UNITRODE
Design Note

Innovative Buck Regulator Uses High Side N-Channel Switch Without Complex Gate Drive

Converts +5 VDC to +3.3 VDC (or others) and draws only 40 microamps in standby mode

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Obtaining very high efficiency in a voltage step-down (Buck regulator) application often requires the use of N channel, low on-resistance MOSFET switches. The difficulty in driving these enhancement mode devices on the high side of a converter is that they require a gate voltage above the input supply to turn-on. This necessity demands an additional supply voltage solely for the high side gate drive. Although P channel devices are a viable alternative for the sake of gate drive simplicity, their associated cost and higher on resistance limits the number of applications. Typically, P channel FETs are used in Buck regulators with output currents below 4 amps, or so. However, the demand of many 1.8 volt through 3.3 volt logic systems is often in the neighborhood of 10 amps, forcing the use of N channel devices.

The circuit shown in Figure 1. incorporates the UCC3803 BiCMOS PWM controller in a conventional voltage mode controlled Buck regulator application. Normally, the IC needs to be supplied with a separate 12 volt supply from the input to the Buck converter. As the MOSFET is switched on, it's source approaches it's drain voltage (5V) and the gate is driven seven volts higher to the IC's 12 volt supply. Logic level MOSFETs are required for this application which become fully enhanced with only five (or so) volts gate to source in comparison to standard devices which require about ten volts. When Q1 is turned off, the gate is driven to ground by the IC's output and diode DO then conducts the full output current of the regulator.

What's unique about this circuit configuration is the way in which VCC is supplied to the IC. Diode D1 is used to route the initial power to the UCC3803's VCC pin from the 5 volt input. Notice

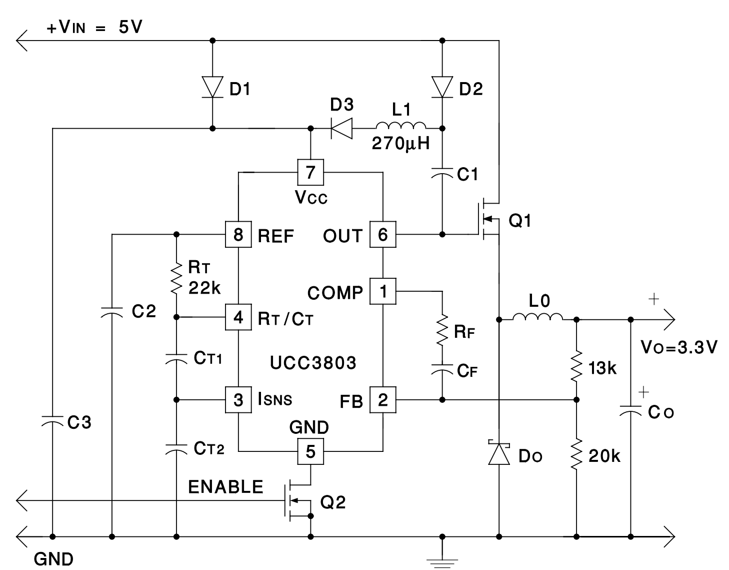

Figure 1. Buck Regulator with High Side NMOS

that diode D2 and capacitor C1 are connected between V_{IN} and the IC's output, pin 6. While the IC is off, it's output is low and capacitor C1 is charged to V_{IN}, or 5 volts. Once the 4.1 volt undervoltage lockout threshold of the IC is crossed, it's PWM output begins switching and goes high. The upper totem-pole transistor within the IC forces the lower end of capacitor C1 (connected to pin 6) up towards the IC's supply voltage, V_{CC}. The initial charge stored by the 5V across C1 is then directed to V_{CC} through diode D3. Essentially, a quasi-resonant tank circuit is formed by the following components; the UCC3803's output, C1, L1 and D3. This simple circuit configuration replenishes the supply voltage (V_{CC}) each time the PWM output switches. After a few initial switching cycles, the ICs supply voltage (V_{CC}) is increased to approximately twice V_{IN}, or about 10 volts. This is a sufficient amplitude to properly drive Logic Level N Channel FETs on the high side of a Buck Regulator. The UCC3803's internal 12 volt supply clamp can also be used to supply a better regulated supply voltage, however any excess current will be shunted to ground. This will reduce overall efficiency slightly, but will immunize the supply voltage from any duty cycle related variations.

The ideal value of inductor L1 is determined by several operating conditions. The critical ones are switching frequency, duty cycle, IC supply current and the current required to supply the MOSFET's gate charge (Q_g) demand. For most high frequency applications, the inductance is in the range of about 50 to 300 microHenries. Note that small, inexpensive surface mount or axial thru-hole components the size of a half-watt resistor are ideal candidates. A one time "tweaking" of the exact value during the prototype stage may be required to deliver the best performance over all line and load conditions. Once the best value is established, an adequate supply voltage will obtained over all specified operating conditions.

Operating at 500kHz, the UCC3803 and bootstrap circuit will collectively draw 8 milliamps from the 5 volt input while boosting the supply voltage to approximately 9 volts. Input current rises to around 12mA in order to raise the supply voltage to 11.5 volts. This amplitude is just below the V_{CC} supply clamp voltage threshold of the UCC3803 IC. In most applications, the DC current from the 5 volt input source required to charge the MOSFET gate will be around 20mA, which adds to the IC and bootstrap circuit demands. Typical consumption of the entire working control circuit will be in the 30 to 50mA range, depending on frequency and MOSFET selections.

A low current standby mode can be obtained by using a small logic level MOSFET to switch the IC's ground connection in and out of circuit. When disabled, the entire circuit draws approximately 40 microamps from a 5 volt input. Other adaptations are possible, as shown in Application Note U-133 of the Unitrode IC databook.

Circuit Modifications:

Other output voltages (2.0, 2.2, 2.5, 2.75, 3.0 VDC) :

Any desired output voltage between 2.0V and V_{IN} can be developed using the exact circuit schematic of Figure 1. The modifications required are only to the component values used in the Buck regulator section (L_{OUT}, C_{OUT} and R1), although some adjustment of L1 may also be needed.

High current output:

A high current output can also be achieved using the schematic of Figure 1. by selecting the components appropriately for the higher output power.

Component List:

C1, C2	0.01µF/16 VDC
C3	1µF/16 VDC
C_{T1}	150pF/10VDC
C_{T2}	270pF/10 VDC
D1, D2, D3	1N4148
U1	UCC3803

NOTE : All other components and values depend upon the exact application.

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