

Features, Value and Benefits of Digital Control for Power Supplies

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INTRODUCTION

Control of Switch Mode Power Supplies (SMPSS) has traditionally been a purely analog domain. The advent of low-cost, high-performance Digital Signal Controllers (DSCs) has opened a whole new dimension for switch-mode power supply control, and there are signs that the power supply industry is heading towards a digital revolution.

This white paper reinforces the notion that digital power supplies are here to stay, and there has not been a better time to make the switch to digital. The AC-DC Reference Design from Microchip is a prime example demonstrating several advantages of digital control.

This white paper aims to point out the benefits of digital power supplies with a quantitative comparison with an analog counterpart, with regard to the following points:

- Comparison of analog and digital power supply Bill of Materials (BOM) costs
- Ability to control advanced topologies and flexibility provided by digital control
- Implementation of value additions to a digital power supply without adding to the cost

WHO SHOULD READ THIS WHITE PAPER?

This white paper targets power supply engineers and managers alike by providing measurable data in favor of switching to digital power supplies. A power supply designer will find novel implementation ideas to easily achieve and exceed design objectives. Based on the many benefits of digital power described in this white paper, engineering managers will be able to make an informed decision and choose digital power as a platform for current and future designs.

This white paper presents real data to back up the claims of digital power supplies of lower cost, higher performance, higher efficiency and higher power density. Each of these claims are addressed and justified with real-world examples.

COST SAVINGS WITH A DIGITAL POWER SUPPLY

Figure 1 illustrates a high level block diagram for a generic two-stage analog AC-DC power supply.

FIGURE 1: TWO-STAGE ANALOG AC-DC POWER SUPPLY

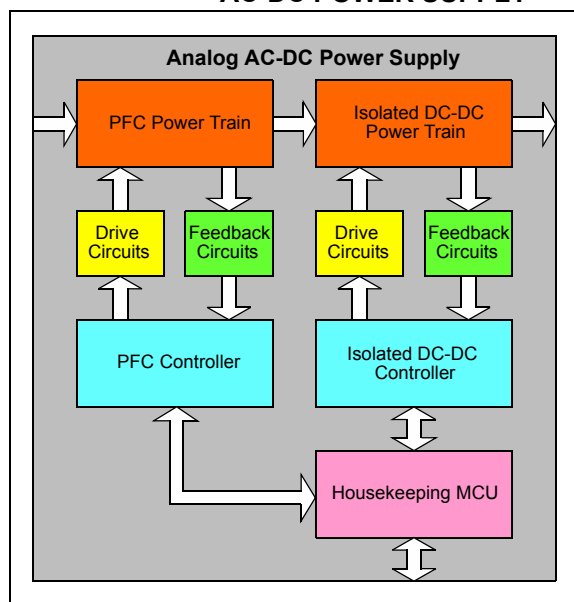
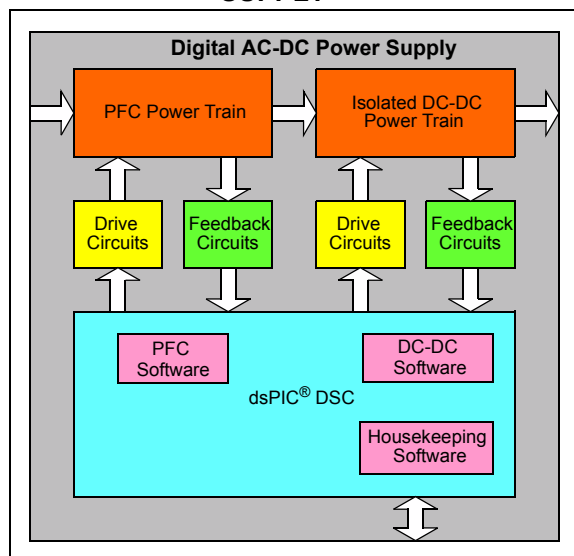


Figure 2 illustrates a high level block diagram for a digital AC-DC power supply.

FIGURE 2: DIGITAL AC-DC POWER SUPPLY



Features, Value and Benefits of Digital Control for Power Supplies

The key components of the analog power supply include:

- **Power Train:** Semiconductor switches, inductors, capacitors and power transformers.
- **Drive Circuits:** Gate drivers and supporting circuitry.
- **Feedback Circuits:** Sensors, amplifiers and resistor networks.
- **Controller:** Dedicated controllers for each power stage.
- **Housekeeping Circuitry:** Dedicated microcontroller and supporting circuitry for sequencing, monitoring and communications.

For the purpose of comparison, a two-stage power supply is considered. The front end converter is a boost Power Factor Correction (PFC) circuit, while the second stage is a DC-DC phase-shifted full bridge converter.

Between an analog and digital power supply, the power train, drive circuits and feedback circuits will remain unchanged. Figure 2 illustrates the corresponding digital power supply for the example described above. For the digital version of this power supply, the dedicated analog controller and housekeeping circuitry can be combined together in a single dsPIC® DSC.

Figure 1 and Figure 2 show only the major differences from a high level; however, all supporting circuitry must also be included in the comparison. Figure 3 illustrates the supporting circuitry required for each analog stage, while Figure 4 illustrates the same for a digital system. Notice the extra connections required for an analog controller (indicated by the arrows in Figure 3 and Figure 4).

FIGURE 3: ANALOG STAGE CIRCUITRY

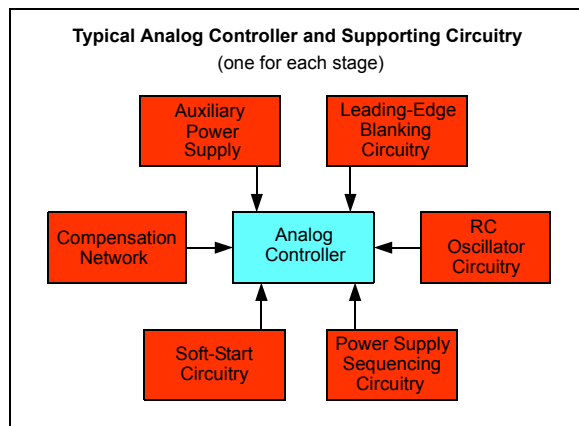
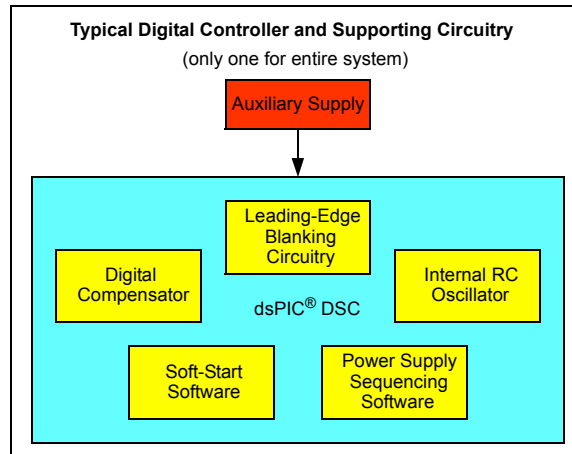


FIGURE 4: DIGITAL STAGE CIRCUITRY



In addition to the primary components, the bill of materials should consider the cost of this supporting circuitry, layout complexity, and the size of the Printed Circuit Board (PCB) in an analog versus digital power supply.

Table 1 provides a comparison of the bill of materials for a 300W analog power supply versus a digital power supply, highlighting the differences mentioned previously. The pricing information used for this comparison was obtained directly from manufacturers' web sites.

TABLE 1: 300W ANALOG AND DIGITAL POWER SUPPLY BOM PRICE COMPARISON

Sr. No.	Description	Price	
		Analog	Digital
1	PFC Controller	\$1.15	\$3.19
2	PSFB Controller	\$3.80	
3	Housekeeping MCU	\$1.37	
4	PFC Controller Support Circuitry	\$0.15	\$0.67
5	PSFB Controller Support Circuitry	\$0.18	
6	Housekeeping MCU Support Circuitry	\$0.11	
7	PFC Gate Driver (optional for Analog)	\$0.00 to \$0.73	\$0.73
8	PSFB Gate Driver	Same	Same
9	Power Train	Same	Same
10	Drive Circuits	Same	Same
11	Feedback Circuits	Same	Same
Total Price of Differentiating Components		\$6.76 to \$7.49	\$4.59

The BOM comparison shown in Table 1 clearly demonstrates the cost savings achieved by implementing a digital power supply over an analog solution.

Some may argue that a digital solution requires the use of dedicated MOSFET gate drivers, while an analog solution may provide the gate drivers on-chip. While this is true for low-power designs, most high-power analog designs will still need to use external gate drivers.

In Table 1, the total BOM cost of an analog supply is shown with and without using an external MOSFET gate driver for the PFC stage. It is evident from this comparison that digital power supplies offer a significant advantage with respect to overall BOM cost.

There are additional savings achieved with digital that are not as obvious. For example, one of the by-products of going digital is the reduction in component count. This helps achieve a simpler layout, smaller PCB size, reduced PCB fabrication and assembly costs, and improved quality and reliability of the product. These secondary cost savings only emphasize the case for choosing the digital power supply route.

ADVANCED FEATURES

Efficiency Optimizations

Two of the most important aspects to consider for any power supply designer are total cost and the system performance. While the cost advantages of a digital power supply over its analog counterpart were analyzed in the previous section, we now investigate the advantages of a digital power supply for higher efficiency.

Any power supply is designed with the maximum efficiency possible. Efficiency numbers have scaled new limits in recent years with advancement of semiconductor technology and novel topologies. Having said that, it is also true that the efficiencies have more or less been maximized at certain operating conditions (can be at half-load or at high line voltages).

Digital power supplies offer the added versatility to optimize the efficiency at multiple operating points.

For the PFC boost converter, switching losses can be reduced at lighter loads by operating the converter at a lower switching frequency. Due to the lighter load, the magnetics will still be able to handle the lower switching frequencies. If an interleaved PFC converter is implemented, one phase can be turned OFF at light loads.

Similarly, for a phase-shifted full-bridge converter, extra switching losses can be eliminated at light loads by turning OFF switching of the synchronous MOSFETs, and using the body diodes instead.

Another example is in a buck converter application. Synchronous buck converters are typically preferred for high current outputs. However, the use of the synchronous MOSFET causes circulating currents at light loads, which in turn causes higher losses. Therefore, the synchronous/free-wheeling MOSFET in a buck converter can be disabled when the converter operates in Discontinuous Current mode.

These techniques described here supplement the efficiency gains obtained by choosing advanced topologies, such as resonant and quasi-resonant converters. Digital control fully supports these advanced topologies, including phase-shifted full-bridge, and LLC-resonant converters to achieve very high efficiency and power density. As a result, digital control provides many options to optimize the efficiency of power supplies over the entire range of operation.

Power Management

A digital power supply offers unprecedented advantages over its analog counterpart in the area of power management. A typical analog power supply will accomplish its power management requirements using a housekeeping MCU as described in Figure 5.

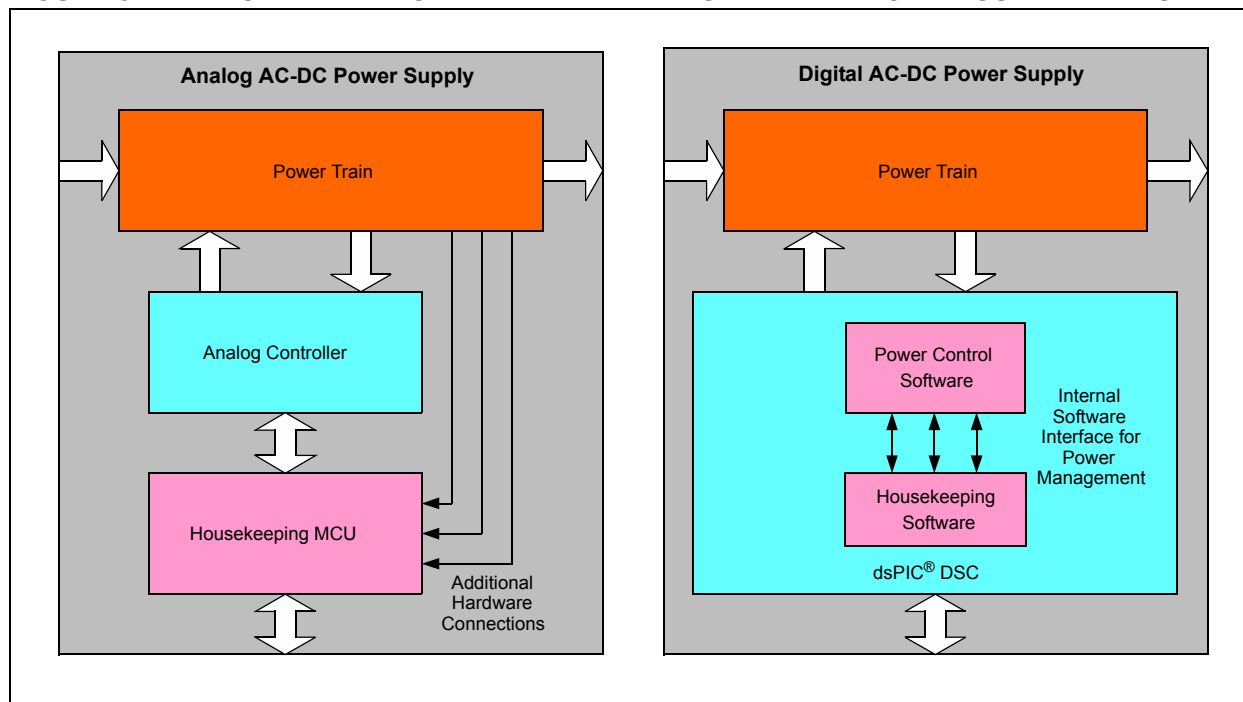
This housekeeping MCU transmits the local system parameters to a master controller or data logger. But how does this MCU obtain this data? It must use additional sensing circuits to collect the required data, and then transmit it. In some cases, the remote system may also send out instructions on the operation of the local power converters. This configuration requires the addition of hardware interfaces between the housekeeping MCU and the power conversion circuits, therefore adding cost to the system.

Conversely, a digital power supply eliminates the need for this additional circuitry because all of the system parameters are already measured by the DSC. These parameters can be stored in the DSC's memory and transmitted to the remote system using on-chip communication peripherals such as SPI, I²C™, UART or CAN. Any modifications to the system operation can also be made by a simple software routine without additional hardware.

The digital power supply also reduces overall cost of the system by eliminating redundant circuitry. For example, consider a two-stage AC-DC power supply. The first stage measures the output voltage for its control loop operations. As this voltage provides the input to the second stage, the same data is also used by the second stage either for feed-forward control or input under/over-voltage protection.

A single DSC eliminates redundant measurements of the same parameter, and internally provides all the options for different control or protection features. The DSC also helps the system react to fault conditions much faster and more effectively than with discrete analog controllers. For example, in a two-stage analog AC-DC Power supply, if a fault occurs on the downstream converter, the front-end PFC Boost converter will not be aware of the fault until this condition has been communicated to the PFC controller. A digital controller on the other hand is aware of all the fault conditions in the entire system and can therefore react almost instantaneously to the fault, regardless of where the fault occurred.

FIGURE 5: POWER MANAGEMENT DIFFERENCES BETWEEN POWER SUPPLY TYPES



Soft-Start and Sequencing in Analog and Digital Power Supplies

When a power supply first starts up, the various storage elements, such as capacitors and inductors, are completely depleted. In such a situation, a sudden rise in the supply voltage can cause large voltage and current surges in the system. Therefore, soft-start is implemented in all stages of the power supply to ensure that system components do not undergo unnecessary stress.

Many (but not all) analog controllers provide a built-in soft-start feature. Analog controllers provide limited flexibility in choosing the soft-start duration and startup delays with additional circuitry.

In multi-stage power supplies, there is also a need for sequencing the outputs in a predefined manner, as some outputs are dependent on others. This can be accomplished using a separate sequencing chip, or by using the housekeeping MCU with additional circuitry.

A digital power supply eliminates the need for additional hardware because all sequencing and soft-start routines can be implemented as part of the power supply control software. A soft-start routine can be implemented for each stage of the power supply, each with a configurable duration and delay. A typical soft-start routine is shown in the C code snippet in Example 1.

In Example 1, the soft-start routine is called immediately after the initialization of the dsPIC DSC. A startup delay is first called, and then the output voltage reference is set to the measured output voltage. The reference is then incremented by a fixed amount until the final desired reference is reached. At this point, the soft-start routine ends and normal system operation begins. The digital controller allows for very flexible use of this soft-start routine. The same routine can be called with different parameters at different times. For example, if the system is attempting to restart after a fault has occurred, the startup delay and soft-start duration can be modified to a different value.

Sequencing can be implemented in a number of flexible configurations without any additional circuitry. A few sequencing schemes are shown in Figure 6.

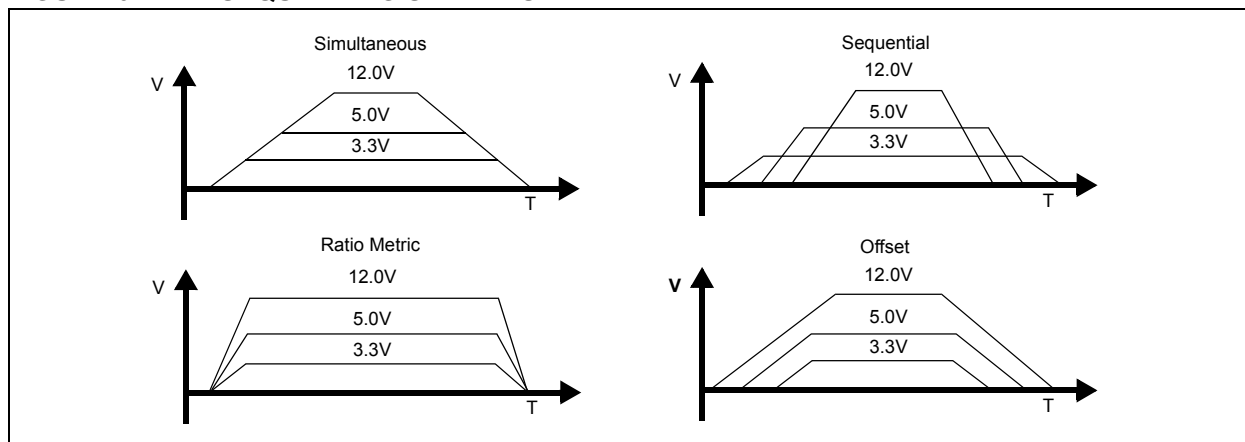
If one converter is dependent on the output of another stage, the software can set flags to indicate when one converter is completely turned ON, and that the voltage is ready for the next stage to begin ramping up.

As shown in Figure 6, the sequencing can easily be implemented in a digital power supply in a number of ways based on the needs of the application. A digital power supply offers great flexibility in picking and choosing the soft-start and sequencing schemes without the addition of dedicated chips or complex circuitry.

EXAMPLE 1: SOFT-START ROUTINE CODE SNIPPET

```
void PFCSoftStartRoutine()
{
    Delay_ms(STARTUP_DELAY);
    pfcVoltagePID.controlReference = pfcInitialOutputVoltage;
    while (pfcVoltagePID.controlReference <= PFCVOLTAGE_REFERENCE)
    {
        Delay_ms(SOFTSTART_INCREMENT_DELAY);
        pfcVoltagePID.controlReference += PFC_SOFTSTART_INCREMENT;
    }
    pfcVoltagePID.controlReference = PFCVOLTAGE_REFERENCE;
}
```

FIGURE 6: SEQUENCING SCHEMES



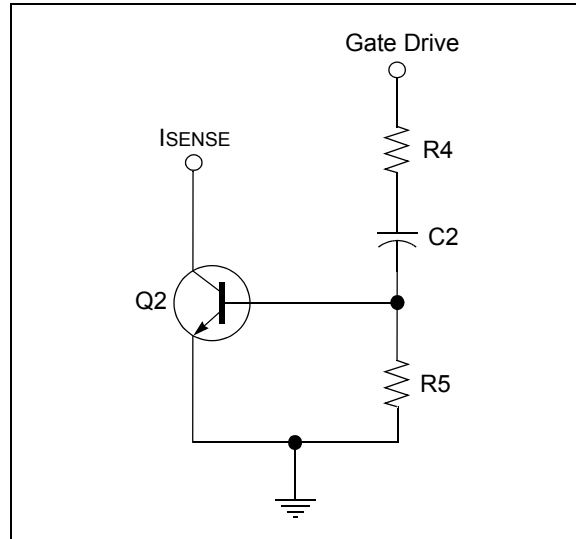
Leading-Edge Blanking (LEB)

Current feedback signals from most power converters must be filtered to eliminate noisy measurements and false tripping of current-limit and fault circuits. With faster switches, the effect of noise on the feedback signals becomes worse. In some situations, the noise spikes due to MOSFET switching instants may even exceed the maximum current-limit setting.

It is difficult to filter out this amount of noise from the current feedback signal without adversely affecting the wave shape. It is desirable to preserve the wave shape for accurate control loop operations and current-limit protection. Therefore, a technique called LEB is often employed to ignore the noise spikes on the feedback signal near the PWM switching edges.

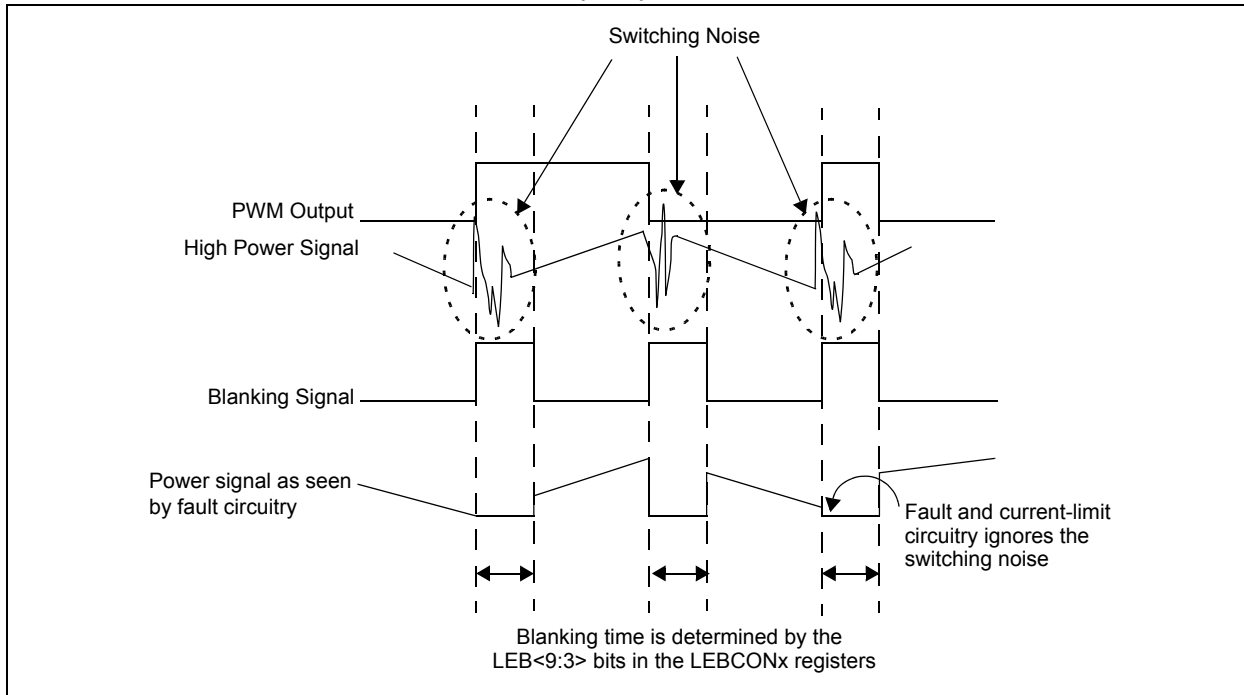
For an analog controller, this involves designing a hardware blanking circuit that ignores (or “blanks”) the feedback signal for a fixed duration. Figure 7 illustrates one possible configuration of the LEB circuit. The circuit essentially masks the noise spikes for a fixed duration, determined by the values of the timing resistor and capacitor. This solution adds cost and complexity to the system and does not offer much flexibility with the blanking duration.

FIGURE 7: LEB CIRCUIT



The dsPIC33F “GS” series of devices are optimized for all power supply applications and provide a built-in LEB feature. The LEB feature can be enabled or disabled at any time and the user can choose which PWM edges to blank out. The blanking time can be adjusted in software and no additional circuitry is required to implement this feature. The operation of the LEB feature in the dsPIC DSC is described in Figure 8.

FIGURE 8: LEADING-EDGE BLANKING (LEB)



Adaptive and Non-Linear Control

With digital power supply controllers comes the ability to change the operation of the power supply at run-time. This capability opens up numerous opportunities for innovation and a chance to gain a competitive advantage over other available products.

One of the possibilities for adaptive control is to use multiple sets of control loop coefficients. As the performance of the system changes at different line/load conditions, the coefficients can be modified on-the-fly to achieve the best performance possible at each operating point.

As another example, consider that a system is rated for operation up to 50°C; however, for some reason, the ambient temperature exceeds this limit. In this case, the software can be written to reduce the current limit settings. This implementation can help to safely extend the operation of the system beyond its normal limits, albeit with some added restrictions.

SUMMARY

Analog controllers have long been the mainstay of power supplies. The power supply market has always demanded lower cost and higher performance power supplies. The recent trend toward smarter designs and greater integration has driven the need for digital power supplies.

Microchip's dsPIC33F "GS" series Digital Signal Controllers have made it possible to achieve all the potential of digital power supply control. As described in this white paper, digital power supplies have been able to meet the market needs and at times even exceed them. The dsPIC DSC has opened up possibilities for innovation previously unheard of in the power supply world and is at the forefront of this digital revolution.

RELATED DEVELOPMENT TOOLS

Microchip Digital AC-DC Reference Design

The AC-DC Reference Design is a complete 300W digital power supply demonstrating the benefits of digital control. The reference design implements four power stages including:

- Boost PFC Converter
- Phase-Shifted Full-Bridge Converter with Synchronous Rectification
- Multi-Phase Synchronous Buck Converter
- Single-Phase Synchronous Buck Converter

This reference design is available royalty free on the Microchip website at: www.microchip.com/acdcpower.

FIGURE 9: DIGITAL POWER AC-DC REFERENCE DESIGN



REVISION HISTORY

Revision A (April 2010)

This is the initial released version of this document.

NOTES:

Note the following details of the code protection feature on Microchip devices:

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