AN1035

Designing with HV Microcontrollers

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INTRODUCTION

When designing embedded microcontroller applications, one of the greatest challenges can be the creation of the power supply for the microcontroller. Particularly when the only supply voltage available is significantly higher than the microcontroller's maximum V_{DD}.

To help simplify embedded design, Microchip has introduced a new feature in a select group of new microcontroller offerings, a 5V shunt regulator. This on-chip regulator allows the microcontroller to operate from a wide variety of supply voltages. As an added bonus, the shunt regulator topology also allows the connection of other circuitry, external to the microcontroller, to be powered by the V_{DD} pin.

This application note discusses the design of power supply circuits using the new shunt regulator, and presents some Tips 'n Tricks for extending the regulator's capabilities.

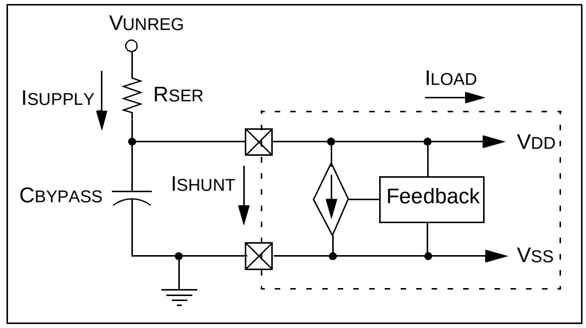
THEORY OF OPERATION

A shunt regulator generates a specific supply voltage by creating a voltage drop across a pass resistor R_{SER}. The voltage at the V_{DD} pin of the microcontroller is monitored and compared to an internal voltage reference. The current through the resistor is then adjusted, based on the result of the comparison, to produce a voltage drop equal to the difference between the supply voltage V_{UNREG} and the V_{DD} of the microcontroller.

The advantage to a shunt regulator is that the supply voltage, V_{UNREG}, is only limited by the power dissipation and breakdown voltage of the external resistor, R_{SER}, not the power or breakdown characteristics of the regulator. The challenge in designing a shunt regulator circuit is choosing an appropriate value for the resistor such that the range of currents over which the regulator has control will produce the correct voltage drop needed to produce a 5.0 V_{DC} supply.

So, all we really need to know to design with a shunt regulator is Ohm's Law. The problem is that the supply voltage, V_{UNREG}, is not constant and neither is the load current. In addition, the range of current over which the regulator has control, is also limited. So the choice of R_{SER} really becomes a balancing act, trying to find a resistance that will meet all three requirements.

FIGURE 1: SHUNT REGULATOR BLOCK DIAGRAM



DESIGN

The best place to start in the design process is to catalog the variations possible in the supply voltage and the load current. For our purposes, the following definitions will be used:

- V_{U_MIN} is the minimum supply voltage to the system.
- V_{U_MAX} is the maximum supply voltage to the system.
- I_{LOAD_MIN} is the minimum load current, excluding the regulator.
- I_{LOAD_MAX} is the maximum load current, excluding the regulator.

Given these values, it is now possible to determine the minimum and maximum pass resistor values for the circuit. Equation 1 and Equation 2 are used to calculate these values.

Note:	The constant 5.0 refers to the V_{DD} voltage of the regulator, the 4 mA constant is the minimum regulation current for the regulator and the 50 mA constant is the maximum regulation current for the regulator.

EQUATION 1:

$$R_{MAX} = \frac{(V_{U\_MIN} - 5.0)}{1.05 \bullet (I_{LOAD\_MAX} + 4\ mA)}$$

EQUATION 2:

$$R_{MIN} = \frac{(V_{U\_MAX} - 5.0)}{0.95 \bullet (I_{LOAD\_MIN} + 50\ mA)}$$

These values, R_{MIN} and R_{MAX}, represent the limits for the resistance of the pass resistor.

> **Note:** If the minimum resistor value is greater than the maximum, then the combination of supply voltage variation and load current variation can not be supported by a single resistor. To correct the problem, either;
>
> 1. The variation in current drawn by the circuit must be reduced.
> 2. A system for varying the pass resistor is required.
> 3. The variation in V_{UNREG} must be reduced.
>
> The **"Tips 'n Tricks"** section of this document demonstrates methods for accomplishing all three options.

If the minimum value is less than the maximum value, a final pass resistor value can be chosen between the two limits. Good design practice is to then check the minimum and maximum regulator currents. Equation 3 and Equation 4 show how these values are calculated.

EQUATION 3:

$$I_{REG\_MAX} = \frac{(V_{U\_MAX} - 5.0)}{R_{SER}} - I_{LOAD\_MIN}$$

EQUATION 4:

$$I_{REG\_MIN} = \frac{(V_{U\_MIN} - 5.0)}{R_{SER}} - I_{LOAD\_MAX}$$

The minimum regulator current must be less than the maximum load current and the difference must be less than the maximum regulator current of 50 mA. If not, then check the calculations for the pass resistor value.

The minimum power rating of the pass resistor can now be calculated using Equation 5. Remember to allow for adequate cooling and an appropriate amount of margin when deciding on the final power rating.

EQUATION 5:

$$POWER = \frac{(V_{U\_MAX} - 5.0)^2}{R_{SER}}$$

The next step is to determine the appropriate size bypass capacitor for the design. While most microcontroller applications can use "rule-of-thumb" values for their bypass capacitors, the unique nature of the shunt regulator complicates the selection.

First of all, the combination of the pass resistor and the bypass capacitor form an unintended RC time constant that limits the rise time of the microcontroller V_{DD}. Therefore, it is necessary to limit the size of the capacitor such that the resulting rise time for the V_{DD} supply is faster than the specified minimum rise time for the microcontroller's V_{DD}. The minimum rise time for a Microchip microcontroller's V_{DD} is 0.5V/mS, until the supply voltage exceeds 2.1V (Power-on Reset trip point). So, the supply must exceed 2.1 volts within 42 mS, (2.1V/0.5V/ms). Using this information and Equation 6, the maximum capacitor value can be determined.

EQUATION 6:

$$C_{MAX} = -\frac{42\ mS}{R_{SER} \bullet \ln\left(\frac{2.1}{5.0}\right)}$$

So, the bypass capacitor must be less than the value specified by Equation 6 to meet the power-up requirements of the Power-on Reset, and greater than 0.1 µF/ .047 µF for noise suppression. Typically, the value is chosen to be closer to the 0.1 µF value for convenience.

> **Note:** The **"Tips 'n Tricks"** section discusses an example in which larger bypass values may be needed to handle severe transient current requirements.

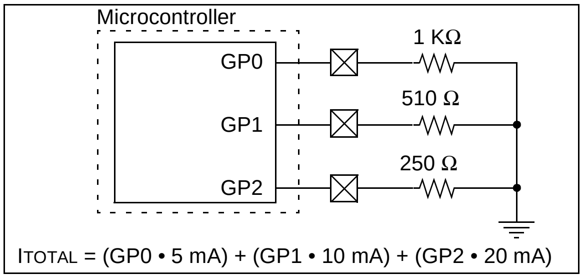
TIPS 'N TRICKS

As mentioned in the previous section, it is often necessary to create a variable pass resistance, reduce the variation in load current, or reduce variations in V_{UNREG} to find a pass resistor's values that will work for all load and supply conditions. This section contains examples for all three.

TIP #1 LOAD RESISTORS

One method for decreasing variations in the load current is to add load resistors to unused microcontroller outputs (see Figure 2). The outputs are set high to increase the load current at times when other portions of the circuit are only drawing minimal currents and pull low to free up load current when the circuit needs more operating current elsewhere. This allows the microcontroller to manage the load, reducing variations in the load current.

FIGURE 2: LOAD DAC SCHEMATIC

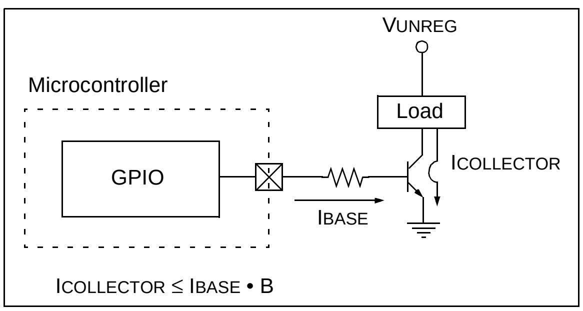


TIP #2 OPEN COLLECTOR DRIVES

Another method for decreasing load current variation is to drive higher current loads with open collector low-side drives (see Figure 3). This removes the drive current requirement from the VDD supply and pushes it onto the higher supply voltage, reducing variations in the load current.

Note:	The base current required to bias the transistor is still sourced from the VDD supply. However, the current gain of the transistor makes the required base current only 1/10 – 1/100th of the actual load current.

FIGURE 3: OPEN COLLECTOR DRIVER SCHEMATIC

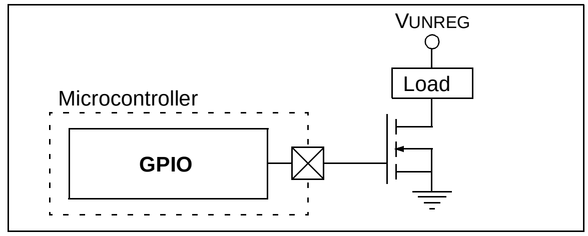


TIP #3 OPEN DRAIN DRIVES

This method for decreasing the maximum load current is basically the same as TIP #2, with the exception that the gate drive of the MOSFET does not require a continuous bias current (see Figure 4). In addition, the ON voltage drop across the MOSFET is significantly lower than a BJT. Avoiding a continuous base bias current further reduces the load current on the system, and lowering the ON voltage of the drive means that more of the energy is actually delivered to the output.

However, there is a drawback to using a MOSFET transistor. A current is required to charge or discharge the gate capacitance each time the transistor is turned on/off. Depending upon the switching speed required, the current needed to charge or discharge the gate capacitance can be as high as several amps. This requires a MOSFET driver, which further increases the current requirements of the circuit. Therefore, the decision to use a BJT versus a MOSFET should be based on the trade off between the bias current/on voltage advantages and the additional current requirements for switching the MOSFET.

FIGURE 4: OPEN DRAIN DRIVER SCHEMATIC



For more information concerning driving MOSFET transistors, refer to Application Note AN786, "*Considerations for Driving Power MOSFET in High-Current, Switch Mode Regulators*" (DS00786) and AN898, "*Determining MOSFET Driver Needs for Motor Drive Applications*" (DS00898).

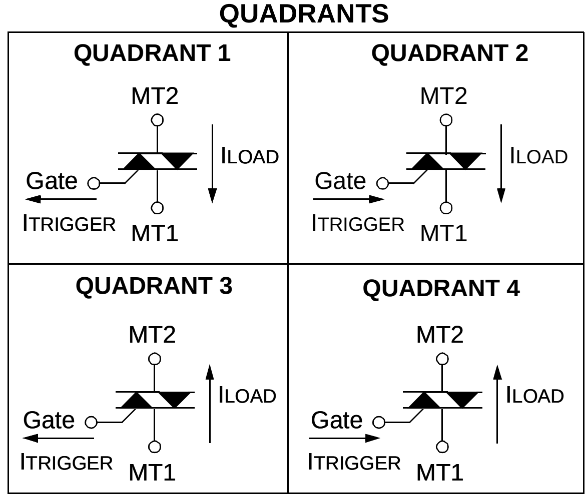
TIP #4 TRIAC DRIVES

In systems controlling AC powered loads, a TRIAC is often employed as the output drive (see Figure 4). However, while TRIACs have been available for many, many years, some engineers are still unfamiliar with their operation and do not take full advantage of recent improvements in their design.

One of the most significant improvements in the TRIAC design is the introduction of "sensitive gate" TRIACs. These devices are designed to trigger on a much smaller gate drive current than traditional devices. The reduced drive current also means that these new TRIACs will work well, not only in quadrants 1 and 3, but also in quadrants 2 and 4, expanding the drive options open to the designer (see Figure 5).

Another improvement has been a reduction in the holding current specification for the device. The holding current is the minimum load current at which the TRIAC will latch on, removing the requirement for a continuous gate current.

FIGURE 5: TRIAC CONDUCTION QUADRANTS



What sensitive gate technology means for shunt regulator powered systems is that the average current drive requirement for a TRIAC drive can be significantly reduced.

- Lower gate drive currents reduce the current that the microcontroller must source or sink to turn on the TRIAC.
- Lower holding currents reduce the time the microcontroller must hold the gate drive during each AC cycle.
- Operation in all four quadrants allow the microcontroller to use either positive or negative gate drive currents to trigger the TRIAC.

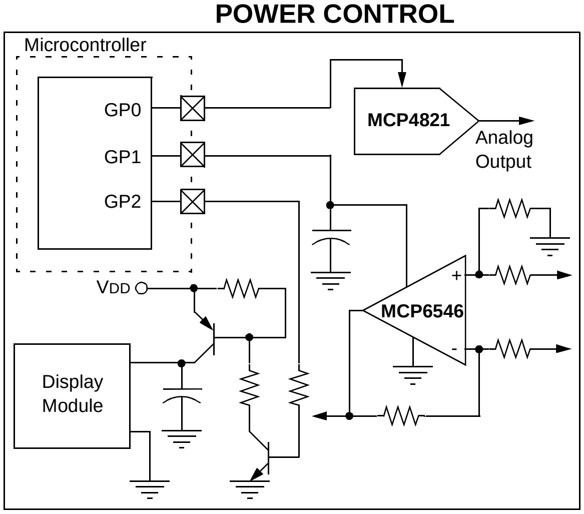
TIP #5 USING GPIO TO SUPPLY VDD

In systems with an external circuitry, it is often advantageous to be able to power-down unused circuitry to reduce current consumption. If the current requirement for a given section is less than the drive limitation of a GPIO (typically 20 mA), then the power for the circuitry can be supplied through a GPIO pin (see Figure 6). This puts control of the circuitry power under software control, which can then power the section only when needed and turn it off when the circuit is idle.

If the current drive for a given section is greater than the drive capability of a GPIO, then a simple external switching transistor can be used to manage the higher current level.

Another option is to use the GPIO to control the Shutdown or Enable input of the active devices in the circuit (op amps, ADCs, Filters or DACs).

FIGURE 6: EXTERNAL CIRCUITRY POWER CONTROL



Managing multiple sections of the design in this fashion allows the software to power-up different sections at different times, reducing variations in the current consumption of the system by eliminating any overlap.

TIP #6 TRANSIENT CURRENT NEEDS

Some transient current requirements can be handled by temporarily overloading the V_{DD} supply. In this scenario, a temporary output drive, which exceeds the current capacity of the system power supply, is enabled. The additional current required to supply the output is drawn from the bypass capacitor in the power supply and the power supply voltage momentarily sags. Once the output is disabled, the current draw is removed and the bypass capacitor charges to 5V again.

The amount of droop in V_{DD} can be minimized by increasing the size of the bypass capacitor for the system.

Note:	This will also increase the amount of time required for the system to recover from the over load. The challenge is to balance the amount of droop against the recovery time. Equation 7 is used to determine the amount of droop the system will experience, and Equation 8 is used to determine the amount of time required for the system to recover from a drop in supply voltage.

EQUATION 7:

$$V_{U\_MIN} = 5.0 - \frac{I_{SURGE} \bullet T_{SURGE}}{C_{BY\_PASS}}$$

EQUATION 8:

$$T_{RECOVER} = \frac{(5.0V - V_{SS\_MIN}) \bullet C_{BY\_PASS}}{(I_{MAX} - I_{NOMINAL})}$$

TIP #7 VARIABLE PASS RESISTOR

Another method for handling a wide variation in supply voltage and load current is to vary the resistance of the pass resistor used in the power supply design (See Figure 7).

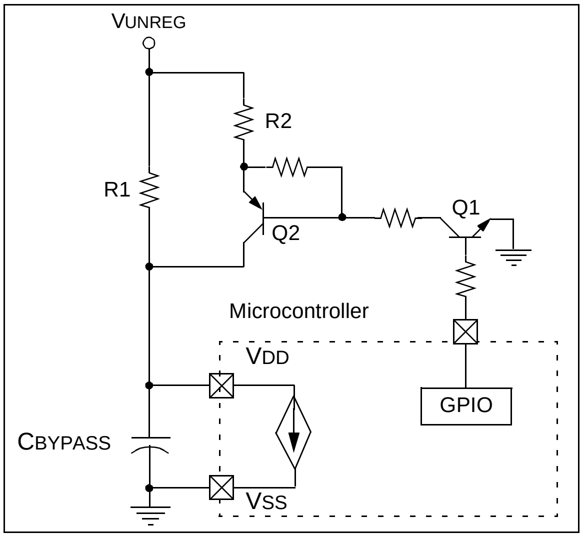
In the example, the pass resistor is bypassed by a lower value resistance under software control. When the GPIO is set high, the open collector drive (Q1) pulls the base of Q2 low, which turns on Q2 and bypasses the pass resistor R1 with a lower value resistance R2.

The result is more current available for the microcontroller and the circuitry powered by V_{DD}. When the circuit returns to low-power operation, GPIO is pulled low, both transistors turn off and the pass resistance is just R1, reducing the system current.

The system is designed as two separate power supplies, one using the minimum and maximum current at the lower Current mode. The second uses the minimum and maximum current at the higher Current mode. The resistor value selected for the lower Current mode is used for R1. R2 is chosen to create a parallel combination that is equal to the pass resistor value selected for the higher Current mode.

This system is a good solution to the problem of a single pass resistor which has a higher minimum value than the desired maximum value.

FIGURE 7: DUAL VALUE PASS RESISTOR SCHEMATIC

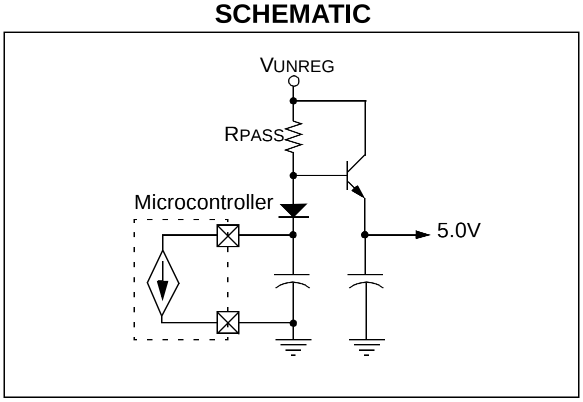


Note:	The breakdown voltage of Q1 and Q2 must be greater than V_{UNREG}.

TIP #8 INCREASING CURRENT WITH A SERIES PASS TRANSISTOR

An external pass transistor, driven by the microcontroller shunt regulator, can produce a higher current power source for external circuitry (see Figure 8). In the example, the pass transistor acts as a series regulator taking its reference from the microcontroller V_{DD}, plus the forward voltage of the diode and providing a 4.9-5.2V power supply. The only requirement on the pass transistor is that the device must have a sufficient break down voltage specification to handle the supply voltage and sufficient power handling capability to deal with the power dissipated while the supply generates the full output control.

FIGURE 8: PASS RESISTOR SCHEMATIC

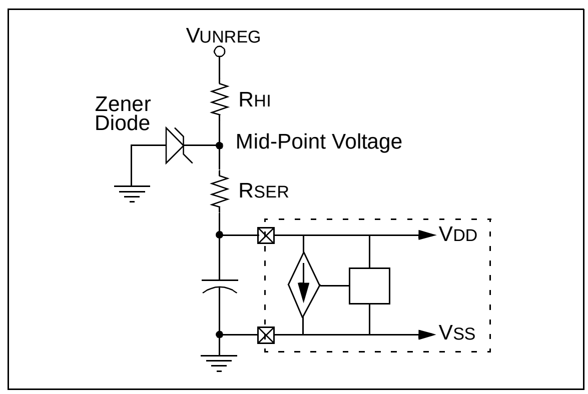


TIP #9 DECREASING VARIATIONS IN V_{UNREG} WITH A SECONDARY DISCRETE SHUNT REGULATOR

In the previous tips, we have examined methods for reducing variations in the load current and methods for varying the value of the pass resistor. The only other variable in the design equations is variation in the supply voltage V_{UNREG}, so, this final tip demonstrates a method for limiting the variation between V_{U_MIN} and V_{U_MAX}.

This is accomplished by regulating the high voltage side of V_{SER} with another shunt regulator, this time in the form of a Zener diode. Figure 10 shows an example circuit. The two resistors, R_{HI} and R_{SER}, form a voltage divider with the mid-point voltage clamped by the Zener voltage of the diode. If V_{UNREG} increases, the Zener diode conducts additional current-to-ground causing the voltage drop across R_{HI} to increase wile holding the mid-point voltage relatively constant. This reduces the variation seen by R_{SER} and the second shunt regulator in the microcontroller, simplifying the choice for R_{SER}.

FIGURE 9: SECONDARY SHUNT REGULATOR



The design for the high-voltage shunt regulator follows the same procedure as the original regulator in the microcontroller. The high and low variations in V_{UNREG} are documented, as are the high and low load currents required for the load (microcontroller, shunt regulator and additional loads). A Zener diode is selected based on a Zener voltage roughly half way between V_{UNREG_MIN} and V_{DD}.

Note:	The current range of the Zener diode should be large enough to put the Zener diode beyond the knee in the diode curve, (see Figure 10), but still well within the maximum power rating for the device. The maximum diode current should also be determined and documented.

Once this information is collected, a minimum and maximum value for R_{HI} can be calculated. Equation 8 and Equation 9 are just variations of Equation 1 and Equation 2 with the Zener voltage substituted for V_{DD}.

EQUATION 9:

$$R_{HI\_MAX} = \frac{(V_{U\_MIN} - V_{ZENER})}{1.05 \bullet (I_{LOAD\_MAX} + I_{ZENER\_MIN})}$$

EQUATION 10:

$$R_{HI\_MIN} = \frac{(V_{U\_MAX} - V_{ZENER})}{0.95 \bullet (I_{LOAD\_MIN} + I_{ZENER\_MAX})}$$

If the value can not be found that falls between the two limits, select a higher power Zener, which will increase I_{ZENER_MAX} or lower the Zener voltage to a value closer to V_{DD}. If a value can not be found, or if the power dissipated by the Zener or R_{HI} is too large, and the other tips in this application note can not provide any relief for the problem, then a switching regulator may be needed to ultimately solve the problem.

However, if a value is found for R_{HI} and the Zener diode, the next step is to determine the variation in I_{ZENER} based on V_{UNREG} and R_{HI}. Equation 11 and Equation 12 are used to determine both the high and low Zener diode current.

EQUATION 11:

$$I_{ZENER\_MAX} = \frac{(V_{U\_MAX} - V_{ZENER})}{R_{HI} \bullet 0.95} - I_{LOAD\_MIN}$$

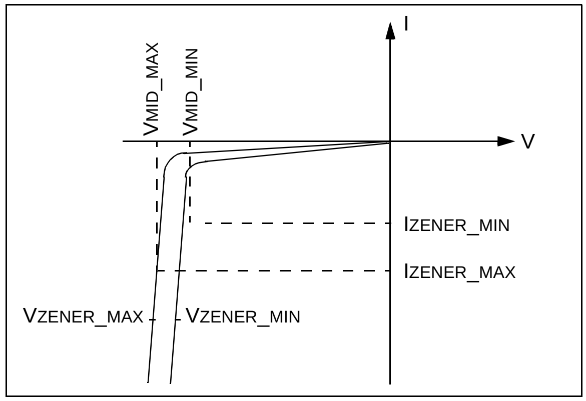
EQUATION 12:

$$I_{ZENER\_MIN} = \frac{(V_{U\_MIN} - V_{ZENER})}{R_{HI} \bullet 1.05} - I_{LOAD\_MAX}$$

Given the minimum and maximum Zener diode currents, the minimum and maximum mid-point voltage can be found from the I-V chart for the Zener diode. See Figure 10 for an example I-V chart. To find the minimum value, scale the curve such that the Zener voltage is equal to the minimum Zener voltage value specified for the diode and take the value from the minimum Zener current estimate. To find the maximum voltage, scale the curve such that the Zener voltage is equal to the maximum specified Zener voltage and take the voltage value based on the maximum current.

The maximum and minimum mid-point voltages are then used for V_{U_MIN} and V_{U_MAX} in the original design Equation 1 and Equation 2 to calculate R_{SER}. The remainder of the design then follows the original procedure from the beginning of this document.

FIGURE 10: I-V CURVE FOR A ZENER DIODE



Note:	The Zener diode power rating will limit the maximum current that the diode can sink when clamping the mid-point voltage. However, most Zener diodes also specify a maximum surge power, which extends the power rating of the device for transient power dissipation. If the maximum value for V_{UNREG} is based on transient jumps in the voltage due to noise or switching of other systems, then a smaller Zener diode may be used provided the transient is within maximum power surge power rating for the diode.

CONCLUSIONS

The inclusion of a shunt regulator can simplify the design of control circuits which must operate from voltages above the normal range of the microcontroller's supply voltage. The circuit can even act as a supply for other active devices in the circuit. All that is required is a little careful design and component selection.

MEMORY USAGE

Not applicable

REFERENCE DOCUMENTATION

- AN786, "*Considerations for Driving MOSFETs in High-Current, Switch Mode Regulators*" (DS00786).
- AN898, "*Determining MOSFET Driver Needs for Motor Drive Applications*" (DS00898).

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