Design Consideration with AP3211

Prepared by Ji Jin
System Engineering Dept.

1. Introduction

The AP3211 is a 1.4MHz fixed frequency, current mode, PWM buck (step-down) DC-DC converter, capable of driving a 1.5A load with high efficiency, excellent line and load regulation. The device integrates N-channel power MOSFET switch with low on-resistance. Current mode control provides fast transient response and cycle-by-cycle current limit.

A standard series of inductors are available from several different manufacturers optimized for use with the AP3211. This feature greatly simplifies the design of switch-mode power supplies.

This IC is available in SOT-23-6 package.

2. Function Block Description

The pin configuration and the representative block diagram of the AP3211 are respectively shown in Figure 1.

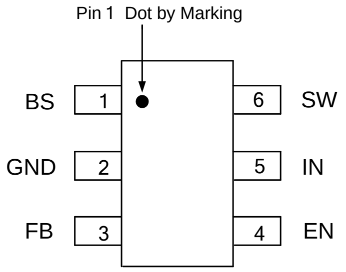


Figure 1. Pin Configuration of AP3211 (Top View)

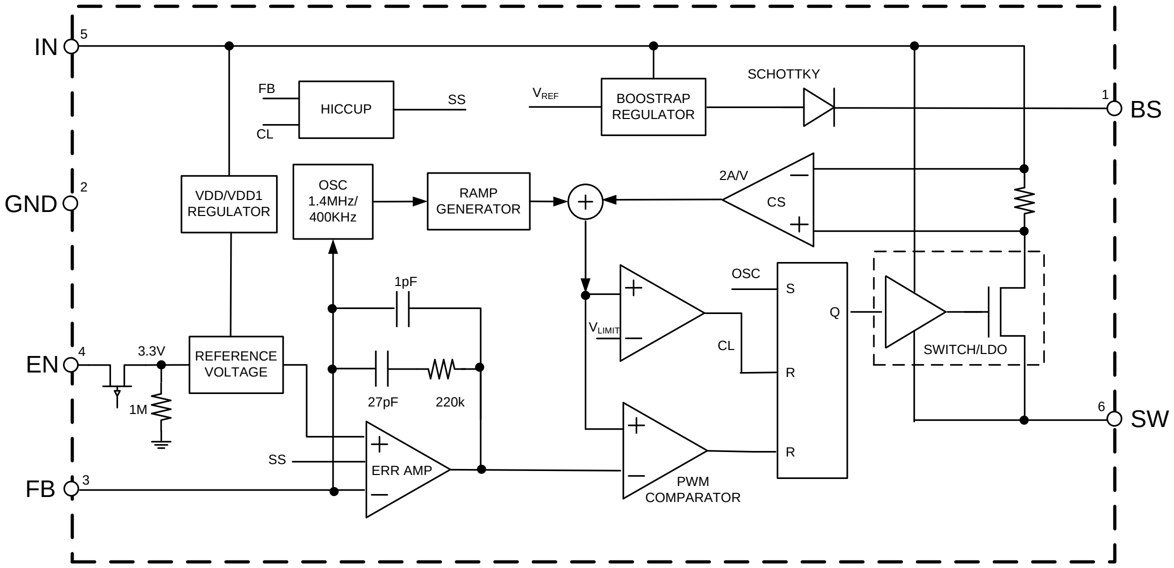


Figure 2. Functional Block Diagram of AP3211

3. Operation

Operation can be best understood by referring to Figure 2 and Figure 3. The current sense signal is compared with the EA output signal to regulate the output voltage and adjust the MOSFET's duty cycle. The AP3211 is also high reliability IC with integrated OCP, OVP, OTP, UVLO circuit. For more information please refer to the functional block diagram (Figure 2).

3.1 Over Current Protection

The AP3211 has internal over current protection function to protect from catastrophic failure. The AP3211 can monitor the drain-to-source current of MOSFET. The peak current-limit threshold is internally set at 2.4A. When the inductor current is higher than the current limit threshold, OCP function will be triggered, forcing MOSFET to turn off, and working in the hiccup mode, which will turn on MOSFET after a constant delay time to keep IC cool when OCP happens.

3.2 Over Voltage Protection

The AP3211 has internal OVP circuits. When V_{OUT} is higher than the OVP threshold, the power switching will be turned off. The AP3211 will restart once released from OVP condition.

3.3 Over Temperature Protection

The OTP circuitry is provided to protect the IC if the maximum junction temperature is exceeded. When the junction temperature exceeds 160ºC, it will shut down the internal control circuit. The AP3211 will restart automatically under the control of soft-start circuit when the junction temperature decreases to 140ºC.

3.4 Under Voltage Lock Out

The AP3211 provides an under voltage lockout circuit to prevent it from undefined status when startup. The UVLO circuit shuts down the device when VIN drops below 3.8V. The UVLO circuit has 200mV hysteresis, which means the device starts up again when VIN rises to 3.6V.

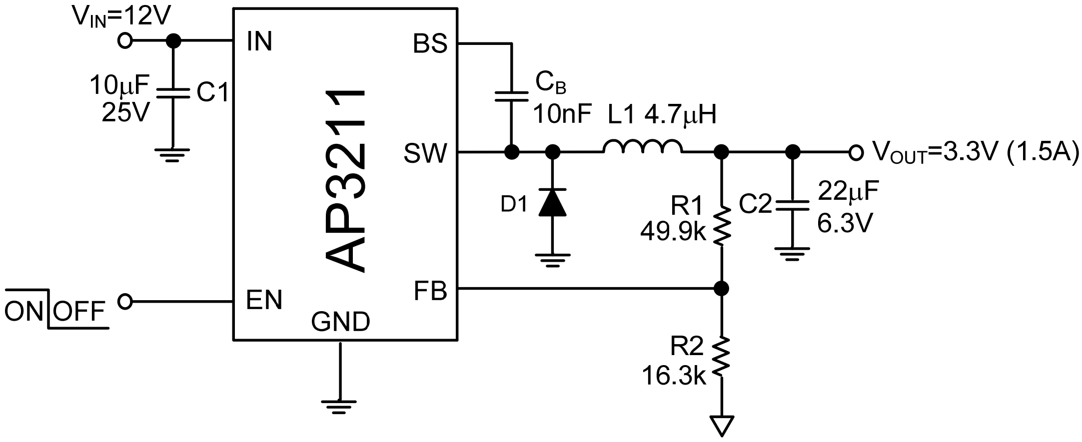


Figure 3. Typical Application of AP3211

4. Application

Typical application circuit is shown in the Figure 3. For the circuit parameters setting please refer to the following descriptions.

4.1 Output Voltage Setting

The output voltage can be set using a voltage divider from the output to FB pin. V_{OUT} is divided by the voltage divider as below:

$$V_{FB} = V_{OUT} \times \left(\frac{R_2}{R_1 + R_2} \right)$$

Where V_{FB} is the feedback voltage, and V_{FB}=0.81V. Thus, V_{OUT} can be expressed as:

$$V_{OUT} = 0.81 \times \left(\frac{R_1 + R_2}{R_2} \right)$$

4.2 Inductor Setting

The inductor is used to supply smooth current to output when driven by a switching voltage. Its value relies on the operating frequency, load current, ripple current and duty cycle. A higher-value inductor can decrease the ripple current and output ripple voltage, however usually with larger physical size. So some compromise needs to be made when selecting the inductor. The peak-to-peak inductor ripple current is 26% of the maximum output current when operating in continuous mode (In most applications, a good compromise is from 20% to 30% of the maximum load current of the converter), and the inductor L1 can be selected according to:

$$L1 = V_{OUT} \times \frac{V_{IN} - V_{OUT}}{f_{SW} \times V_{IN} \times I_{OUT} \times 26\%}$$

Where V_{IN} is the input voltage, I_{OUT} is the output current, and f_{SW} is the oscillator frequency.

Another important parameter for the inductor is the current rating. After fixing the inductor value, the peak inductor current can be expressed as:

$$I_{PEAK} = I_{OUT} + \frac{(V_{IN} - V_{OUT}) \times V_{OUT}}{2 \times f_{SW} \times V_{IN} \times L1}$$

Where I_{PEAK} is the peak inductor current.

The current rating of the selected inductor should be ensured to be 1.5 times of the peak inductor current.

4.3 Input Capacitor Setting

A high-quality input capacitor with big value is needed to filter noise at input voltage source and limit the input ripple voltage while supplying most of the switch current during ON time. For input capacitor selection, a ceramic capacitor is highly recommended due to its low impedance and small size. However, tantalum or low electrolytic capacitor is also sufficed.

There are two important parameters of the input capacitor: the voltage rating and RMS current rating.

The voltage rating should be at least 1.25 times greater than the maximum input voltage, and the RMS current of input capacitor can be expressed as:

$$I_{CIN\_RMS} = I_{OUT} \times \sqrt{\frac{V_{OUT}}{V_{IN}} \left(1 - \frac{V_{OUT}}{V_{IN}} \right)}$$

Where I_{CIN_RMS} is the RMS current of input capacitor. As indicated by the RMS current equation above, I_{CIN_RMS} reaches the highest level at the duty cycle of 50%. So the RMS current of input capacitor should be greater than half of the output current under this worst case. For reliable operation and best performance, ceramic capacitors are preferred for input capacitor because of their low ESR and high ripple current rating. And X5R or X7R type dielectric ceramic capacitors are preferred due to their better temperature and voltage characteristics. Additionally, when selecting ceramic capacitor, make sure its capacitance is big enough to provide sufficient charge to prevent excessive voltage ripple at input. The input ripple voltage can be approximately expressed as below:

$$\Delta V_{IN} = \frac{I_{OUT}}{f_{SW} \times C_{IN}} \times \frac{V_{OUT}}{V_{IN}} \left(1 - \frac{V_{OUT}}{V_{IN}} \right)$$

4.4 Output Capacitor Setting

The output capacitor can be selected based upon the desired output ripple and transient response. The output voltage ripple depends directly on the ripple current and is affected by two parameters of the output capacitor: total capacitance and the Equivalent Series Resistance (ESR). The output ripple voltage can be expressed as:

$$\Delta V_O = \Delta I_L \times \left[R_{ESR} + \frac{1}{8 \times C_{OUT} \times f_{SW}} \right]$$

Where ΔV_O is the output ripple voltage and R_{ESR} is ESR of output capacitor. For lower output ripple voltage across the entire operating temperature range, X5R or X7R ceramic dielectric capacitor, or other low ESR tantalum capacitor or aluminum electrolytic capacitor are recommended.

The output capacitor selection will also affect the output drop voltage during load transient. The output drop voltage during load transient is dependent on many factors. However, approximations of the transient drop ignoring loop bandwidth can be expressed as:

$$V_{DROP} = \Delta I_{TRAN} \times R_{ESR} + \frac{L \times \Delta I_{TRAN}{}^{2}}{C_{OUT} \times (V_{IN} - V_{OUT})}$$

Where ΔI_{TRAN} is the output transient load current step, and V_{DROP} is the output voltage drop (ignoring loop bandwidth).

Both the voltage rating and RMS current rating of the capacitor need to be carefully examined when designing a specific output ripple or transient drop. The output capacitor voltage rating should be greater than 1.5 times of the maximum output voltage. In the buck converter, output capacitor current is continuous. The RMS current is decided by the peak-to-peak inductor ripple current. It can be expressed as:

$$I_{COUT\_RMS} = \frac{\Delta I_L}{\sqrt{12}}$$

Where I_{COUT_RMS} is the RMS current of output capacitor.

4.5 Schottky Diode Selection

There are two principles in selecting a Schottky diode in buck application with the AP3211. The first is low forward voltage drop and the second is fast switching speed, which can decrease the Schottky power loss and increase conversion efficiency. The reverse breakdown voltage of the Schottky diode should be larger than the output voltage and the average current rating of the Schottky should be larger than the I_{PEAK}.

4.6 Feedback Resistor Network Selection

The AP3211 integrates loop compensation inside, optimal compensation depends on the output capacitor, inductor, load, compensation network, feedback resistor ratio and also the device itself. For a stable system, the values for the feedback resistor network are shown in Table 1.

V_{OUT} (V)	R1(kΩ)	R2(kΩ)
1.8	80.6 (1%)	64.9 (1%)
2.5	49.9 (1%)	23.7 (1%)
3.3	49.9 (1%)	16.2 (1%)
5	49.9 (1%)	9.53 (1%)

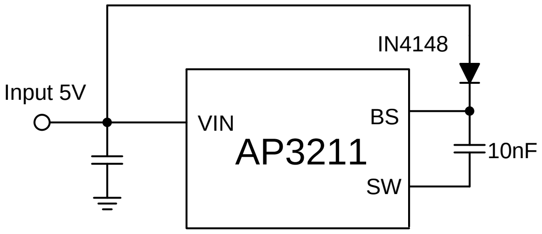
Table 1. Resistor Selection for Common Output Voltages

4.7 Bootstrap Capacitor

The bootstrap capacitor provided is used to drive the power switch's gate above the supply voltage. The bootstrap capacitor is supplied by an internal 5V supply and placed between SW pin and BS pin to form a floating supply across the power switch driver. So the bootstrap capacitor should be a good quality and high-frequency ceramic capacitor. For best performance, the bootstrap capacitor should be X5R and X7R ceramic capacitor, and is recommended to be 10nF.

4.8 External Bootstrap Diode

A low-cost external diode, such as IN4148, is recommended for higher efficiency when the system has a 5V fixed input or a 5V/3.3V output voltage. The bootstrap capacitor is also recommended to be used to increase the available voltage for power switch in the applications that the duty cycle is larger than 65% or the output voltage (V_{OUT}) is larger than 12V.



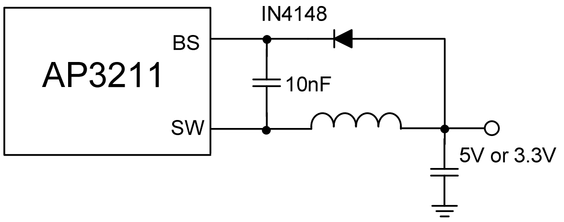


Figure 4. Application of Adding Optional External Bootstrap Diode

5. PCB Layout Guidance

PCB layout is an important part for DC-DC converter design. Poor PCB layout may reduce the converter performance and disrupt its surrounding circuitry due to EMI. A good PCB layout should follow guidance below:

5.1 Power Path Length

The power path of AP3211 includes an input capacitor, output inductor, Schottky diode and output capacitor. Place them on the same side of PCB and connect them with thick traces or copper planes on the same layer. The power components must be kept together closely. The longer the paths, the more they act as antennas, radiating unwanted EMI.

5.2 Coupling Noise

The external control components should be placed as close to the IC as possible.

5.3 Feedback Net

Special attention should be paid to the route of the feedback wring. The feedback trace should be routed far away from the inductor and noisy power traces. Try to minimize trace length to the FB pin and connect feedback network behind the output capacitors.

5.4 Via Hole

Be careful to the via hole. Via hole will result in high resistance and inductance to the power path. If heavy switching current must be routed through via holes and/or internal planes, use multiple parallel via holes to reduce their resistance and inductance.

Typical examples of AP3211 PCB layer are shown in Figure 5, 6, 7.

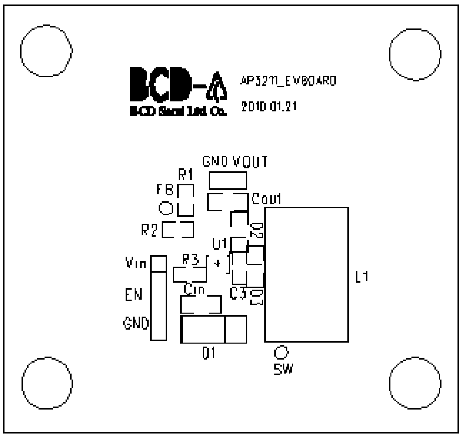


Figure 5. Demo Board Top Layer (Silkscreen)

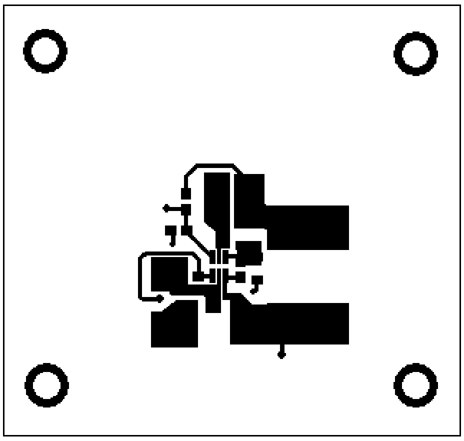


Figure 6. Demo Board Top Layer (Component Side)

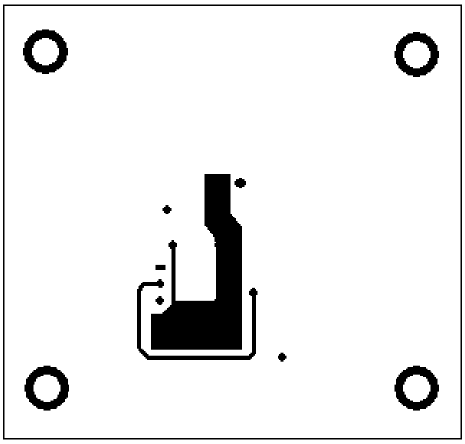


Figure 7. Demo Board Bottom Layer