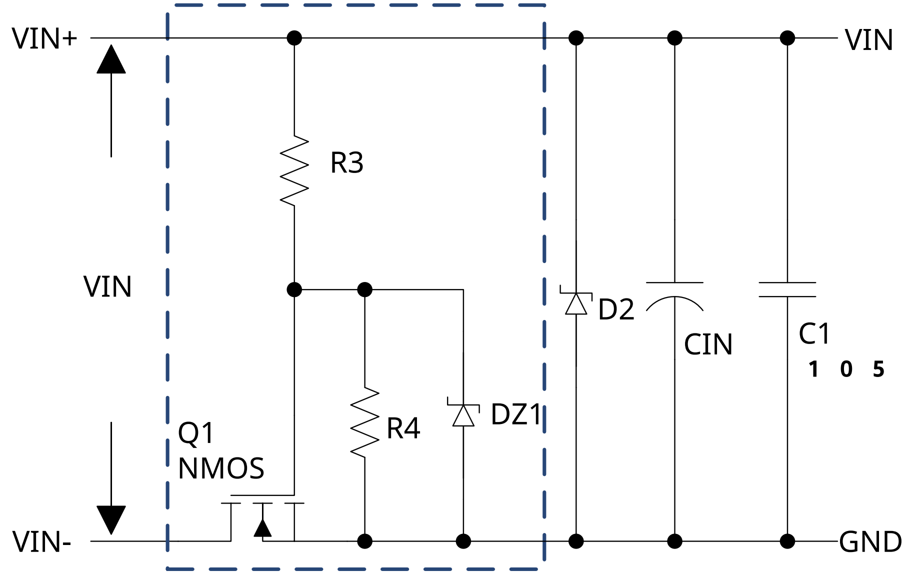
circuit in wireframe).

Q1: VDS≥1.5*VINMAX;

DZ1: VDZ1=10V, 500 mW;

R3: 20 K;

R4: 20 K.



Q2. The input peak voltage damages the chip

Solution 1 : Add transient peak voltage to the input to absorb

Receiver circuit (the circuit in the blue dotted line box on the right);

D2:VD2=1.2*VINMAX≤40V

Solution 2 : Add an overvoltage protection circuit to the input (right

The circuit in the red dotted box in the figure).

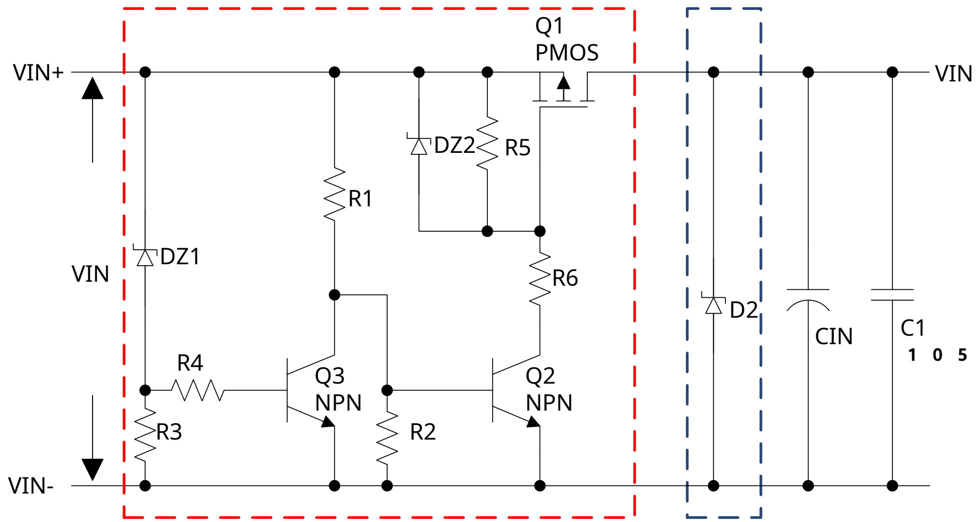
Q1: VDS≥1.5*VINMAX;

DZ1: VDZ1=1.2*VINMAX≤40V, 500 mW; DZ2: VDZ2=10V, 500 mW;

R1, R3, R4, R5, R6: 20 K;

R2 :10K;

Q2 , Q3: VCE≥1.5*VINMAX.



Q3. How to adjust the output voltage

Solution 1 : Adjust the voltage divider resistor (right picture R3).

Solution 2 : PWM signal change duty cycle adjustment

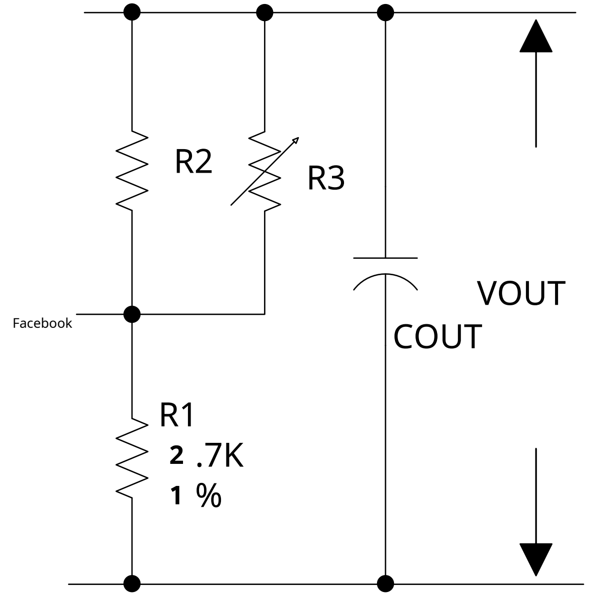
Node output voltage (the circuit in the blue dashed box in the lower right figure):

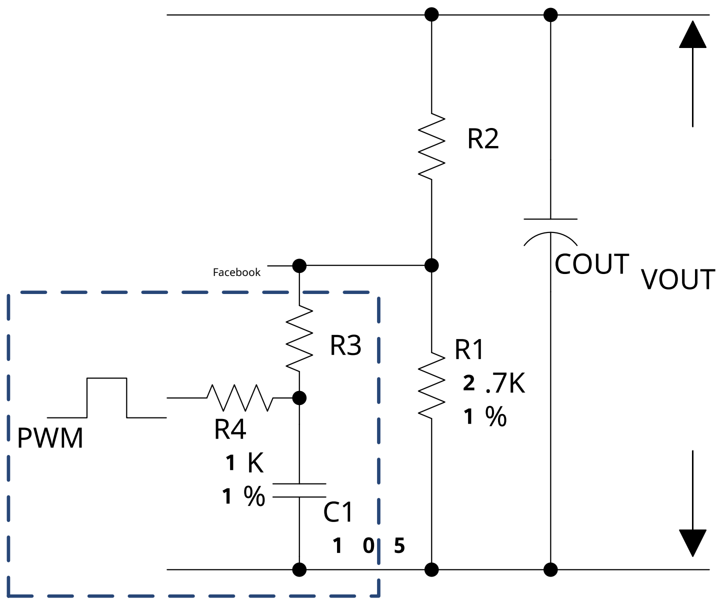
PWM: frequency 1 KHz~10KHz;

When the high level is 5 V, R3 selects 4 K;

When the high level is 3 .3V, R3 selects 0 .5K.

$$out = \left(V_{FB} - \frac{R1*V_{PWM}*DUTY}{R1+R3+R4}\right)*\left(1+\frac{R2}{R1}\right)$$





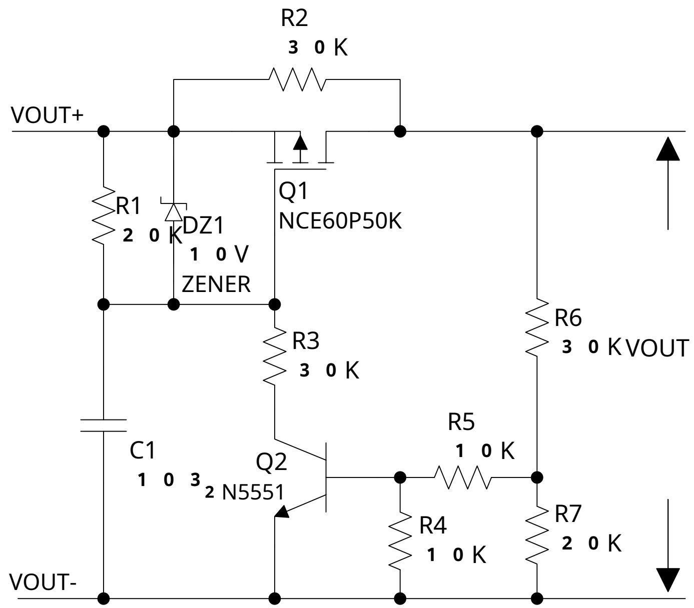
Q4. How to implement output short circuit protection

Solution: Add a short-circuit protection circuit to the output (right

The circuit in the blue dotted box)

Q1: VDS≥1.5*VOUT; ID≥2*IOUT

The smaller the RDS, the smaller the loss, and the lower the heat generation of Q1.



Q5. Low conversion efficiency

Test error: Use a multimeter to test the input voltage, input current, output voltage, and output current to calculate the conversion efficiency. The data displayed by the power supply and load cannot be used, and the error is large;

PCB layout: ensure the trace width of the large current path, reduce the impact of parasitic parameters on system performance, and place the input capacitor close to the VIN and GND of the chip;

Component parameters: When the system is working normally, inductance and Schottky have a great influence on the efficiency, it is recommended to use low V Schottky with F value, power inductor with small core loss and sufficient saturation current capability, a so-soUnder normal circumstances, the inductance of the ring sendust core is about 5 % higher than the inductance efficiency of the yellow and white ring iron powder core.

Q6. How to realize the input undervoltage protection

Solution: Add an undervoltage protection circuit to the input.

DZ1:VDZ1=undervoltage protection voltage, 500 mW;

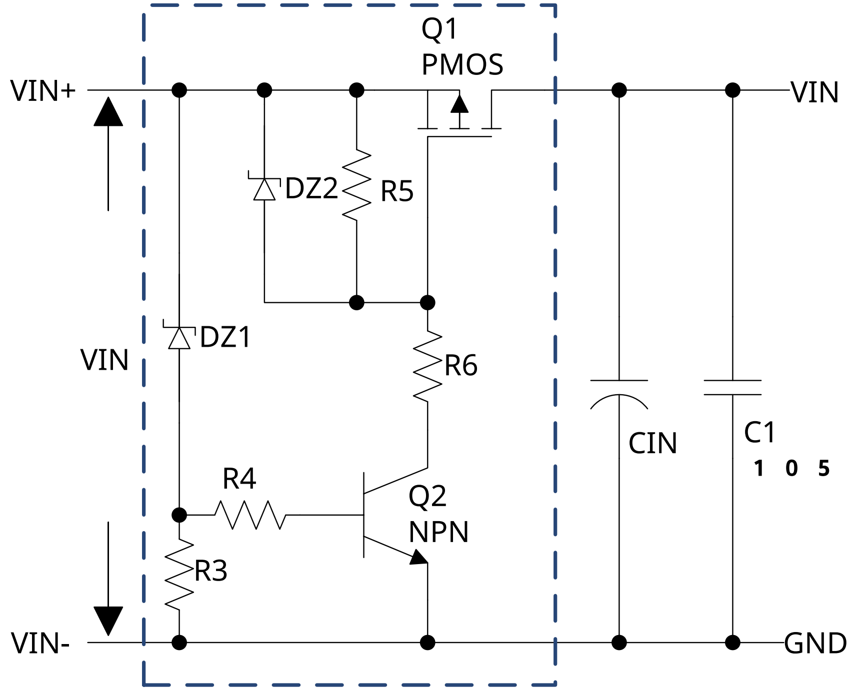
DZ2: VDZ2=10V, 500 mW;

Q1: VDS≥1.5*VINMAX, ID≥2*IINMAX;

Q2: VCE≥1.5*VINMAX;

R4, R5: 20K;

R3, R6: 30K.



Q7. Electrical properties of XL6008, XL6012, XL6019 chip back iron

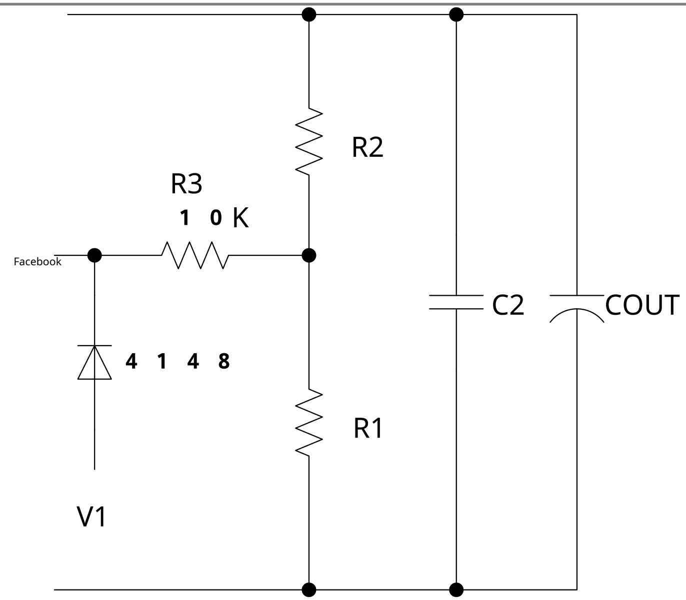
The electrical property of the back iron is consistent with that of pin 3 of the chip.

Q8. How to turn off the chip does not work

Solution 1 : FB increases high level, the chip does not work

as (upper right picture);

V1: 2 .5≤V1≤VIN.



Solution 2 : Input plus MOS shutdown (lower right

The circuit in the dotted box in the figure), the output is equal to 0 .

V2: V2≤0.6V turns off the output, V2≥1.4V turns on Q1 and restores the output;

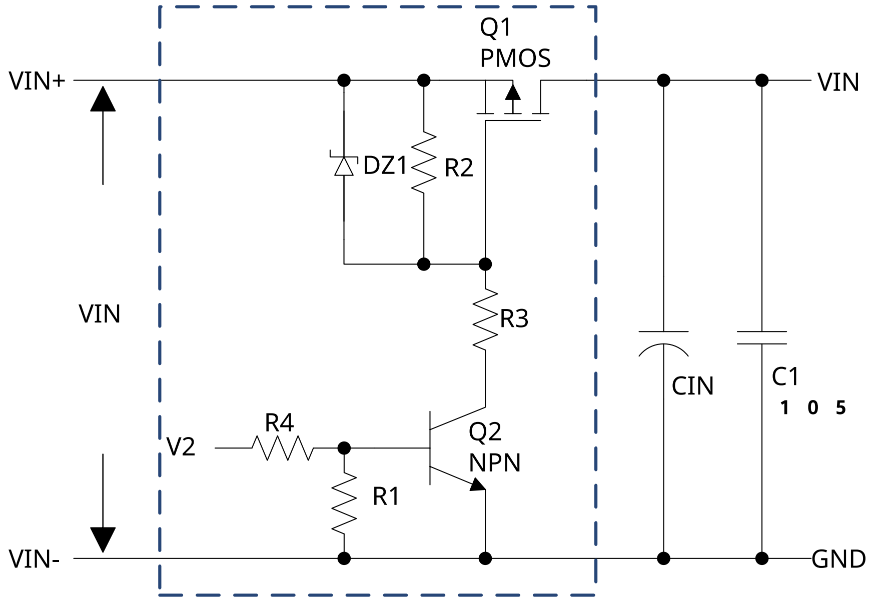
Q1: VDS≥1.5*VINMAX;

DZ1: VDZ1=10V, 500 mW;

R1, R2, R4: 20 K;

R3: 30 K;

Q2: VCE≥1.5*VINMAX.



Q9. The chip does not work

- In the application of adding undervoltage protection, confirm whether the parameters of the undervoltage protection circuit are wrong (the value of DZ is inappropriate, and the voltage of EN pin to ground is lower than 0 .8V);
- Check whether the voltage divider resistor R1 has virtual or missing soldering.

Q10. The difference between the output voltage and the set value is large

- Confirm whether the voltage divider resistors R1 and R2 are soldered or missing;
- Whether the input capacitor is placed close to the chip VIN and GND;
- Whether the PCB trace width of the large current path is sufficient;
- Whether the inductor is a power inductor, whether the inductance and current capacity are sufficient;
- Whether the freewheeling diode is selected as Schottky.