Design Consideration with AP3041

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1. Introduction

The AP3041 is a current-mode, high-voltage low-side channel MOSFET controller, which is ideal for boost regulators. It contains all the features needed to implement single-ended primary topology DC/DC converters.

The input voltage of AP3041 ranges from 5V to 27V. Its operation frequency is adjustable from 100kHz to 1MHz.

The AP3041 has UVLO (Under Voltage Lock Out) circuit. It uses two external resistors to set the UVLO voltage. The AP3041 also has an over output voltage protection to limit the output voltage. The OVP voltage can be set through external resistors. If the output voltage is higher than the OVP high threshold point, it will disable the driver and the system is latched up. The output short circuit protection as well as LED low side short to ground detection function can be applied in system.

The AP3041 has other protection functions, such as LED short protection, LED high-side short to ground protection, diode short protection, over current protection, over temperature protection and so on. The AP3041 is available in SOIC-16 package.

2. Functional Block Description

The pin configuration and the representative block diagram of the AP3041 are respectively shown in Figure 1 and Figure 2.

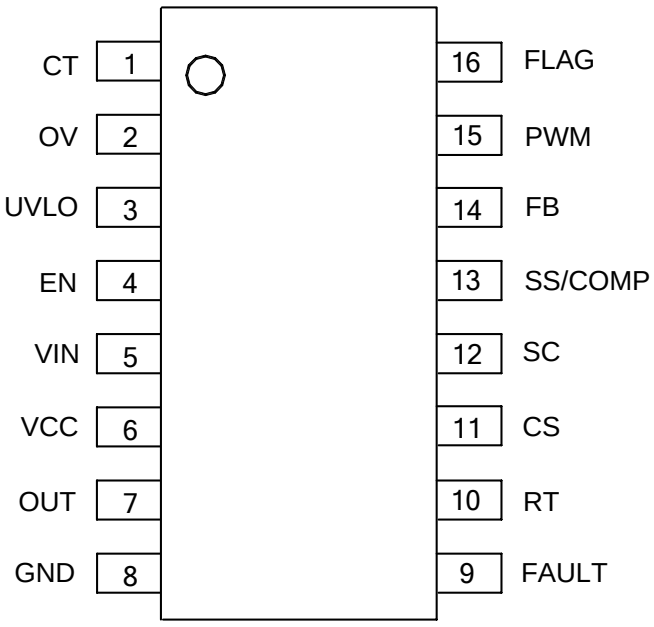

Figure 1. Pin Configuration of AP3041 (Top View)

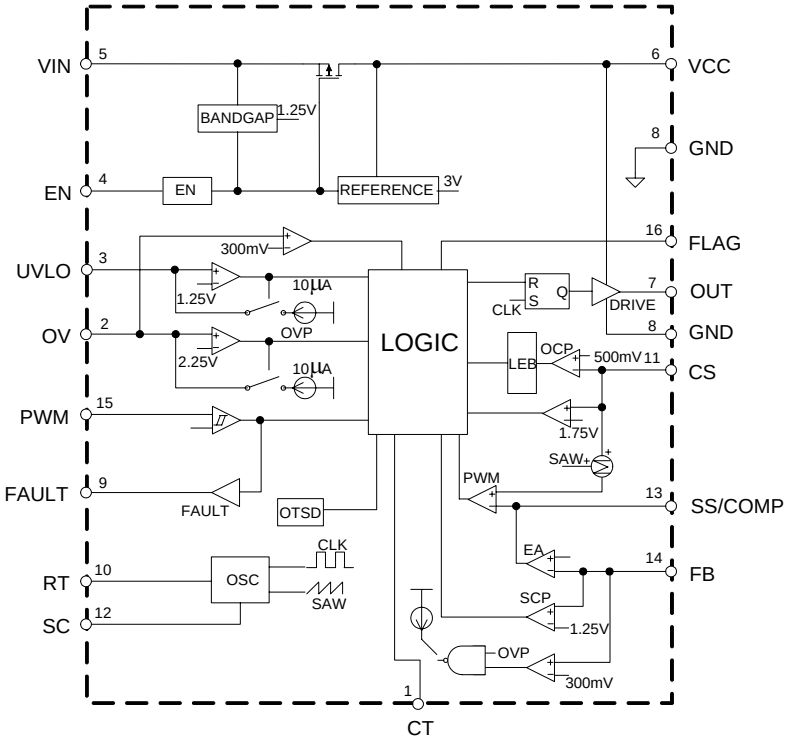

Figure 2. Functional Block Diagram of AP3041

3. Operation

The AP3041 is a current-mode control LED driver IC designed to control single switch PWM converters in a constant frequency mode. The controller uses a peak current-mode control scheme (with programmable slope compensation) and includes an internal transconductance amplifier to accurately control the output current over all line and load conditions. The external 10V FET drivers ($11V<V_{IN}<27V$) allow for the use of standard level MOSFETs.

Operation can be best understood by referring to the Figure 2. At the start of each oscillator cycle, the SR latch is set and external power switch Q1 (refer to Figure 3 and 4) turns on. The switch current will increase linearly. The voltage on external sense resistor R_{CS} (refer to Figure 3 and 4), which connected from CS pin to GND, is proportional to the switch current. This voltage is added to a stabilizing ramp and the result is fed into the non-inversion input of the PWM comparator. When this non-inversion input voltage exceeds inversion input voltage of PWM comparator, which is the output voltage level of the error amplifier EA, the SR latch is reset and the external power switch turns off. It is clear that the voltage level at inversion input of PWM comparator sets the peak current level to keep the output in regulation. The output voltage level is the amplified signal of the voltage difference between feedback voltage and reference voltage of 0.5V. So, a constant output current can be provided by this operation mode. When the AP3041 is enabled, the chip checks the topology connection first. The FLAG pin drives the external PMOS to turn on slowly. Then the chip monitors the OV pin if the Schottky diode is not connected or the boost output is short to GND. If the OV voltage is lower than 0.3V, the chip will be disabled and the external PMOS is turned off together. If they are all in function, it then starts boosting the step-up converter with soft-start.

The AP3041 offers complete protection features such as power MOSFET over current protection (OCP), over voltage protection (OVP), output-to-ground short-circuit protection, LED cathode-to-anode short-circuit protection, LED cathode-to-ground short-circuit protection, rectifier diode short-circuit protection and thermal protection.

4. Typical Application

In Figure 3 and 4, input capacitor C_{IN}, output capacitor C_{OUT} , inductor L, switch Q1 and diode D1 build a typical boost converter. The output current is decided by R5 and internal 0.5V reference of AP3041. (The external function will be introduced later).

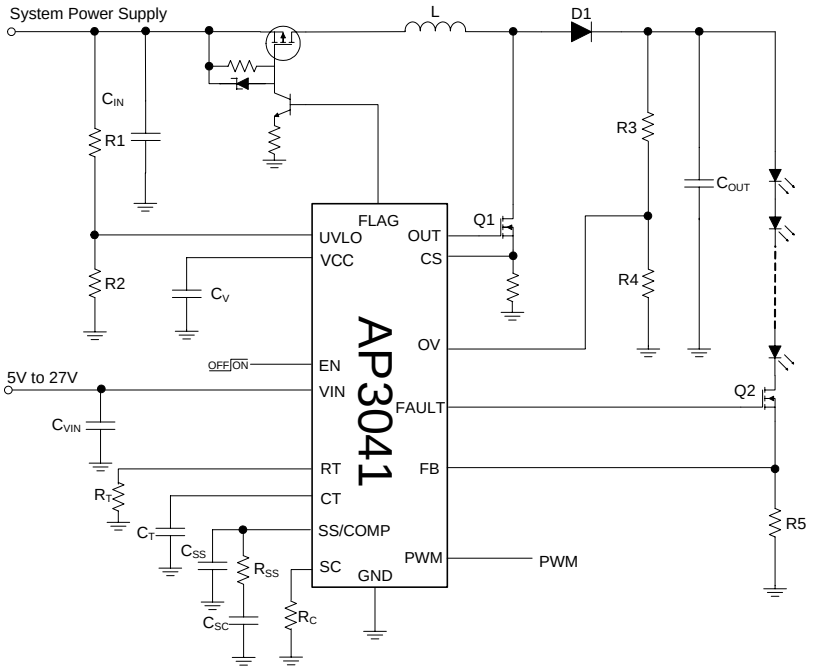

Figure 3. Typical Application Circuit of AP3041 (For General Use)

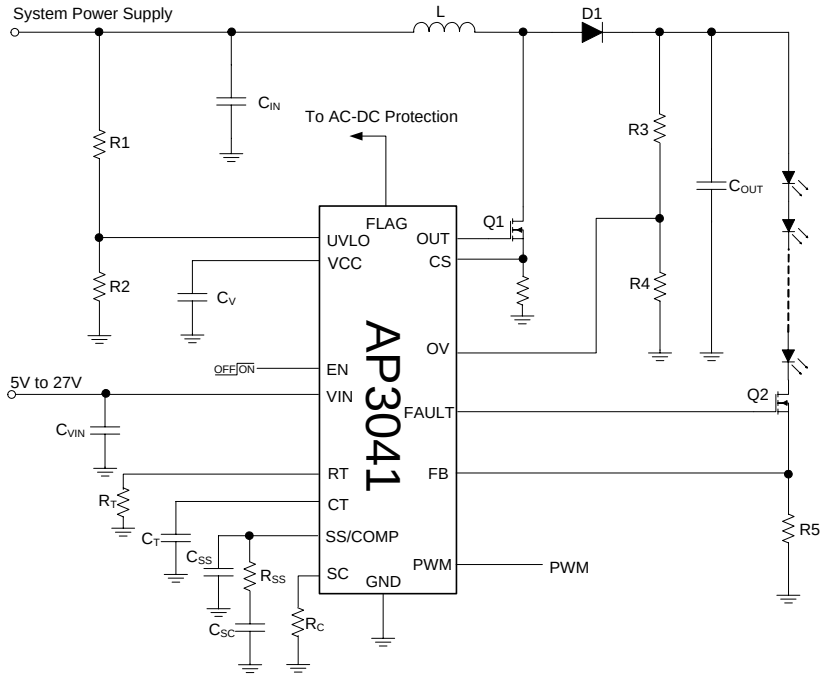

Figure 4. Typical Application Circuit of AP3041 (For AC-DC&LED Backlighting, 2-in-1 Solution)

4.1 System Start-up

The AP3041 is enabled by applying a voltage of greater than 2.0V to pin EN. When the AP3041 is enabled, the chip checks the topology connection first, and monitors the OV pin to see whether the Schottky diode is not connected or the boost output is short to GND. If the OV voltage is lower than 0.3V, the chip will be disabled. The AP3041 will also check other safety limits, including UVLO, OCP and OTP after passing OV test. If they are all in function, it then starts boosting the step-up converter with an external soft-start.

The AP3041 has a soft-start circuit to limit the inrush current during start-up. The time of startup time is controlled by an internal 20μA current source and an external soft-start capacitor C_{SS} connected from SS/COMP pin to GND (see Figure 3). An under-voltage lockout protection feature is provided by VCC pin. If the voltage at pin VCC drops below a threshold of approximately 4.7V, the IC will lockout. The IC resumes operation when the voltage at pin VCC exceeds a threshold of approximately 5.0V. It is recommended on the start-up sequence that the enable signal comes after input voltage and PWM dimming signal established.

4.2 High Operation Frequency Selection

The controller operates in a fixed frequency mode. The constant operation frequency is user-defined by external resistor R_T connected between pin RT and GND. The operation frequency can be approximated by the below curve:

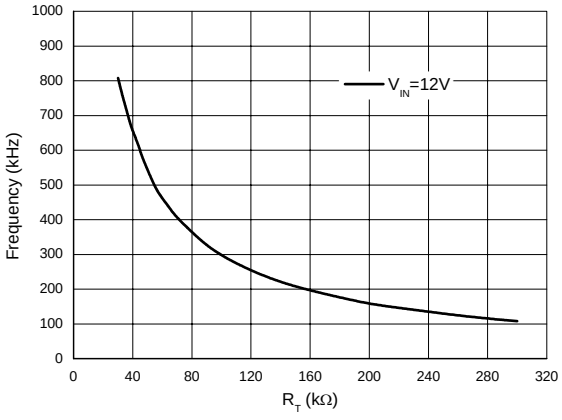

Figure 5. Frequency vs. R_T

4.3 LED Current Regulation and PWM Dimming Control

The LED current is controlled by the feedback resistor (R5 in Figure3). LED current accuracy is determined by the regulator's feedback threshold accuracy and is independent of the LED's forward voltage variation. So, precision resistors are preferred. The resistance of R5 is in inverse proportion to the LED current since the feedback reference is fixed at 500mV. The formula for R5 and LED current can be expressed as below:

$$I_{LED} = \frac{500mV}{R5}(mA)$$

For R5=4.2Ω, the LED current is set to 120mA.

External PWM dimming control is achieved by applying an external PWM signal with a peak of greater than 2.0V and a valley of less than 0.5V to pin PWM. When the voltage at pin PWM exceeds a threshold of 2.0V, the LED string is turned on. When the voltage at pin PWM is less than a threshold of 0.5V, the LED string is turn off.

The AP3041 provide minimum on-time feature. If PWM dimming signals on time is less than 4 to 5 oscillators time, the LED turning-on time hold for 4 to 5 oscillator time (see Figure 6). The PWM dimming range of the AP3041 is $0\% < D_{PWM} \leq 100\%$.

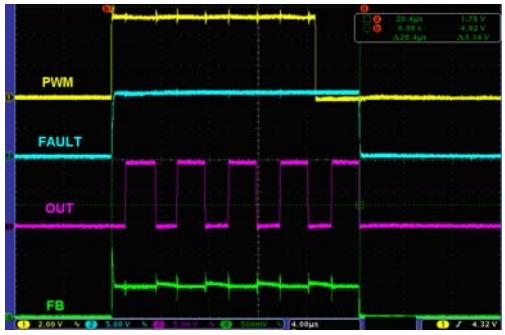

Figure 6. Dimming Minimum on Time Control

4.4 Slope Compensation

Choosing a slope compensation that is one half of the down slope of the inductor current ensures that the converter will be stable for all duty cycles. The slope compensation in AP3041 can be programmed by one external resistor R_{SC} connected between pin SC and

GND (Figure 3). A slope voltage, proportional to the switching frequency, is sourced out of the SC pin. The voltage at the CS pin is then the sum of the voltage across the resistor and the voltage across the current sense resistor, with the voltage across the resistor providing the required slope compensation.

5 Protection Features

5.1 Output Short Circuit Protection

At the normal operation or after soft-start condition, an output-to-ground short-circuit condition is triggered when the voltage at pin OV is less than a threshold of approximately 0.3V. The system remains in lockout mode (OUT and FAULT turned off) and the status of pin FLAG become low.

When short-circuit condition is removed, the voltage at the OV pin rises up approximately 0.3V, with the output returning to normal operation.

5.2 WLED Low-side Short to Ground Detection

When LED low-side is short to ground, the device should check whether the soft-start is finished. If the system is on soft-start condition, this function detection is disabled, and it should wait until the soft-start is finished. At normal operation or after soft-start condition, if this error continues, it will cause FB voltage lower than 0.3V and trigger the internal 5μA current source to begin charging an external C_T capacitor to 2.6V and then give a fault output as well as latching-up the system. The system remains in lockout mode (OUT and FAULT turned off) and the status of pin FLAG become low. Toggle EN or VIN pin to restart the system. The delay time of system is determined by the C_T capacitor.

$$t = \frac{2.6V \times C_T}{5\mu A}$$

Once V_{FB} rises up by a threshold of approximately 0.3V before V_{CT} exceeds a threshold of approximately 2.6V, the output resumes normal operation and capacitor C_T is discharged.

5.3 WLED High Side Short to Low Side Protection

When the LED high voltage output is short to LED return path during normal operation, the V_{FB} will be higher than 1.25V. The LED dimming MOSFET Q2 and boost MOSFET Q1 is turned off immediately to limit the inrush current, then system shutdown and latch-up. The system remains in lockout mode (OUT and FAULT turned off) and the status of pin FLAG becomes low. The FB input of AP3041 includes a built-in 1μs (minimum) blanking time to prevent the noise at FB pin. Toggle EN or VIN pin to restart the system.

5.4 Input Under Voltage Protection

The AP3041 contains an Under Voltage Lock Out (UVLO) circuit. Two resistors R1, R2 are connected from UVLO pin to ground and the system power supply. The resistor divider must be designed such that the voltage on the UVLO pin is higher than 1.25V when system power supply voltage is in the desired operating range. If this under voltage threshold is not met., all functions of AP3041 are disabled and the system remains in a low-power standby state. The UVLO hysteresis is accomplished through an internal 10μA current source that is switched on or off into the impedance of the set-point divider. When the UVLO threshold is exceeded, the current source is activated to instantly raise the V_{UVLO}. When V_{UVLO} voltage falls below the threshold the current source is turned off, causing the voltage on the UVLO pin to fall. The formula for UVLO can be expressed as blow:

For the input threshold voltage,

$$V_{IN\_THRESHOLD} = 1.25 \times \frac{R1 + R2}{R2}$$

For the input hysteresis voltage,

$$V_{IN\_HYSTERSIS} = 10 \times R1$$

5.5 Over Voltage Protection

The AP3041 has an Over Voltage Protection (OVP) circuit. The OV pin is connected to the center tap of a resistive voltage-divider from the high voltage output to GND (refer to Figure 3). During normal operation, when the loop is open or the output voltage becomes excessive in any case, resulting in V_{OV} exceeding 2.25V, all functions of the AP3041 are disabled, while SSCOMP pin voltage is kept floating to maintain the drive duty cycle. The capacitor C_T connected to pin CT is charged by a 5μA internal current source.

Once the voltage at the OV pin drops below the threshold of 2.25V before the voltage at CT pin exceeds a threshold of approximately 2.6V, the system resumes normal operation and capacitor C_T is discharged.

If the over voltage condition still exists when the voltage at CT pin exceeds a threshold of 2.6V, the system is shut down and latch-up. The system remains in lockout mode (OUT and FAULT turned off) and the status of pin FLAG become low. The OVP hysteresis is accomplished with an internal 10μA current source and the operation mode is the same as UVLO. The formula for OVP can be expressed as:

For OVP threshold voltage,

$$V_{OVP} = 2.25\left(\frac{R3+R4}{R4}\right)$$

For OVP hysteresis,

$$V_{OVP\_HYSTERSIS} = 10 \times R3$$

Toggle EN or VIN pin to restart the system.

5.6 Power MOS Over Current Protection

The switching current of the power MOSFET is sensed by their respective resistors connected to pin CS. When the voltage at CS pin (V_{CS}), exceed a threshold of approximately 0.5V, the power MOSFET over current protection function is triggered. The power MOSFET is turned off immediately and is not turned on until the next operation cycle. The CS input of the AP3041 includes a built-in 100ns (minimum) blanking time to prevent spurious turn off due to the initial current spike when the MOSFET turns on.

5.7 Diodes Short Protection

When diodes cathode short to anode at soft-start or normal operation, the V_{CS} is higher than 1.75V and the system will be latched-up. The system remains in lockout mode (OUT and FAULT turned off) and the status of pin FLAG becomes low.

The CS input of the AP3041 includes a built-in 150ns (minimum) blanking time to prevent spurious turn off due to the initial current spike when the MOSFET turns on.

Toggle EN or VIN pin to restart the system.

5.8 Thermal Protection

If ≥160ºC junction temperature sensed by the thermal protection circuit, the LED switch Q1 and Q2 is turn off immediately to prevent the device from damage. The thermal protection and shutdown circuit has a 20ºC system hysteresis, which can prevent the converter from thermal damage under unexpected condition.

5.9 Fault Status Indicator

During normal operation, the FLAG pin outputs logic high. When the IC enters the shutdown or lock-out mode to any reason, as above description, pin FLAG becomes low. Utilizing this function, signal form pin FLAG can cut off the power supply under the fault condition.

6. Layout Consideration

The RT, CT, SC and SS/COMP pins are mainly dealing with small signal, so place the corresponding components as close to the corresponding pins of device as possible.

There are two high-current loops in the solution. One is the high-current input loop, and the other is the high-current output loop. The high-current input loop goes from the positive terminal of the C_{IN} to the inductor, to the MOSFET, then to the current-sense resistor, and to the C_{IN}'s negative terminal. The high-current output loop goes from the positive terminal of the C_{IN} to the inductor, to the diode, to the positive terminal of the C_{OUT}, reconnecting between the C_{OUT} and the C_{IN} ground terminals. Minimize the area of the two high-current loops to avoid excessive switching noise. The trace connected with these two high-current loops must be short and thick.