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e^2PowerEdge™

Economic Energy using Low V_{CEsat} BJT's

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Introduction

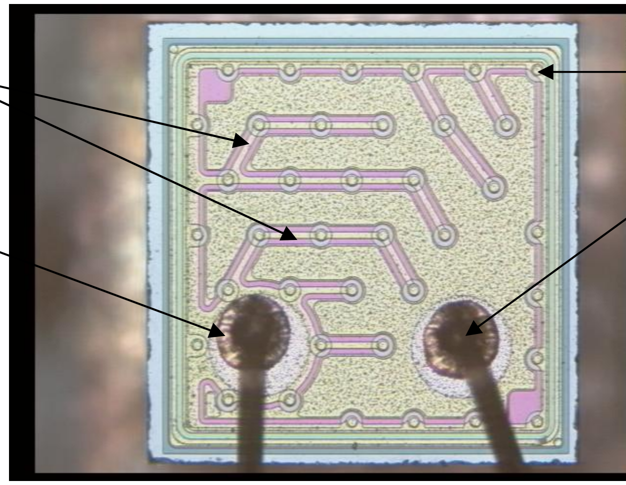
ON Semiconductor's e^2PowerEdge™ family of low V_{CEsat} Bipolar Junction Transistors (BJT) are miniature surface mount devices featuring ultra low saturation voltage V_{CEsat} and high current gain capability. These are designed for use in low voltage, high speed switching applications where affordable efficient energy control is important. Typical application are power management in any circuit that needs low losses.

In portable and battery powered products such as cellular and cordless phones, PDAs, computers, printers, digital cameras, digital camcorders, DVD players and MP3 players. The functions controlled in portable products are battery charging, battery management, over voltage protection, low drop out regulation, LED backlight switching, Royer converter for LCD Backlights, vibrator, disc drives, and peripheral power, such as cameras and flash units.

Other applications are low voltage servo motor controls in mass storage products such as disc drives and tape drives; controlling small motors as in electric shavers. In the automotive industry they can be used in air bag deployment, controlling mirrors and fuel pumps, and in circuits used for instrument clusters, steering, transmission, toll readers, LED lighting and power inverters. In industrial applications they are ideal for circuits providing control in smoke detectors, vending machines, In Focus projectors, gas meters, Telecommunication SLIC and RF access boxes. Where high currents need to be controlled at high frequencies the Low V_{CEsat} BJT is the ideal driver for a highly efficient Trench MOSFET. The Linear Gain (Beta) of Low V_{CEsat} BJT makes them ideal components in analog amplifiers.

Technology

The Low V_{CEsat} BJT devices use a technology that was first developed over 20 years ago and was primarily used to achieve similar performance in a smaller die (die shrink). This technology is called a "Perforated Emitter" and today is being focused towards reducing the forward saturation voltage to achieve very low forward resistance. The perforated emitter is a method of extending the base electrical layer across the complete die to contact multiple perforations through the emitter. Each of these perforations creates miniature transistors within the device and thus allows the current to be distributed evenly and with greater efficiency. Photograph 1.



Photograph 1

Some of the new Low V_{CEsat} BJT's are now available with a saturation voltage at 1.0 Amps of well under 50 mV. This equates to a forward resistance of under 50 mΩ, and proves very competitive against a higher cost MOSFET.

PMU with an external pass transistor

The majority of portable products are moving towards an integrated Power Management Unit (PMU) circuit designed specifically to control the different functions within the product. The circuits, for the control of currents under 100 mA, are typically all imbedded within the PMU, including the final pass transistor. However, for the control of currents from 100 mA to 5.0 A an external pass transistor (MOSFET) is the typical design of choice. An alternative to the MOSFET is to use a lower cost Low V_{CEsat} BJT. The new family of Low V_{CEsat} BJTs offer potential savings of 5 to 20 cents compared to designs using MOSFETs. Low V_{CEsat} BJTs perform the same function as a MOSFET at a lower cost, and as an added bonus, in many cases provide for improved power consumption resulting in improved battery life. In many designs the high current gain allows Low V_{CEsat} BJT devices to be driven directly from the PMU's control outputs.

Design Considerations

The Low V_{CEsat} BJT is a current driven device, compared to the MOSFET which is a voltage driven device. For this reason the designer needs to understand the current limitations of the PMU control circuits being used, to determine the specific circuit requirements when designing with a Low V_{CEsat} BJT. For example, if the Low V_{CEsat} BJT is to control a current of 1.0 Amp and it has a worst case gain (h_{FE}) of 100 then the base current will need to be a minimum of 10 mA (I_B) to ensure the Low V_{CEsat} BJT goes into saturation. The control pin of the PMU must be able to supply the 10 mA for the Low V_{CEsat} BJT to be driven directly; otherwise an additional drive stage would be required. The designer also has to consider the power rating of the package for the Low V_{CEsat} BJT. For Example; the On Semiconductor Low V_{CEsat} BJT NSS12600CF8T1G is mounted on a FR4 printed circuit board 100 mm^2 pads. The input voltage to be switched is 5.0 V and the maximum constant current is 6.0 A. Ambient temperature is 25^0 C. The Power rating (P_D) with the specified pad is 1.0 W.

The typical Vce-sat for the NSS12600CF8T1G at 1.0 A is 45 mV. This equates to a power dissipation of 45 mW. The Minimum Gain (h_{FE}) at 1.0 A is 250. Thus the drive current (I_B) would need to be a little over 4.0 mA. The maximum limit on Vce-sat at 1.0 A is 80 mV (from Data Sheet with beta 100), this equating to 80 mW, well below the 1.0 W rating for the package at 25^0 C.
Derating the device for temperature. The Thermal Resistance for de-rating with minimum pads ($R_{\theta JA}$) is 125^0 C/W (From Data Sheet). The formula for de-rating is $P_D =$ (Tj-max – Tamb) / $R_{\theta JA}$
For an application where Tj-max = 75^0 C, The Maximum allowable Power dissipation would become $P_D = (75 – 25) / 125 = 400$ mW.
The maximum calculated power of 80 mW still falls below the adjusted power when the device is de-rated for a higher temperature of 75^0 C.

Charging Circuit
A review of charging circuit (Figure 1) in a portable product shows the pass transistor Q1 (Power MOSFET 2.0 Amp, 20 V, TSOP6 package) and the blocking Schottky Diode D1 can be replaced by a Low V_{CEsat} BJT and a resistor. In this example the Low V_{CEsat} BJT saved \$0.10 from the typical MOSFET cost and 316 mW lower power loss.

All the control for charging of the Lithium Ion battery is imbedded in a PMU. The PMU control pin changes to high to turn on the external pass transistor Q1 and the charging current is set at 1 Amp. The series Schottky Diode D1 is required to block any reverse current from the battery.
The typical power dissipated through the pass transistor Q1 and the reverse blocking diode D1 was calculated as:
Q1 Power = I^2 x R, 1.0 Amp^2 x $R_{DS(ON)}$ (60 mΩ) = 60 mW
D1 Power = I x V_F, 1.0 Amp x V_F Schottky (360 mV) = 360 mW
Total Power dissipated through Q1 and D1 = 420mW

The typical high volume cost of the MOSFET and Schottky Diode is \$0.175

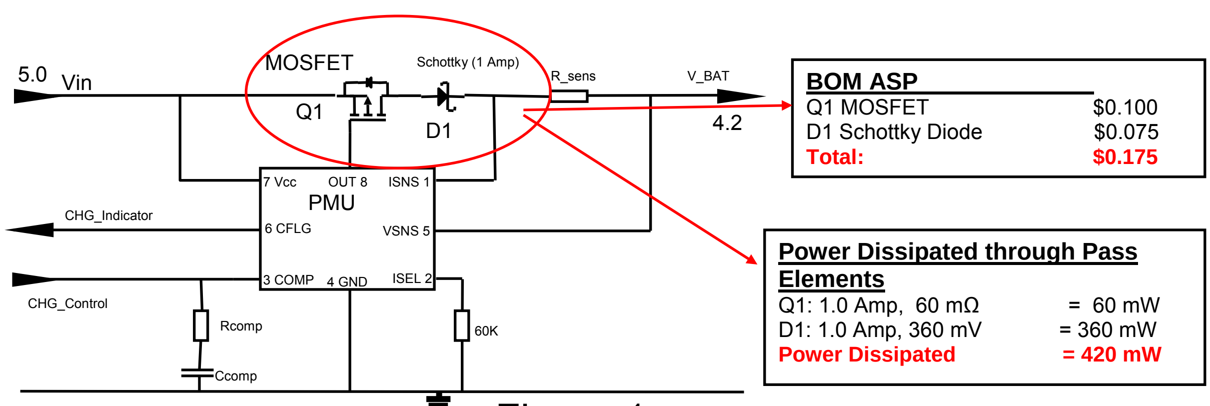


Figure 1

The charging circuit (Figure 2) can be configured using a Low V_{CEsat} BJT to replace the MOSFET and the Schottky Diode. The Schottky Diode is not required because the Low V_{CEsat} BJT has this function inherent to its design. The control pin on the PMU is able to

provide a maximum of 20 mA. The PMU would initiate a fast charge with the battery voltage of 3.0V. With Q2 in saturation both the collector and emitter will be at approximately 3.0 V, thus the base would be 2.3 v. The base current required to drive the ON Semiconductor NSS12600CF8T1G Low V_{CEsat} BJT, which has a minimum gain of 250, into saturation needs to be a little over 4.0 mA for a 1.0 Amp charging current. Selecting a standard resistor value of 200 Ω for the base resistor will ensure the Low V_{CEsat} BJT is in saturation and that the limit for the drive pin is not exceeded.
The typical power dissipated through the pass transistor Q2 and bias resistor R1 was calculated as:
Q2 Power = I x V, 1.0 Amp x Vce-sat (1.0 Amp, Beta 100 = 80 mV) = 80 mW
R1 Power = I^2 x R, 0.011 Amp^2 x 200 Ω = 24 mW
Total Power dissipated through Q2 and R1 = 104 mW

The typical high volume cost of the Low V_{CEsat} BJT and Resistor is $0.10

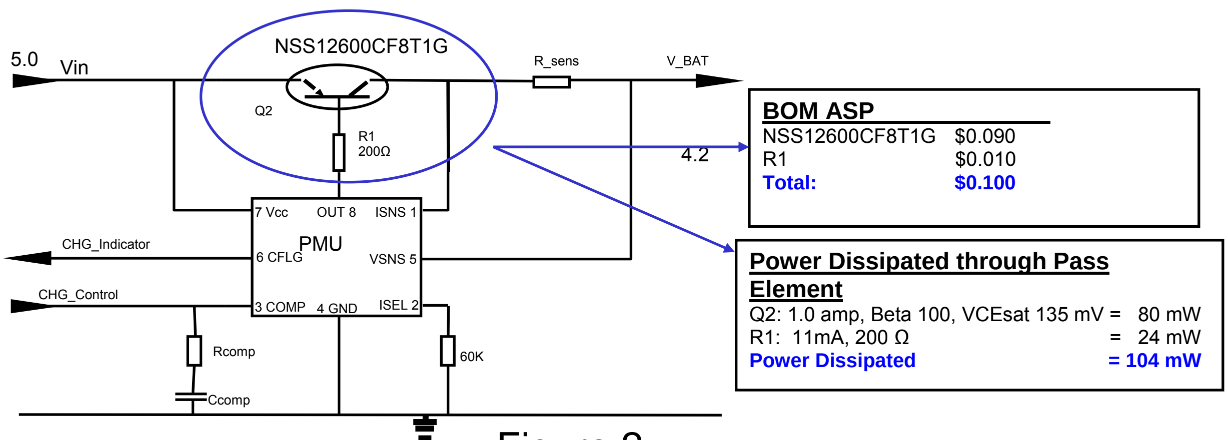


Figure 2

Charging Circuit Savings

The savings resulting from exchanging the MOSFET bypass transistor and Schottky Diode with a Low V_{CEsat} BJT and bias resistor were **$0.075 per unit**.
The exchange also resulted in a power dissipation savings of **316 mW** making the thermal considerations of the portable product much simpler.

More Complex Circuits

Integrated Circuits designed specifically with an external bypass MOSFET may not have the ability to supply the required current to drive the Low V_{CEsat} BJT into saturation directly. In these circuits an extra digital transistor or small general purpose MOSFET (Q4) can be used as illustrated in Figure 3.

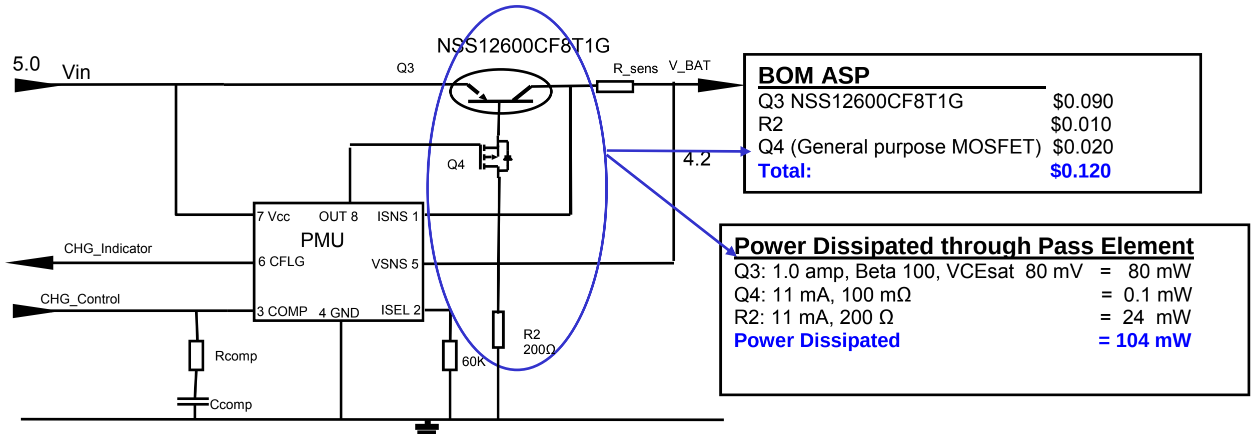


Figure 3

The results are not quite as significant as the charging example. The cost savings is still \$0.055 per unit. Power saving is significant also – 316 mW less.

Bi-Directional Current Control

Figure 4 is an illustration of a battery management application with a dual MOSFET configuration. By connecting the MOSFETs with their drains together one eliminates the requirement for a blocking schottky diode and it also allows for the control of current in either direction. i.e. Charging current in to the battery, power out to support USB.
The disadvantage of having the two MOSFETs in series is the doubling of the resistance through the pass elements and thus doubling the power loss. It is a better solution compared to the use of a blocking schottky diode, but it does cost significantly more.

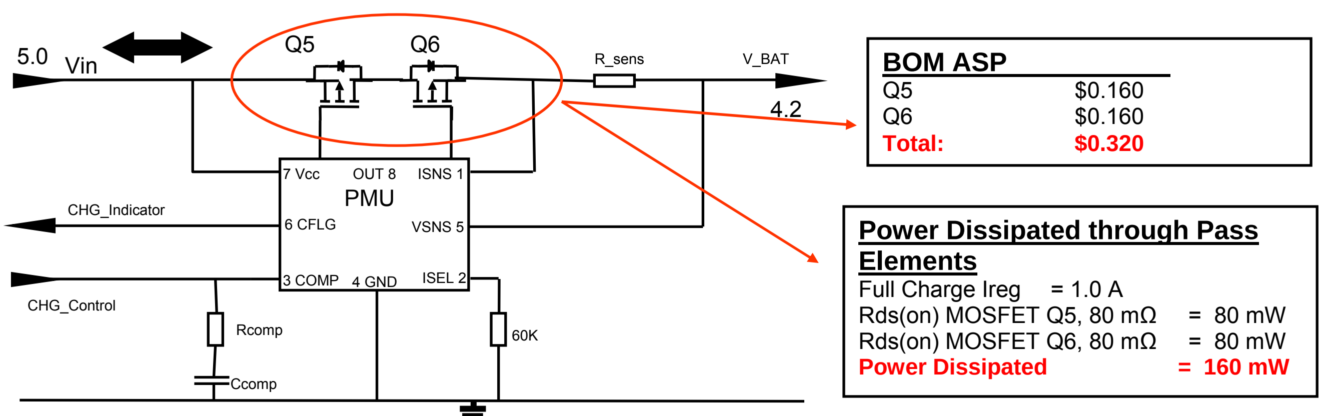


Figure 4

Figure 5 is a similar battery management application using two Low V_{CEsat} BJT. In this design the Low V_{CEsat} BJTs are connected in parallel and only one is turned on at a time; Q7 for charging the battery, Q8 to allow power out to a peripheral. As only one device is turned on at a time we only have to consider the resistance and power loss through one device. There are also significant savings in the cost of two Low V_{CEsat} BJT compared to two MOSFETs.

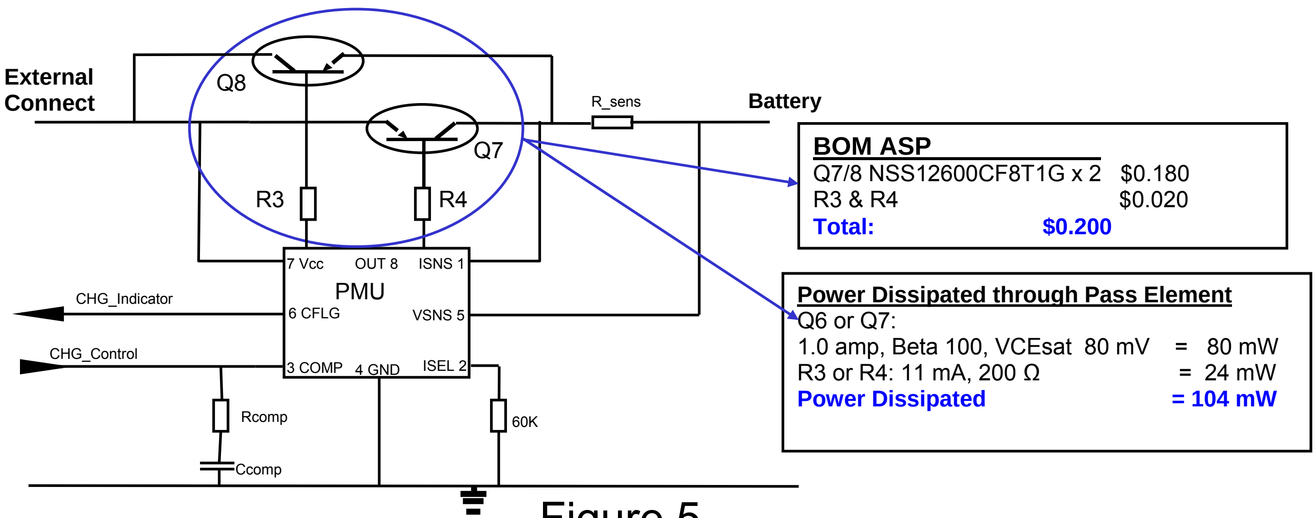


Figure 5

Load Switch - Vibrator Control in Cellular Phones

A Low V_{CEsat} BJTs is an ideal switch for controlling functions within a portable product that are only on for a short duration. The vibrator in a cellular phone is good example; Figure 6 is an illustration of the use of a Low V_{CEsat} BJTs, being controlled with a Digital Transistor, to turn the vibrator on and off.

A MOSFET approach may be more efficient and the power loss less but considering the short time the vibrator is on, the lower cost of the Low V_{CEsat} BJTs is very attractive.

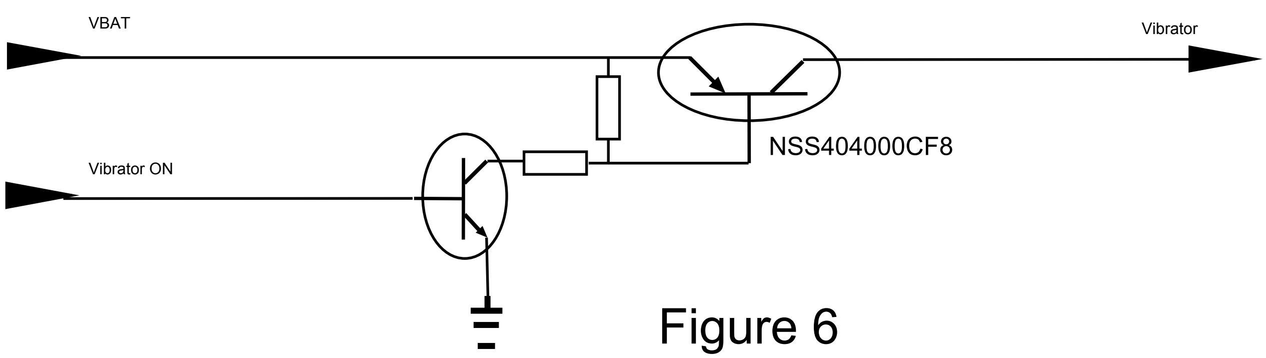


Figure 6

Load Switch – Back Light Control in a cellular phone
Cellular phones often use multiple arrays of LED for illumination of keypads. Figure 7 is an illustration using a Low V_{CEsat} BJT to control the LED backlights.

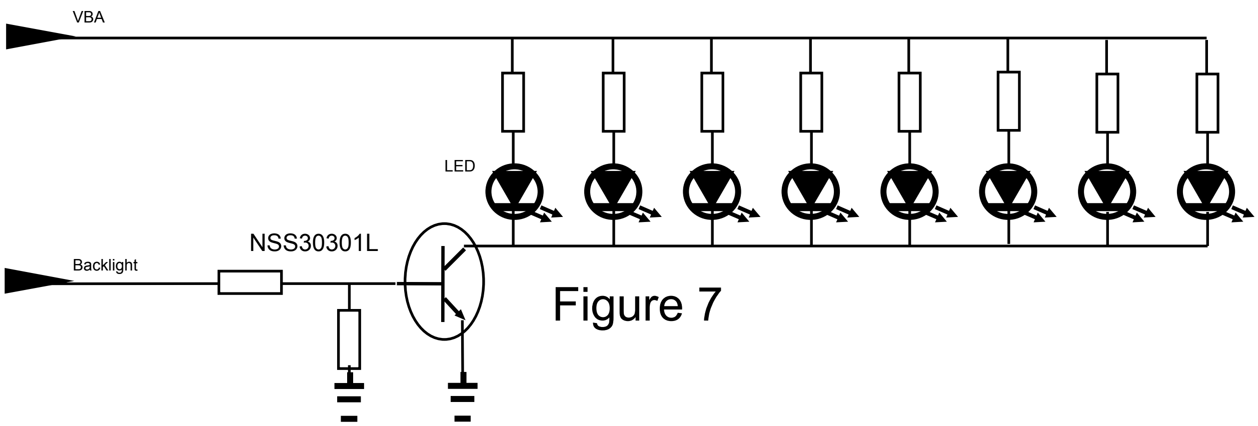


Figure 7

LED Driver Circuits

Pass Element in Buck / Boost converter
The MC34063 Step Up / Down / Inverting Switching Regulator can be configured to drive LEDs. The Low VCEsat BJT, NSS40600CF8T1G is an ideal pass element, Q1 as shown in Figure 8.

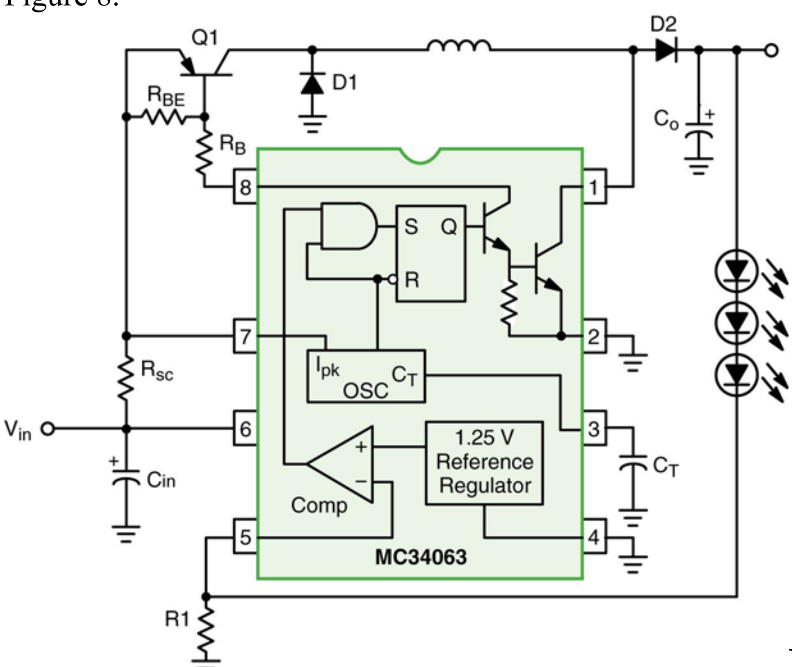
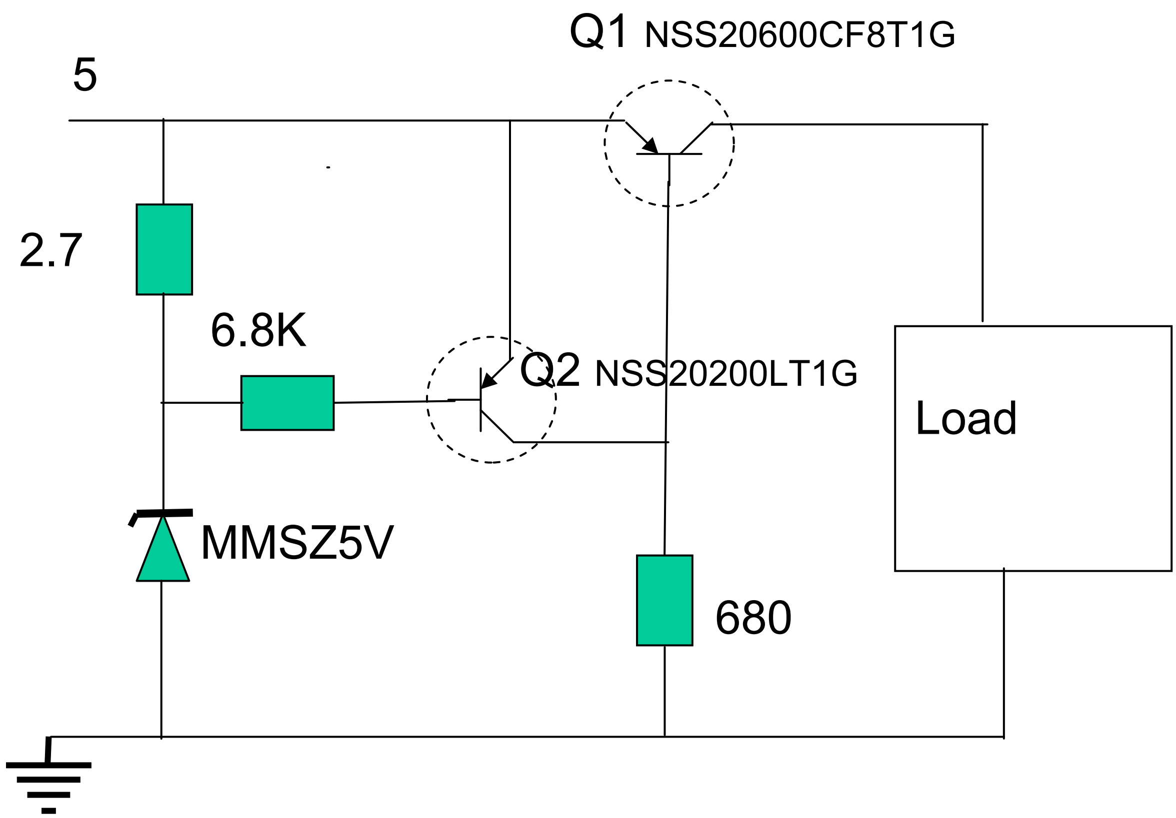
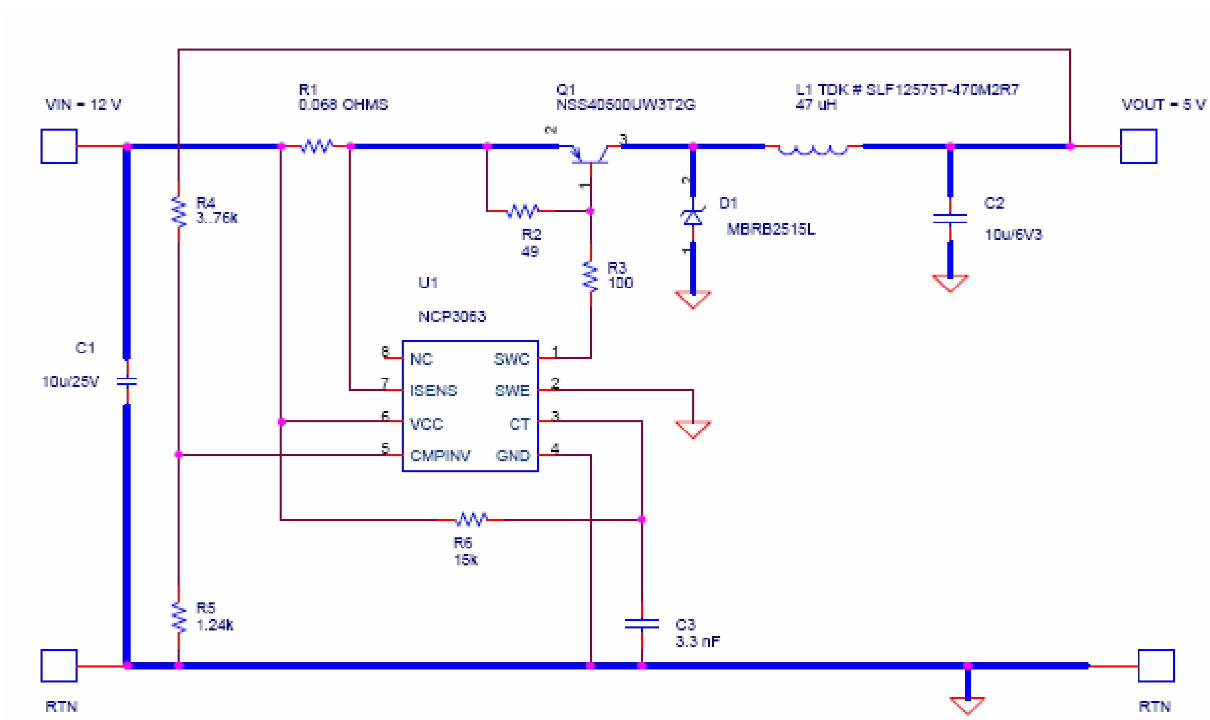


Figure 8



Over Voltage Protection



NCP3063 Buck reference designs

Additional Advantages of using a Low V_{CEsat} BJT

The Low V_{CEsat} BJT is less susceptible to ESD damage compared to the MOSFET and thus a savings can be found in not having to provide extra ESD protection.

The Low V_{CEsat} BJT has a lower turn on voltage (0.7v typical) compared to a MOSFET (typically 4.0v – 10.0v) and is thus very attractive for low voltage circuits and for situations where a controlled power down is required as the battery voltage drops. The low turn on voltage would also eliminate the need for an oscillator and charge pump, normally needed for a MOSFET.

The Low V_{CEsat} BJT blocks voltage in both directions, eliminating the need for a blocking schottky diode which is sometimes required when using a MOSFET.

The Low V_{CEsat} BJT typically have a better temperature coefficient compared to a MOSFET which provides for higher efficiency when operating at high temperatures resulting in less temperature elevation in the portable product..

Feature	**BJT**	**MOSFET**
Low Vce-sat / Rds-on	Excellent in saturation Needs current drive	Needs high voltage Gate Drive to get 100% enhancement
Blocking Capability	Bi-directional	Mono-directional, needs schottky diode
Pulse Current	High per Si Density	Good per Si Density
Drive Voltage	Less than 1V	2v to 10v depending on design
Drive Current	Moderate	Low
Switching Speed	Saturated – Low Linear - High	High
ESD Sensitivity	Excellent	Sensitive
Cost Rce /mm^2	Excellent	Moderate
High Current Switching	Moderate	Excellent
High Voltage Switching	Excellent	Excellent
Low Voltage Switching	Excellent	Poor

Application	Feature	Benefit
Pulsed Mode Battery Charging	Low Vce-sat hFE > 200 Low Rce /mm^2 Small size – 4.0 mm^2 Low profile – 0.75 mm PNP transistor	High efficiency High gain Low cost vs MOSFET Less board space More compact design High side control, Bi-directional voltage blocking
Linear Mode Battery Charging	High power dissipation / mm^2 hFE > 200 Low Rce /mm^2 Small size – 4.0 mm^2 Low profile – 0.75 mm PNP transistor	Efficient charging time High gain Low cost vs MOSFET Less board space More compact design Bi-directional voltage blocking
MosFET Gate Drive	High Pulse Current High Frequency hFE > 200 Low Rce /mm^2 Small size - 4.0 mm^2 Low profile – 0.75 mm PNP / NPN transistor	Fast switching time Fast switching time High current gain Low cost vs MOSFET Less board space More compact design High / Low switch
Royer Converter for LCD Backlight	Low Vce-sat High Frequency hFE > 200 Low Rce /mm^2 Small size - 4.0 mm^2 Low profile – 0.75 mm PNP / NPN transistor	High efficiency Fast switching time High current gain Low cost vs MOSFET Less board space More compact design Design flexibility, Bi-directional voltage blocking
Low Drop Out (LDO) Regulator	Low Vce-sat High power dissipation / mm^2 hFE > 200 Low Rce /mm^2 Small size - 4.0 mm^2 Low profile – 0.75 mm PNP / NPN transistor	High efficiency High current control High gain Low cost vs MOSFET Less board space More compact design High or Low side control, Bi-directional voltage blocking
Servo Motor Drive	PNP / NPN transistor Low Vce-sat High Frequency hFE > 200 Low Rce /mm^2 Small size - 4.0 mm^2 Low profile – 0.75 mm	High / Low Bridge, Bi-directional voltage blocking High efficiency Low switching Losses High current gain – lower control current Low cost vs MOSFET Less board space Design flexibility
Over voltage protection	PNP / NPN transistor Low Vce-sat High power dissipation / mm^2 High Frequency hFE > 200 Low Rce /mm^2 Small size - 4.0 mm^2 Low profile – 0.75 mm	High / Low Bridge, Bi-directional voltage blocking High efficiency High current control Low switching Losses High current gain – lower control current Low cost vs MOSFET Less board space Design flexibility