POWER MANAGEMENT

SAM DAVIS

POWER

SUPPLIES

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APPLICATIONS

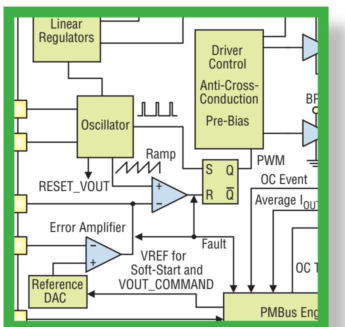
COMPONENTS

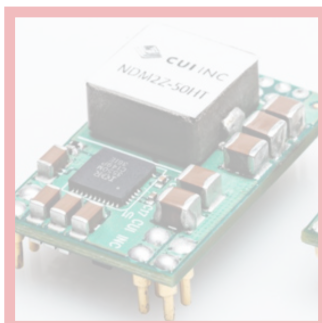
SEMICONDUCTORS

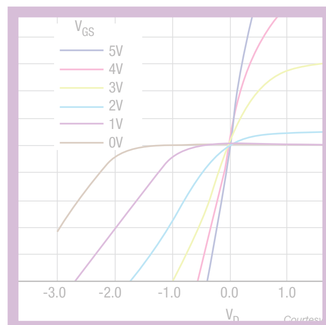
electronic design

POWER MANAGEMENT

BY **SAM DAVIS**







SAM DAVIS

INTRODUCTION TO POWER MANAGEMENT

Power management technology plays a major role in virtually all electronic systems, including analog, digital, and mixed-signal systems. It doesn't matter whether it is consumer, industrial, computer, or transportation electronics, power management technology plays a pivotal role. Regardless of the application, power management technology regulates, controls, and distributes power throughout the system. Therefore, power management affects the reliability, performance, cost, and time-to-market for electronic systems. An analogy would be that power management functions in a manner similar to the body's blood vessels that supply the proper nutrients to keep the body alive. Likewise, power management supplies and controls the power that keeps an electronic system alive.

Designing system power management is much more complicated now than it was a decade ago. Today, designers must cope with ICs that operate below 1 V, or others that may consume over 100 A. In addition, there is a trend toward mixed-signal systems employing analog and digital circuits. Plus, processors of different types are now part of some power management functions. And, there are also system-oriented functions that require application-specific ICs to perform specific power management tasks.

The primary power management device is the power supply that accepts an ac or dc input and produces a regulated dc output that powers the electronic system. The key component of the power supply is the voltage regulator that is usually an integrated circuit (IC), with several different types that provide specific characteristics. Other important components are the power semiconductors and the various power management ICs that perform a variety of functions.

This book covers power management components and systems, with an emphasis on their application. The book also includes updated information for articles that appeared in Power Electronics Technology magazine. There is also new material that has not appeared before. All the important information about power management is contained in one book. There are 25 chapters that describe the components and systems associated with power management.

CHAPTER 1:

POWER SUPPLY FUNDAMENTALS

The key component of the dc power management system is the power supply that provides dc power for the associated system. The specific type of dc power management depends on its power input, which includes:

- AC input—A power supply that accepts an ac utility power input, rectifies and filters it, then applies the resulting dc voltage to a regulator circuit that provides a constant dc output voltage. There is a wide variety of ac-dc supplies that can have an output voltage from less than 1V to thousands of volts. This dc power management system usually employs a switch-mode power supply, although some linear supplies are available.
- DC input—A power supply that accepts a dc voltage input, typically 5 V, 12V, 24V, or 48 V and produces a dc output voltage. At the low end, a supply of this type can produce less than 1Vdc, whereas other dc-dc supplies can produce thousands of volts dc. Here, power management usually employs a switch-mode power supply.
- Battery input (for portable equipment)—Because of size and weight restrictions of portable equipment, this power management function is usually integrated with the rest of the electronic system. Some of these systems also include an ac adapter, which is a small power unit that plugs into the ac wall outlet and provides a dc output voltage. Usually, the ac adapter is used to power the unit and can also recharge the system battery.
- Ultralow voltage input (energy harvesting)—Energy harvesting can provide the power to charge, supplement, or replace batteries. A key component in energy harvesting is a power converter that can operate with ultralow voltage inputs. In operation, this power converter captures a minute amount of energy, accumulates it, stores it, and then maintains the stored energy as a power source. Low-voltage inputs can come from solar power, thermal energy, wind energy, or kinetic energy.

Linear vs. Switch-Mode Power Supplies

There are two basic power supply configurations used with dc power management subsystems: linear and switch-mode. Linear power supplies always conduct current. Switch-mode supplies convert dc to a switched signal that is then rectified to produce a dc output. Differences between these two configurations include size and weight, power-handling capability, EMI, and regulation.

The linear regulator's main components are a pass transistor, error amplifier, and voltage reference, as seen in Fig. 1-1. The linear regulator maintains a constant output voltage by using the error amplifier to compare a portion of the output voltage with a stable voltage reference. If the output voltage tends to increase, feedback causes the pass transistor to lower the output voltage and vice versa. OEM linear supplies can handle several amperes of current. They are usually bulky benchtop or rack-mounted supplies.

In most applications, older, high-current linear supplies have been superseded by switch-mode supplies.

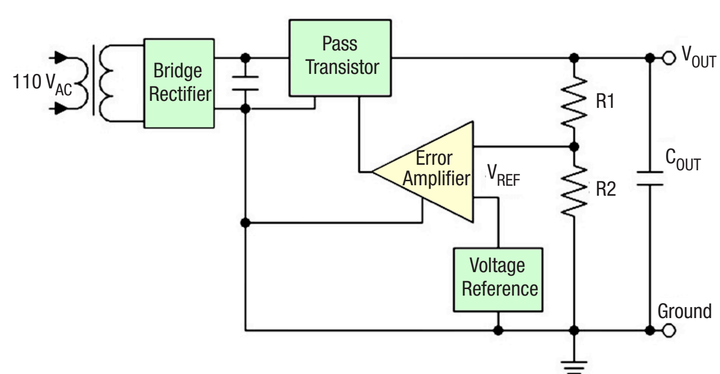


Figure 1-1. Basic AC-DC Linear Power Supply

Shown in Fig. 1-2 is a typical isolated switch-mode supply. Here, the ac input voltage is rectified and filtered to obtain a dc voltage for the other power-supply components. One widely used approach uses the on and off times pulse-width modulation (PWM) to control the power-switch output voltage. The ratio of on time to the switching period time is the duty cycle. The higher the duty cycle, the higher the power output from the power semiconductor switch.

The error amp compares a portion of the output voltage feedback with a stable voltage reference to produce the drive for PWM circuit. The resulting drive for the PWM controls the duty cycle of the pulsed signal applied to the power switch, which in turn controls the power-supply dc output voltage. If the output voltage tends to rise or fall, the PWM changes the duty cycle so that the dc output voltage remains constant.

An isolation circuit is required to maintain isolation between the output ground and the power supplied to the power supply's components. Usually, an optocoupler provides the isolation while permitting the feedback voltage to control the supply's output.

The inductor-capacitor low-pass output filter converts the switched voltage from the switching transformer to a dc voltage. The filter is not perfect, so there is always some residual output noise called "ripple." The amount of ripple depends on the effectiveness of the low-pass filter at the switching frequency. Power-supply switching frequencies can range between 100kHz to over 1MHz. Higher switching frequencies allow the use of smaller-size, lower-value inductors and capacitors in the output low-pass filter.

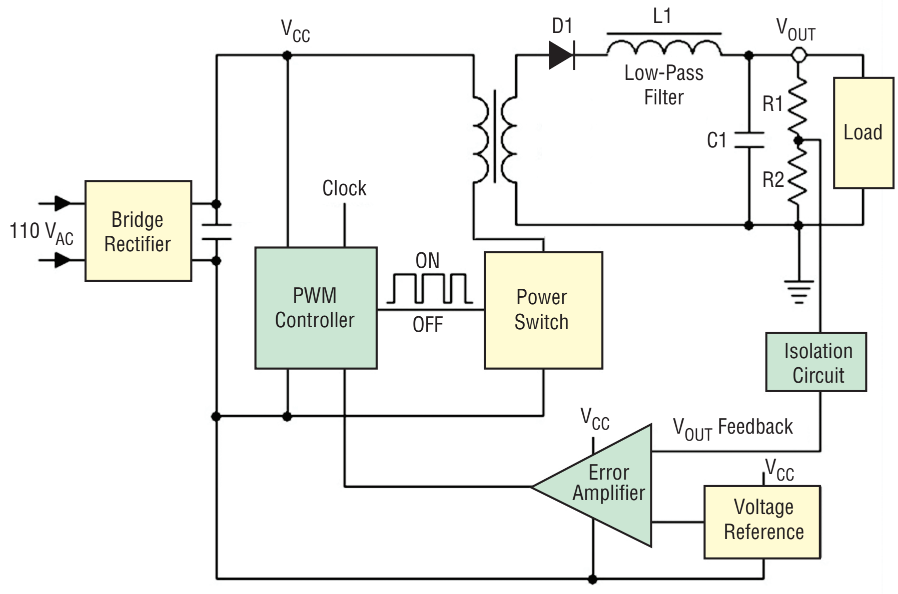


Figure 1-2. Typical Isolated AC-DC Switch-Mode Power Supply

However, higher frequencies can also increase power semiconductor losses, which reduces power-supply efficiency.

The power switch is a key component in the power supply in terms of power dissipation. The switch is usually a power MOSFET that operates in only two states—on and off. In the off state, the power switch draws very little current and dissipates very little power. In the on state, the power switch draws the maximum amount of current, but its on-resistance is low, so in most cases its power dissipation is minimal. In the transition from the on state to the off state and off to on, the power switch goes through its linear region so it can consume a moderate amount of power. The total losses for the power switch are therefore the sum of the on and off state plus the transition through its linear regions. The actual losses depend on the power switch and its operating characteristics. Table 1-1 compares the characteristics of isolated, ac-dc linear and switch-mode power supplies.

TABLE 1-1. LINEAR VS. SWITCH-MODE

Parameter	Linear Power Supply	Switch-Mode Power Supply
Size	Can be twice the size	Half the size
Weight	Heavier because of ac input power transformer	Higher frequency, lower weight switching transformer
Efficiency	50-70%	80-90+%
Design Complexity	Simpler	More Complex
EMI	"Quiet" (None)	More (depends on switching frequency and layout)

Voltage Regulator ICs

Regulating the output voltage of virtually all power supplies is dependent on voltage regulator ICs. These ICs obtain a DC input from rectified AC or a battery. In operation, the voltage regulator feeds back a percentage of its output voltage that is compared with a stable reference voltage. If the output voltage tends to rise or fall compared with the reference, the feedback causes the output to remain the same. Chapter 7 provides the details of voltage regulator ICs. Also, there are lab kits to help engineers understand voltage regulator IC operation.

Related Articles

1. Sam Davis, Component Power Analysis Supports Design of 94% Efficient 200 W AC-DC Supply, powerelectronics.com, December, 2013.
2. Michael O'Loughlin, Voltage/Current Sensing Technique Cuts Flyback Converter Costs, powerelectronics.com, November, 2012.
3. Don Knowles, The AC-DC Power Supply: Make It Or Buy It?, powerelectronics.com, August, 2012.
4. Steve Sandler, Measuring Stability: Stability and Why It Matters, powerelectronics.com, December, 2014.
5. Sam Davis, Digitally-Controlled AC-DC Supply, powerelectronics.com, January, 2012.
6. Sam Davis, Bi-Directional Controller IC Employs Supercapacitors for dc Power Backup, powerelectronics.com, May, 2014.
7. Sam Davis, DC-DC Converter Design Considerations for Wearable Devices, powerelectronics.com, February, 2014.
8. Steve Sandler, Five Things Every Engineer Should Know about Bode Plots, powerelectronics.com, January, 2014.
9. Viral Vaidya, High-Voltage Synchronous Regulators Address Industrial Power Dilemma, powerelectronics.com, December, 2013.
10. am Davis, Power-Management IC Supports Automotive Instrument Cluster Design, powerelectronics.com, March, 2014.
11. Ernie Wittenbreder, Topology Selection by the Numbers Part One, powerelectronics.com, March, 2006.
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14. Sam Davis, Power Supply Characteristics FAQs, powerelectronics.com, April, 2014.
15. Christophe Basso, Why is it Important to Plot a Power Stage Small-Signal Response?, powerelectronics.com, September, 2013.
16. Power-Management Lab Kits for Young and Old Engineers powerelectronics.com, July 13, 2016.

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CHAPTER 1:

POWER SUPPLY CHARACTERISTICS

Efficiency is one of the most important power supply characteristics. It determines the thermal and electrical losses in the system, as well as the amount of cooling required. Also, it determines the physical package sizes of both the power supply and the final system. Plus, it determines the system component operating temperatures and the resultant system reliability. These factors contribute to the determination of the total system cost, both hardware and field support. Power-supply data sheets usually include a plot of efficiency versus output current, as shown in Fig. 2-1. This plot shows that efficiency varies with the power supply's applied voltage as well as the output load current.

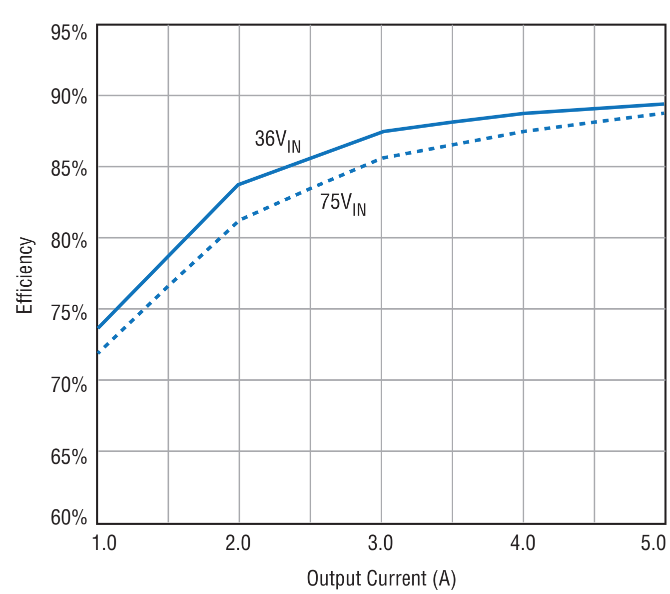
Efficiency, reliability, and operating temperature are interrelated. Power-supply data sheets usually include specific airflow and heat-sink requirements. For example, the ambient operating temperature affects the output load current that the power supply can handle reliably. Derating curves for the power supply (Fig. 2-2) indicate its reliable operating current versus temperature. Derating shows how much current the supply can be safely handle if it is operating with natural convection, or 200 LFM and 400 LFM.

Protecting the Supply

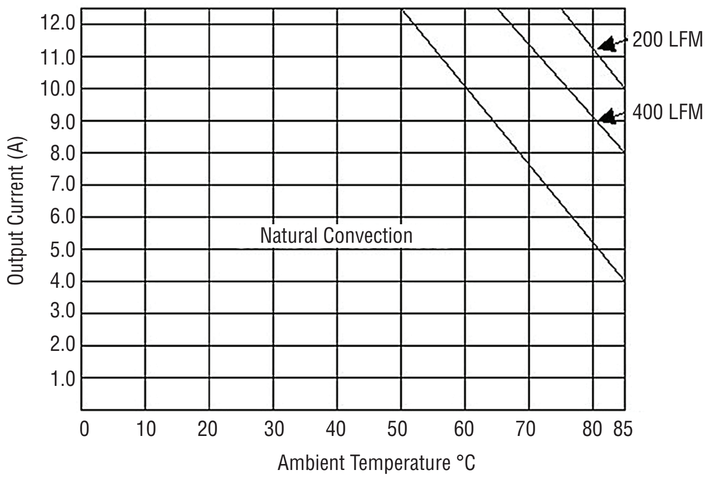
There are several other characteristics that impact power-supply operation. Among these are those employed to protect the supply, which are listed below.

Overcurrent: A failure mode caused by output load current that is greater than specified. It is limited by the maximum current capability of the power supply and controlled by internal protection circuits. It can also damage the power supply in some cases. Short circuits between the power-supply output and ground can create currents within the system that are limited only by the maximum current capability and internal impedance of the power supply. Without limiting, this high current can cause overheating and damage the power supply as well as the load and its interconnects (printed circuit board traces, cables). Therefore, most power supplies should have current limiting (overcurrent protection) that activates if the output current exceeds a specified maximum.

Overtemperature: A temperature that is above the power supply's specified value must be prevented or it can cause power-supply failure. Excessive operating temperature can damage a power supply and the circuits connected to it. Therefore, many supplies employ a temperature sensor and associated circuits to disable the supply if its operating temperature exceeds a specific value. In



2-1. Typical efficiency plot for a power supply.



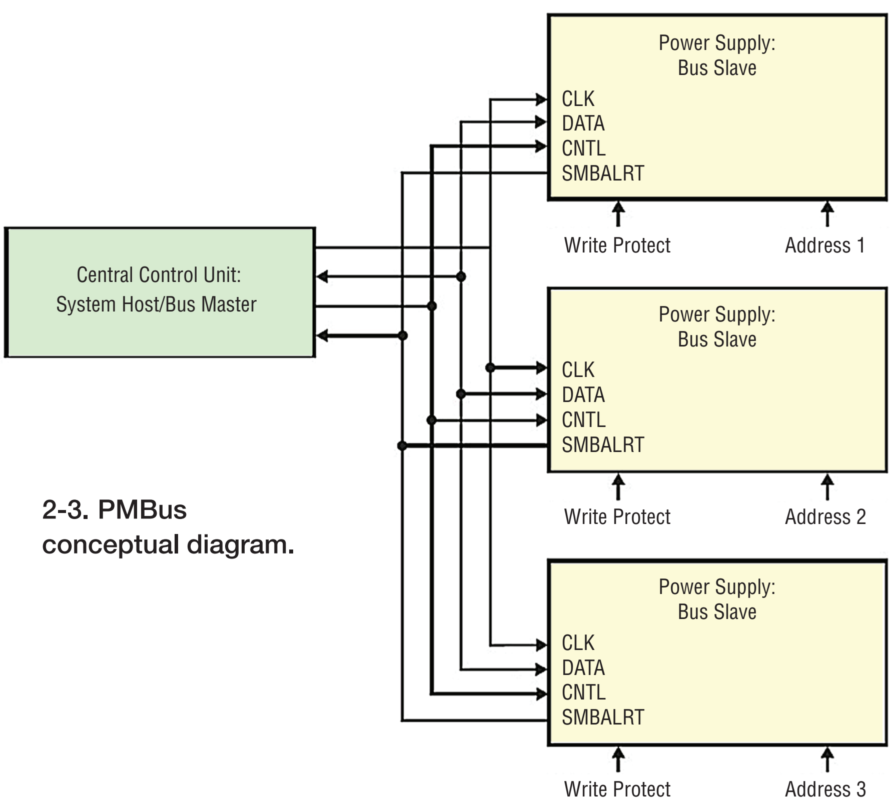
2-2. Typical derating curves for a power supply.

particular, semiconductors used in the supply are vulnerable to temperatures beyond their specified limits. Many supplies include overtemperature protection that turns off the supply if the temperature exceeds the specified limit.

Overvoltage: This failure mode occurs if the output voltage goes above the specified dc value, which can impose excessive dc voltage that damages the load circuits. Typically, electronic system loads can withstand up to 20% overvoltage without incurring any permanent damage. If this is a consideration, select a supply that minimizes this risk. Many supplies include overvoltage protection that turns the supply off if the output voltage exceeds a specified amount. Another approach is a crowbar zener diode that conducts enough current at the overvoltage threshold so that it activates the power-supply current limiting and it shuts down.

Soft Start: Inrush current limitation may be needed when power is first applied or when new boards are hot plugged. Typically, this is achieved by a soft-start circuit that slows the initial rise of current and then allows normal operation. If left untreated, the inrush current can generate a high peak charging current that impacts the output voltage. If this is an important consideration, select a supply with this feature.

Undervoltage Lockout: Known as UVLO, it turns the supply on when it reaches a high enough input voltage and turns off the supply if the input voltage falls below a certain value. This feature is used for supplies operating from utility power as well as battery power. When operated from battery-based power UVLO disables the power supply (as well as the system) if the battery discharges so much that it drops supply's input voltage too low to permit reliable operation.

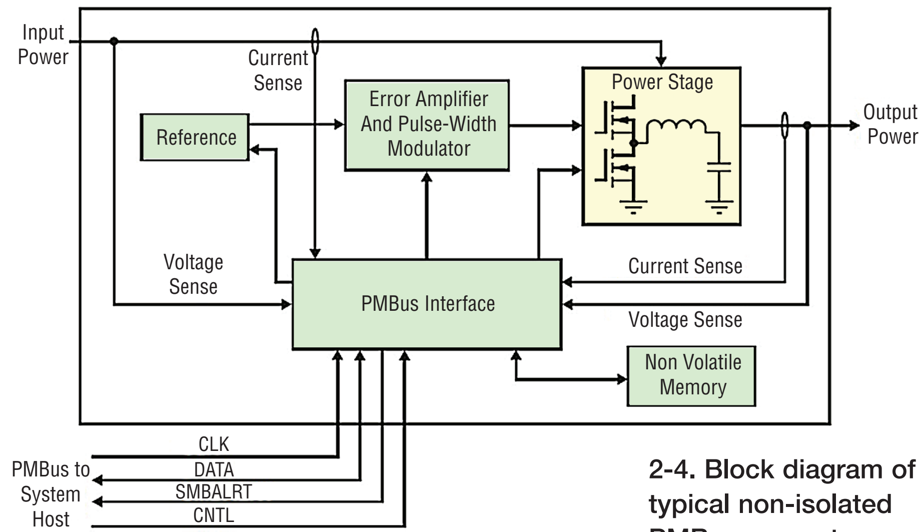


2-3. PMBus conceptual diagram.

Electromagnetic Compatibility (EMC): Involves design techniques that minimize electromagnetic interference (EMI). In switch-mode power supplies, a dc voltage is converted to a chopped or a pulsed waveform. This causes the power supply to generate narrow-band noise (EMI) at the fundamental of the switching frequency and its associated harmonics. To contain the noise, manufacturers must minimize radiated or conducted emissions.

Power-supply manufacturers minimize EMI radiation by enclosing the supply in a metal box or spray coating the case with a metallic material. Manufacturers also need to pay attention to the internal layout of the supply and the wiring that goes in and out of the supply, which can generate noise.

Most of the conducted interference on the power line is the result of the main switching transistor or output rectifiers. With power-factor correction and proper transformer design, connection of the heat sink, and filter design, the power-supply manufacturer can reduce conducted interference so



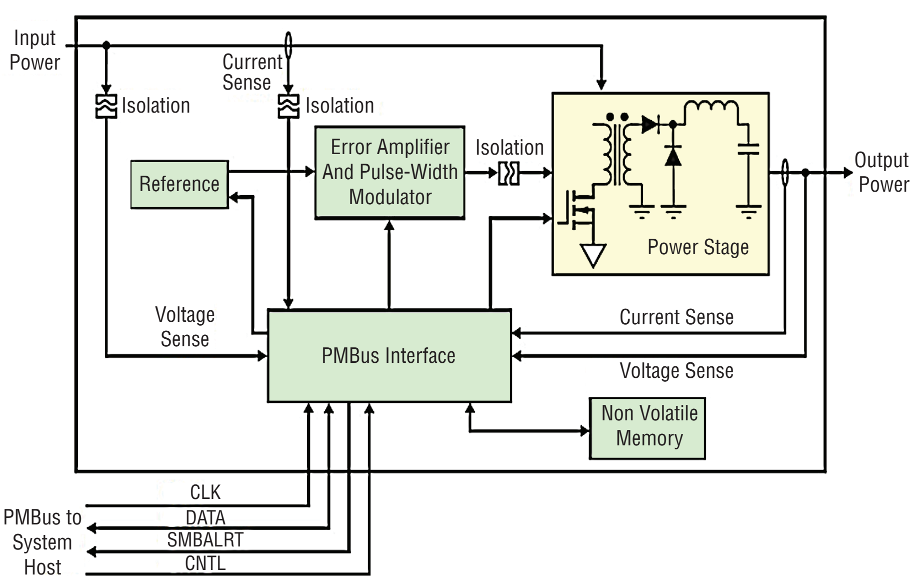
2-4. Block diagram of typical non-isolated PMBus converter.

that the supply can achieve EMI regulatory agency approvals without incurring excessive filter cost. Always check to see that the power-supply manufacturer meets the requirement of the regulatory EMI standards.

There are several power-supply characteristics that affect their operation:

Drift: The variation in dc output voltage as a function of time at constant line voltage, load, and ambient temperature.

Dynamic response: A power supply may be employed in a system where there is a requirement to provide fast dynamic response to a change in load power. That can be the case for the load of high-speed microprocessors with power-management functions. In this case, the microprocessor may be in a standby state and upon command it must start up or turn off immediately, which imposes high dynamic currents with fast ramp rates on the power supply. To accommodate the microprocessor, the supply's output voltage must ramp up or down within a specified time interval, but without excessive overshoot.



2-5. Block diagram of typical isolated PMBus converter.

Efficiency: Ratio of output-to-input power (in percent), measured at a given load current with nominal line conditions (Pout/Pin).

Holdup time: Time during which a power supply's output voltage remains within specification following the loss of input power.

Inrush current: Peak instantaneous input current drawn by a power supply at turn-on.

International standards: Specify a power supply's safety requirements and allowable EMI (electromagnetic interference) levels.

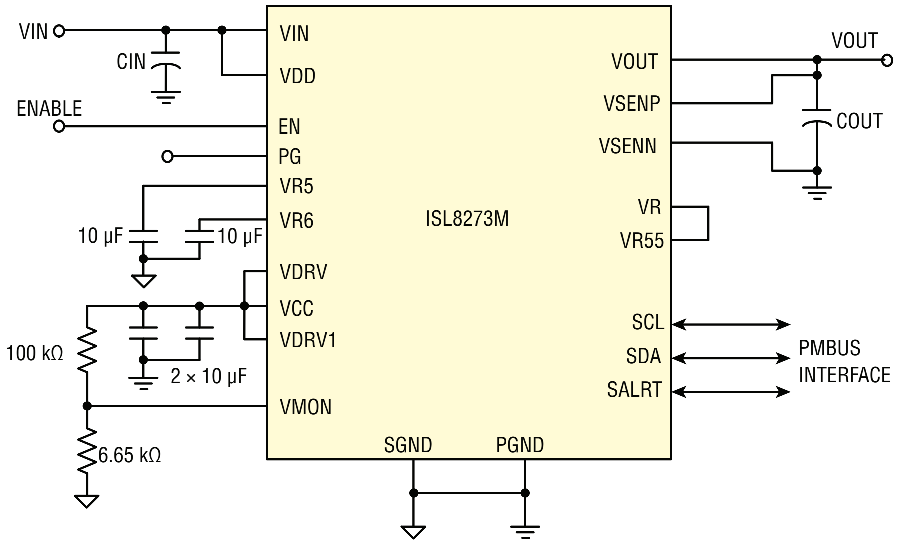
Isolation: Electrical separation between the input and output of a power supply measured in volts. A non-isolated has a dc path between the input and output of supply, whereas an isolated power supply employs a transformer to eliminate the dc path between input and output.

Line regulation: Change in value of dc output voltage resulting from a change in ac input voltage, specified as the change in ± mV or ± %.

Load regulation: Change in value of dc output voltage resulting from a change in load from open-circuit to maximum-rated output current, specified as the change in ± mV or ± %.

Output noise: This can occur in the power supply in the form of short bursts of high frequency energy. The noise is caused by charging and discharging of parasitic capacitances within the power supply during its operating cycle. Its amplitude is variable and can depend on the load impedance, external filtering, and how it is measurement.

Output voltage trim: Most power supplies have the ability to "trim" the output voltage, whose adjustment range does not need to be large, usually about ±10%. One common usage is to compensate for



2-6. ISL8273M is compatible with PMBus Power System Management Protocol Specification Parts I and II version 1.2.

the dc distribution voltage drop within the system. Trimming can either be upward or downward from the nominal setting using an external resistor or potentiometer.

Periodic and random deviation (PARD): Unwanted periodic (ripple) or aperiodic (noise) deviation of the power-supply output voltage from its nominal value. PARD is expressed in mV peak-to-peak or rms, at a specified bandwidth.

Peak current: The maximum current that a power supply can provide for brief periods.

Peak power: The absolute maximum output power that a power supply can produce without damage. It is typically well beyond the continuous reliable output power capability and should only be used infrequently.

Power-supply sequencing: Sequential turn-on and off of power supplies may be required in systems with multiple operating voltages. That is, voltages must be applied in a specific sequence, otherwise the system can be damaged. For example, after applying the first voltage and it reaches a specific value, a second voltage can be ramped up, and so on. Sequencing works in reverse when power is removed, although speed is not usually as much of a problem as turn-on.

Remote on/off : This is preferred over switches to turn power supplies on and off. Power-supply data-sheet specifications usually detail the dc parameters for remote on/off, listing the on and off logic levels required.

Remote sense: A typical power supply monitors its output voltage and feeds a portion of it back to the supply to provide voltage regulation. In this way, if the output tends to rise or fall, the feedback regulates the supply's output voltage. However, to maintain a constant output at the load, the power supply should actually monitor the voltage at the load. But, connections from a power supply's output to its load have resistance and current flowing through them that produces a voltage drop that creates a voltage difference between the supply's output and the actual load. For the optimal regulation, the voltage fed back to the power supply should be the actual load voltage. The supply's two (plus and minus) remote sense connections monitor the actual load voltage, a portion of which is then fed back to the supply with very little voltage drop because the current through the two remote sense connections is very low. As a consequence, the voltage applied to the load is regulated.

Ripple: Rectifying and filtering a switching power supply's output results in an ac component (ripple) that rides on its dc output. Ripple frequency is some integral multiple of the converter's switching frequency, which depends on the converter topology. Ripple is relatively unaffected by load current, but can be decreased by external capacitor filtering.

Tracking: When using multiple output power supplies whereby one or more outputs follow another with changes in line, load, and temperature, so that each maintains the same proportional output voltage, within specified tracking tolerance, with respect to a common value.

PMBus

The PMBus specification describes the addition of digital control for a power supply over a specified physical bus, communications protocol, and command language. A conceptual diagram of PMBus-capable power supplies controlled from a central location is shown in Fig. 2-3. It contains a bus master and three slaves. Figures 2-4 and 2-5, respectively, show the block diagrams of typical non-isolated and isolated converters that might be found in the system shown in Fig. 2-3.

A typical system employing a PMBus will have a central control unit and at least one PMBus-enabled power supply attached to it. The connected power supplies are always slaves, and the central control unit is always the master. The central control unit initiates all communication on the bus, and the slave power supplies respond to the master when they are addressed.

The PMBus specification only dictates the way the central control unit and the slave power supplies communicate with each other. It does not put constraints on power-supply architecture, form factor, pinout, power input, power output, or any other characteristics of the supply. The specification is also divided into two parts.

Part I: Physical implementation and electrical specifications.

Part II: Protocol, communication, and command language.

To be PMBus-compliant, a power supply must:

- Meet all requirements of Part I of the PMBus specification.
- Implement at least one of the PMBus commands that is not a manufacturer-specific command.
- If a PMBus command is supported, execute that command as specified in Part II of the PMBus specification.
- If a PMBus command is not supported, respond as described in the "Fault Management and Reporting" section of Part II of the PMBus specification.

In addition, the device must be capable of starting up unassisted and without any communication with or connection to the PMBus. This behavior may be overridden by programming new defaults for the device, but the capability to start up unassisted must be present. This implies that the PMBus device must be able to store operating defaults for its configurable parameters on the device itself in some form of nonvolatile storage.

Doing so can significantly decrease the amount of time required for the system to start up, since no communication is required to configure the device for its operating parameters. If the central control unit gets power from a PMBus device that it is controlling, then that PMBus device must obviously be set to start up automatically, or the central control unit would never start and the system would not function.

To get the latest and most complete specification for PMBus, download it from the PMBus Web site at http://pmbus.org/specs.html. The PMBus is derived from the System Management Bus (SMBus) Specification Version 1.1, which is an improvement over the I^2C bus. I^2C is a simple two-line, synchronous serial communication bus originally designed to allow communication between two or more integrated circuits that are in close proximity to each other. SMBus extensions and improvements over I^2C include host notification via the SMBALRT bus line and packet error checking (PEC) to help prevent erroneous operation from noise issues.

There are several differences between the PMBus and SMBus specifications. Those most notable from a system-design perspective are the optional host notify protocol and the group command protocol.

Host notification is required for SMBus compliance, but is optional for PMBus compliance. However, most PMBus devices will support this feature, since it tells the host that a problem exists so it can take appropriate action without having to continually poll each slave device to check for problems. This lightens the load on both the host and the bus itself, providing greater system capability. Host notification is done using a single line (SMBALRT) that is passively pulled high.

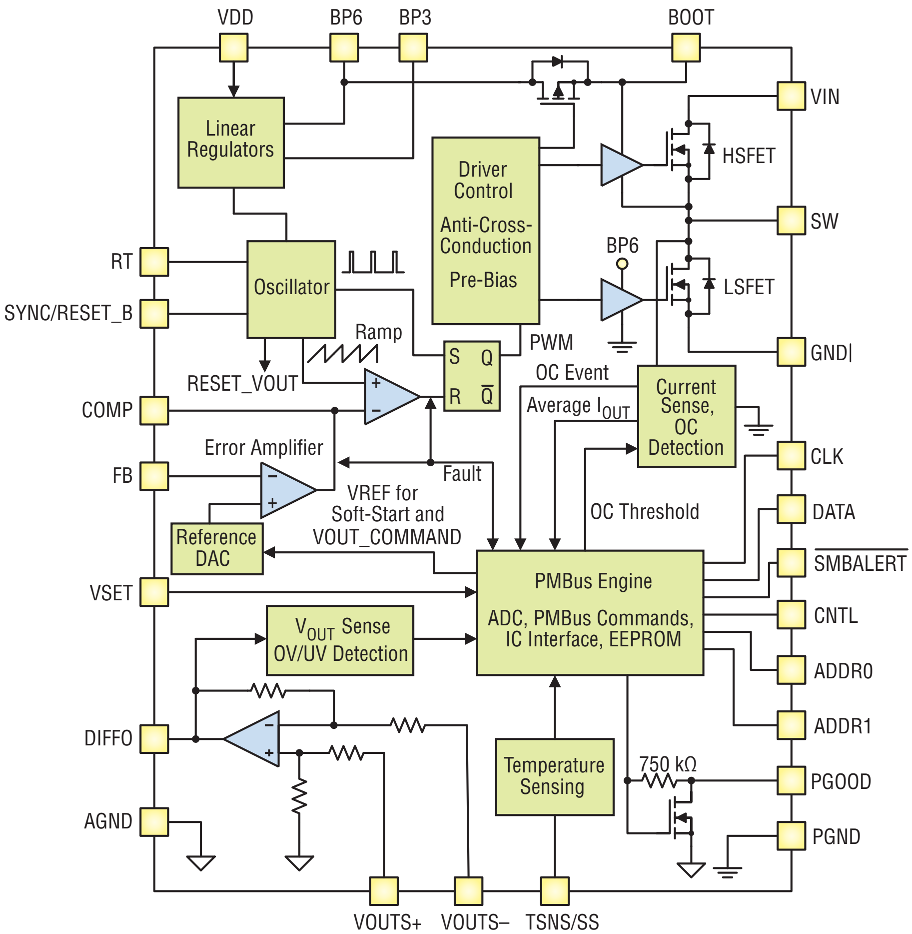
When a slave has information that the host is likely to need, the slave pulls the SMBALRT line low. The host can then poll each device individually or use the protocol described in the "SMBus Host Notify Protocol" section of the SMBus 2.0 specification.

The group command protocol is designed to allow several PMBus-compliant devices to simultaneously execute commands. For more specific information on this feature, refer to Part I,

Section 5.2 of the PMBus Specification.

You can group PMBus commands into several categories; a partial list of the actual commands is listed below:

- On, off, and margin testing
  - OPERATION
  - ON_OFF_CONFIG
  - VOUT_MARGIN_HIGH
  - VOUT_MARGIN_LOW
  - Output-voltage related
  - VOUT_COMMAND
  - VOUT_TRIM
  - VOUT_CAL_OFFSET
  - VOUT_SCALE_LOOP
  - VOUT_SCALE_MONITOR
- Addressing, memory, communication, and capability
  - STORE_DEFAULT_ALL
  - RESTORE_DEFAULT_ALL
  - STORE_DEFAULT_CODE,
  - RESTORE_DEFAULT_CODE
  - WRITE_PROTECT
  - PAGE
  - PHASE
  - QUERY
- Fault management
  - IOUT_OC_FAULT_LIMIT
  - IOUT_OC_FAULT_RESPONSE
  - IOUT_OC_WARN_LIMIT
  - OT_WARN_LIMIT
  - OT_FAULT_LIMIT
  - OT_FAULT_RESPONSE
  - VIN_UV_WARN_LIMIT
  - VIN_UV_FAULT_LIMIT
  - VIN_UV_FAULT_RESPONSE
  - CLEAR_FAULTS
- Sequencing
  - TON_DELAY



2-7. TPS544C25 synchronous buck converter with PMBus and frequency synchronization.

- TON_RISE
- TOFF_DELAY
- TOFF_FALL
- Status
- STATUS_BYTE,
- STATUS_WORD
- STATUS_VOUT
- STATUS_IOUT
- STATUS_CML
- Telemetry
- READ_VIN
- READ_VOUT
- READ_IIN
- READ_IOUT
- READ_TEMPERATURE
- READ_DUTY_CYCLE
- READ_PIN
- READ_POUT
- Other
- FREQUENCY_SWITCH
- VIN_ON
- VIN_OFF
- POUT_MAX

Version 1.3 of PMBus was added in 2014. The major new addition to PMBus is the AVSBus, which is an interface designed to facilitate and expedite communication between an ASIC, FPGA, or processor and a POL control device on a system, for the purpose of adaptive voltage scaling. When integrated with PMBus, AVSBus is available for allowing independent control and monitoring of multiple rails within one slave.

- The AVSBus is behaviorally and electrically similar to SPI bus without chip select lines. AVS_MData and AVS_SData are equivalent to MOSI and MISO. AVS_Clock is equivalent to CLK of the SPI bus. Maximum bus speed is 50 MHz.
- AVSBus is an application-specific protocol to allow a powered device such as an ASIC, FPGA, or Processor to control its own voltage for power savings.
- The combination of these protocols in a slave device is an efficient and effective solution for systems containing loads that need to adapt the operating voltage.

ISL8273M

Intersil's ISL8273M provides a PMBus digital interface that enables the user to configure all aspects of the module operation as well as monitor the input and output parameters (Fig. 2-6). The ISL8273M can be used with any SMBus host device. In addition, the module is compatible with PMBus Power System Management Protocol Specification Parts I and II version 1.2. The ISL8273M accepts most standard PMBus commands. When configuring the device using PMBus commands, it is recommended that the enable pin is tied to SGND.

The SMBus device address is the only parameter that must be set by the external pins. All other device parameters can be set using PMBus commands.

The ISL8273M can operate without the PMBus in pin-strap mode with configurations programmed by pin-strap resistors, such as output voltage, switching frequency, device SMBus address, input UVLO, soft-start/stop, and current sharing.

The TPS544x25 from Texas Instruments are PMBus 1.2 compliant, non-isolated synchronous buck converters with integrated FETs, capable of high-frequency operation and 20-A or 30-A from a 5 mm × 7 mm package (Fig.

2-8. TDK-Lambda's 35A iJA series of POL non-isolated dc-dc converters are PMBus compliant.

2-7). High-frequency, low-loss switching, provided by an integrated NexFET power stage and optimized drivers, allows for very high-density power solutions. These devices implement the industry standard fixed-switching frequency, voltage-mode control with input feed-forward topology that responds instantly to input voltage change. These devices can be synchronized to the external clock to eliminate beat noise and reduce EMI/EMC.

The PMBus interface enables the Adaptive Voltage Scaling (AVS) through NexFET Power Stage VOUT_COMMAND, flexible converter configuration, as well as key parameter monitoring including output voltage, current, and an optional external temperature. Response to fault conditions can be set to either restart, latch-off, or ignore depending on system requirements. Two on-board linear regulators provide suitable power for the internal circuits.

Features

- Input voltage: 4.5V to 18V
- Output voltage: 0.5V to 5.5V
- Single thermal pad
- 500mV to 1500 mV reference for AVS and margining through PMBus
- 0.5% reference accuracy at 600mV and above
- Lossless low-side MOSFET current sensing
- Voltage mode control with input feed-forward
- Differential remote sensing
- Thermal shutdown

iJA Series

TDK-Lambda's 35A iJA series of POL (point-of-load) non-isolated dc-dc converters are PMBus compliant and feature digital control (Fig. 2-8). These converters provide better dynamic performance and improved system stability, as well as allow a great deal of flexibility and customization to the end application's needs.

The PMBus read-write functionality of the converter provides real-time, precision monitoring of voltage, current, and temperature, and allows full programmability of the iJA parameters. Function-setting pins make them easy to use in applications where PMBus communication is not implemented. A GUI (graphical user interface) and evaluation boards are available for development support.

Operating from an 8 to 14VDC input, the iJA series can provide output voltages from 0.6 to 3.3V, with a precision set-point accuracy of 1%. The series is designed to meet a wide range of applications, including servers, routers, and other Information & Communication Technology (ICT) equipment, semiconductor manufacturing equipment, measuring equipment, and general industrial equipment.

The surface-mount converters occupy only 0.45 square inch of board space, representing an ultra-high power density of 580 Watts per cubic inch. Overall dimensions are 22.9mm × 12.7mm × 9.7mm with a weight of just 6.5g. Optimization of components using digital control enables a high current output in high-temperature, low-airflow environments. The iJA power module has a typical efficiency of 94% with a 3.3V output, 12V input, and 80% loading.

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CHAPTER 3:

POWER SUPPLIES-MAKE OR BUY?

Power supplies are necessary in virtually every piece of electronic equipment. Therefore, equipment manufacturers are confronted with the task of deciding whether to make or buy a power supply for their system. DC power management employs a power supply that can either be bought or made by the equipment manufacturer. The make-or-buy decision for power supplies can have a major impact on the cost and time-to-market for the end-item electronic equipment.

The equipment manufacturer has several challenges to consider before making a power supply in-house:

- Can they make it cheaper than a purchased power supply?
- Is time-to-market a consideration?
- Are the necessary people and resources available to make the power supplies, including design and production facilities?
- Does the design and production include the time, costs, and fees associated with getting agency certifications specific to power supplies?

Unless the equipment manufacturer can meet these challenges, it most likely will buy the power supplies and then implement the power management subsystem. Among the reasons for an equipment manufacturer to make the power supply in-house are:

- They can't install a commercial power supply because there is not enough room, such as in a battery-based portable system.
- They must meet unique safety and EMC (electromagnetic compatibility) requirements that are not available in commercial units, such as found in military and aerospace systems.
- They want the equipment to be proprietary.
- They think they can make it cheaper.

There are other factors to consider when deciding between making and buying the power supplies:

- Overall budget.
- Time-to-market for the end-item equipment.
- Finding and employing "safety critical" components for the power- supply section.
- Time, costs, and fees associated with getting agency certifications specific to power supplies.
- Will your competitors have an advantage if they purchase a technically superior standard power supply?

If the equipment manufacturer's decision is to buy the power supplies, the first step is to find a manufacturer certified to meet the required reliability, safety, and EMC specifications. This usually means an investigation into the proposed manufacturer and development of the appropriate specification for the power supplies. Also, this usually requires a means for the equipment manufacturer to inspect the incoming power supply to ensure it meets its specifications. Plus, the equipment manufacturer may want to establish multiple sources to ensure delivery of enough products. In addition, the power-supply manufacturer should provide documentation and technical support, if it is required. The power-supply company should also be able to support the return of failed units.

Involve the power-supply manufacturer early on in the design stage for architectural, product, and cooling discussions. Traditionally, power supplies have been subject to the tailpipe syndrome (i.e., remembering them when the project is nearly complete and having little time to select them).

If the equipment manufacturer decides to make the power supplies, it will start with a paper design, followed by a prototype, design review, and then a decision on whether to go ahead with production. Given the go-ahead, the purchasing department can order all the components, which usually includes qualified components from qualified vendors. As long as there are no long lead-time components, production can start. Allow sufficient time for relevant safety agency approvals.

There are alternatives to making and manufacturing the power supplies. For example, one alternative is to subcontract the design phase. In addition, the production can also be subcontracted. The cost of subcontracting should be compared with doing everything in-house.

When the first units are completed they will have to be tested for safety, EMC, and reliability over the required temperature range. This depends on the appropriate standards that must be met, which might vary for some countries. If the manufacturer doesn't have this facility in-house, the units can be sent to a testing laboratory.

The equipment manufacturer should check the supply's reliability. They can send one or two supplies to a facility that performs HALT (Highly Accelerated Life Test) or ALT (Accelerated Life Test).

- HALT is the process of determining the reliability of a product by gradually increasing stresses until the product fails. This is usually performed on entire systems, but can be performed on individual assemblies as well.
- ALT is the process of determining the reliability of a product in a short period of time by accelerating stresses (usually temperature) on the product. This is also good for finding dominant failure mechanisms. ALTs are usually performed on individual assemblies rather than full systems.
- Calculate the electrolytic capacitor life using measured temperature data

The equipment manufacturer may also want to check each power supply by "burning them in." This is usually done by powering each supply for a given period (for example, 24 hours) and then checking them to see if they are operating properly. Often, this is done by putting several supplies on a burn-in rack at the same time.

What OEM ac-dc power supplies can be purchased?

1. AC adapters.
2. Front-end power supplies for Distributed Power Architecture (DPA).
3. Centralized power supplies (single- and multiple-output voltages).
4. AC-DC brick power supplies.
5. High-voltage power supplies.

What OEM dc-dc converters can be purchased?

1. DC-DC brick dc-dc converters (single- and multiple-output voltages)
2. Non-brick dc-dc converters (single- and multiple-output voltages).
3. Encapsulated dc-dc converters (single- and multiple-output voltages).
4. Bus dc-dc converters.
5. Point-of-load (POL) converters (non-isolated).
6. Power over Ethernet power (PoE) supplies.
7. High-voltage dc-dc converters.

It is a good idea to select a power supply that provides a safety margin for the future. Too often, electronic systems expand from their initial requirements and need additional current, power, and sometimes even a new output voltage. A new output voltage requires an additional power supply or one with an adjustable output voltage, although most supplies can accommodate a 10% variation in output voltage.

The OEM power supply must provide the necessary output voltage, current, and power. With such a broad range of standard products, you should see what type of power supply can meet your requirements. One way to start is to understand the characteristics of the available power supplies. If you can't find a standard supply to meet your requirements, you will probably need to buy a custom-designed supply that is more expensive than a standard unit. An economic alternative to a custom power supply is the wide range of "modular power supplies"

Power Supply Requirements

AC Input Voltage Range ☐ Line Frequency ☐ Hz

DC Input Voltage Range ☐

Power Factor Correction? Yes ☐ No ☐ RoHS Compliant? Yes ☐ No ☐

Operating Temperature Range ☐ °C

	Volts (V)	Current (A)	Peak Current (A)	Regulation (±)
Output #1				
Output #2				
Output #3				
Output #4				
Output #5				
Output #6				

Agency Safety Approvals ☐

Package Enclosed ☐ Open Frame ☐ PCB Mount ☐ DIN Rail ☐ Surface Mount ☐ SIP ☐ DIP ☐

Cooling Integral Fan ☐ System Fan ☐ Convection-Cooled ☐

Price Target ☐ Estimated Annual Usage ☐

3-1. Power-supply requirements worksheet.

on the market today that can be tailored to your needs without the NRE and delays associated with a custom design.

One of the best ways to find the optimum power supply for your application is to fill out a form similar to that in Fig. 3-1. This allows you to list your requirements and then leave it up to the power-supply vendor to give you the answer. The completed form also allows you to use the same information if you are looking for a second source. ⏻

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CHAPTER 4:

POWER SUPPLY PACKAGES

Power-supply packages will influence the performance, cost, and size of the power supply used in the power-management subsystem. Therefore, the selection process for purchasing a power supply should take the package style into account. Package styles can range from the open-frame type without an enclosure to the completely enclosed type, like the standard brick.

The quest for multiple source dc-dc converter modules has led to a family of standard "brick" sizes. There are now "16th-brick" and "eighth-brick" sizes to go along with the full-bricks, half-bricks, and quarter-bricks. And, power densities have gone beyond 50W/in.3 Many of these modules are interchangeable with those of many manufacturers, which ensures multiple sources. In addition, pinouts of the brick converters are now a de facto standard, allowing interchangeability between different manufacturers' products. Currently, distributed power architecture (DPA) system bricks can dissipate hundreds of watts. Table 4-1 lists the size for each of the brick sizes. Generally, the larger the size, the higher the maximum power output.

Modular brick dc-dc converters supplied by the front-end supply provide electrical isolation, increased load transient performance, and a modular upgrade path (Fig. 4-1). Their lower output voltage draws a larger current (for a given power level) and has less tolerance for deviations in its voltage caused by voltage drops on the lines between the converter output and its load.

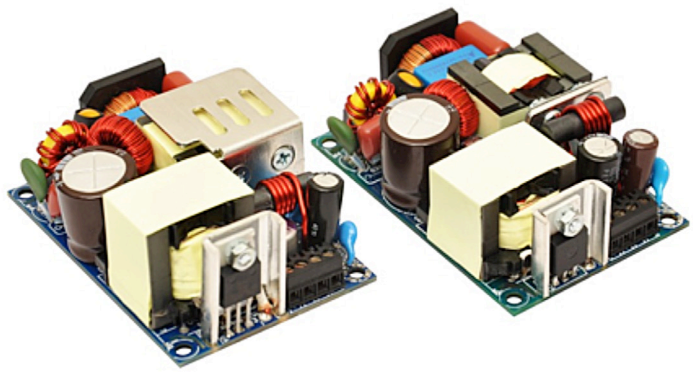
4-1. TDK-Lambda's CN-A Series of dc-dc converters have a 60V to 160VDC input range with output voltages from 5V to 24VDC (adjustable ±10%). Output power ratings are 30W, 50W, and 100W. These isolated power modules are in the industry-standard quarter-brick footprint.

TABLE 4-1. SIZE OF BRICK DC-DC CONVERTERS

Type	Length	Width	Height
1/16 brick	1.65	0.8	0.5
1/8 brick	2.28	0.9	0.5
1/4 brick	2.28	1.45	0.5
1/2 brick	2.40	2.28	0.5
3/4 brick	3.45	2.40	0.5
Full brick	4.60	2.40	0.5

There are also ac-dc bricks. Initially, these bricks required two modules. One module for the ac input rectification and power factor correction (PFC), and another for the dc-dc isolation and low voltage conversion. Now, these two functions are available in a single brick, thus eliminating module interconnects and saving 25% or more printed circuit board space.

An example of a single module ac-dc brick with PFC is TDK-Lambda's 1000W PFE1000F series that is available with 12V, 28V, and 48V nominal outputs that are adjustable to ±20%. The series can operate with a baseplate temperature range from -40°C up to +100°C. Line and load regulation is 0.4% max and efficiency is in the range of 82% to 86% depending on output voltage.



4-2. Gresham Power Electronics' (M)WLP75 AC/DC converter. This open-frame series is the fourth addition to the EOS low-profile, high-efficiency (M)WLP series. Available in medical and industrial versions, (M)WLP75 features include: 75W convection rating; efficiencies up to 93%; -40 to 70°C operation; standby power < 0.3 Watt; weight 150g; dual fusing; and Class II Option available for medical applications and RoHS compliance.

These models accept an 85Vac to 265Vac input at 47-63Hz and have active power-factor correction (PFC), an input-to-output isolation of 3kVAC, and an input-to-baseplate rating of 2.5kVAC with application circuitry. In addition, overvoltage, overcurrent, and over-temperature protections are included.

The PFE1000F comes in a 6.3 × 3.94 × 0.53-in. package that is larger than a dc-dc full-brick, but its construction resembles its dc-dc cousins. Other members of the PFE series are rated at 300W, 500W, and 700W and are housed in a full-brick package the same size as the dc-dc full-brick. These full-brick ac-dc supplies also have PFC.

An advantage of the DPA approach with multiple dc-dc converter brick modules is that the heat produced by each of the modules is spread throughout a system. In contrast, most of the heat associated with a centralized power system is in the single power supply.

Use of a dc bus voltage, typically 48V, also means cables with lower current are bused throughout the system. Higher current requirements are handled by the dc-dc converter modules that are located close to their loads, which minimizes distribution losses and enables smaller, less expensive conductors to be used for the cables that bus the secondary voltage.

From a reliability standpoint, each element in a DPA has its own power supply, so failure of a single dc-dc converter module will only affect a single function or printed circuit board, which aids the design of fault-tolerant systems.

DC-DC converter brick modules are a key ingredient in DPA systems. The performance of these converters is directly related to the IC operating voltage requirements that are dropping from the historic standard of 5V to 1.5V, with projections of less than 1.0V over the next decade. Besides the 5V and 3.3V outputs, some converters now provide 2.5V, 1.8V, and 1.2V, and some can supply 0.8V.

"Off-the-shelf" standard brick converters can lower system development costs and also shorten design cycles because if they have already been tested and are available from multiple sources. If the system's powering requirements change, it is relatively simple to replace one converter module with another, that is, no major redesign is usually required.

The majority of packaged dc-dc converter brick modules are mounted on p.c. boards holding associated digital circuits. Therefore, the converter module's size impacts a board's circuit density. This includes the converter's footprint area that determines how much circuitry can be placed on the board. Converter module height is also important because it affects spacing between boards within the system. Eliminating the need for a heat sink also allows tighter board-to-board spacing.

To operate without a heat sink and provide more power output, the brick dc-dc converter must be efficient, particularly at the new lower semiconductor operating voltages. Therefore, the converter must minimize its internal power loss and the operating temperature of its components. Achieving higher efficiency also reduces the system's input power and cooling requirements. Plus, it influences system manufacturing and operating costs.

Minimizing internal power loss lowers the converter's case temperature, which may eliminate the need to employ forced-air cooling. Most converters have maximum case temperature ratings less than 100°C.

One approach to reducing internal power loss and improving converter efficiency is to employ synchronous rectifiers consisting of power MOSFETs. This higher efficiency obtained by synchronous rectifiers means the converter dissipates less heat and may no longer require a heat sink.

Non-Brick Power Supplies

Non-brick dc-dc power supplies are available in both single- and multiple-output versions. They come in open-frame, such as these from Gresham Power Electronics

4-3. Astrodyne's modular 3.8 kW Mercury-Flex is hot-swappable, enabling maximum uptime. For applications that require higher power, you can connect the modules in parallel current sharing groups through a four-module shelf assembly. This enables designs of upwards to 228 kW in a single universal 19-in. rack (30U).

(Fig. 4-2). Most of these modules deliver from 20W to 500W, which is somewhat less than their larger brick cousins. They may be rack-mounted, DIN-Rail mounted, or packaged within an electronic system. Some of these power supplies have a high enough isolation voltage to allow them to be certified for use in medical systems.

The physical size of these power supplies varies over a wide range, from a length of 0.65 in. to 21.2 in. Some packages employ SMT, DIP, or SIP connections, whereas some use through-hole pins and others use screw terminals.

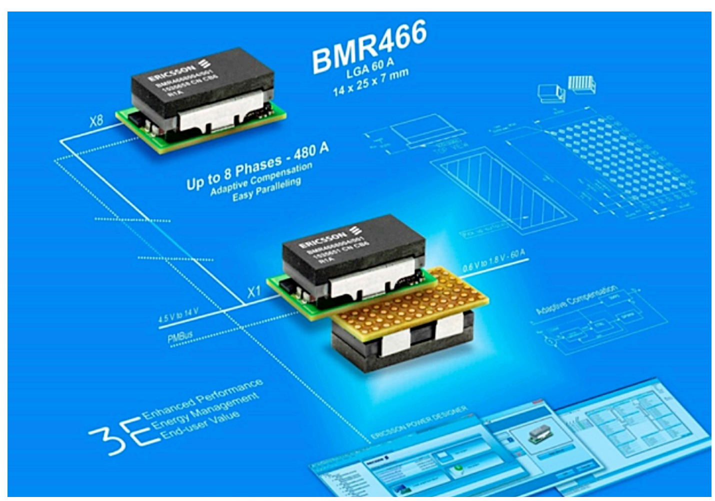
Non-brick supplies with multiple outputs include those employed with Compact PCI systems that employ 5V, 3.3V, and ±12V.

Astrodyne TDI digitally programmable ac/dc power supply provides 3,800 W of regulated power and can operate as either a current or voltage source up to 400 V or 170 A (Fig. 4-3). Intended for industrial applications that require a flexible, digitally controlled industrial power supply with a universal voltage range of 90 VAC to 264 VAC and a 50/60 Hz single-phase input, the Astrodyne TDI Mercury-Flex is offered in a variety of adjustable dc output voltage range models including 0-28V, 0-56V, 0-85V, 0-125V, and 0-400V. This reliable unit delivers efficiency up to 93%, with a power factor of 0.97 or better, helping to lower energy requirements and heat dissipation. Its 14 VDC auxiliary output is useful for powering miscellaneous user circuits.

CUI Inc.'s PFR-2100 is a 2000 W front-end ac-dc power supply in an enclosed package (Fig. 4-4). The PFR-2100 series is a blind-mate rectifier with a programmable output voltage range of 100~410 Vdc. Key features include a hot-swap blind-docking capability implemented through the use of a single connector that integrates ac, dc, and I/O signals. The PFR-2100 delivers high efficiency up to 93% in a package measuring 11.5 × 5.2 × 2.5 in. (292.1 × 132.08 × 63.5 mm). The series is ideally suited for use in data-center high-voltage dc bus power systems, broadcast amplifiers, and EV battery-charging systems.

The programmable dc output voltage delivers a constant current up to 5.125 A with droop current sharing for paralleling up to 12 units. Additional features include power-factor correction, remote on/off control, power good signal, and front-panel LED indicators. The PFR 2100 series complies with all applicable EMC require-

4-4. CUI's PFR-2100 is a 2,000 W front-end supply in an enclosed package.



4-5. The BMR466's unique LGA (Line Grid Array) footprint is 0.98 × 0.55 in. and has an exceptionally low profile of 0.276 in., which facilitates compact system design.

4-6. MinMax AAF-05 Series features: ultra compact size (1.0 × 1.0 × 0.64 in.); fully encapsulated plastic case for PCB and chassis mounting version; Universal Input 85—264VAC, 47~440Hz; Protection Class II as per IEC/EN 60536; and I/O Isolation 3000VAC with reinforced insulation.

ments to accommodate worldwide applications and offers 60950-1 safety approvals. Protections for overvoltage, overcurrent, and overtemperature are also provided.

BMR466

Ericsson's BMR466 is a 60A digital point-of-load (POL) dc/dc power module for powering microprocessors, FPGAs, ASICs, and other digital ICs on complex boards. The BMR466's unique LGA footprint is 0.98 × 0.55 in. and has an exceptionally low profile of 0.276 in., which facilitates compact system design (Fig. 4-5). Spreading the placement of the 60A units across printed circuit boards means that heat dissipation can be distributed, optimizing the use of multi-layer board technology and simplifying cooling arrangements. In addition, the use of a surface-mount LGA package with symmetric contact layout offers superior mechanical contact and high reliability after soldering. The elimination of connecting leads results in lower inductance, enabling excellent noise, and EMI characteristics. This is further enhanced because a high number of the LGA contacts are ground pins.

Up to eight of the fully regulated 60A (maximum) POL converters can be connected in parallel to deliver up to 480A in multi-module and multi-phase systems. This produces an economical, efficient, and scalable power solution with a small footprint, high stability, advanced-loop compensation, and class-leading thermal characteristics.

Operating from a 4.5V to 14V input, the BMR466 is ideally suited to operation across a range of intermediate bus voltages and complies with the Dynamic Bus Voltage scheme to reduce power dissipation and save energy. The factory default output voltage is set to 1.2V, but can be adjusted from 0.6V to 1.8V either via a pin-strap resistor or PMBus commands. The BMR466 powertrain guarantees high efficiency and reliability and is built from the latest generation of power-transistor semiconductors, enabling the module to deliver up to 94.9% with a 5V input and a 1.8V output, at half load.

Through software control, the BMR466 uses class-leading adaptive compensation of the PWM control loop and advanced energy-optimization algorithms to reduce energy consumption and deliver a stable and secure power supply with fast transient performance over a wide range of operating conditions. In multi-module systems, two or more of the single-phase BMR466 POL converters can be synchronized with an external clock to enable phase spreading, which means the reduction of input ripple current and corresponding capacitance requirements and efficiency losses. The ripple current can be estimated using the Ericsson Power Designer (EPD) software tool, which enables easy capacitor selection. The BMR466 is also fully compliant with PMBus commands and has been integrated into the EPD software, which makes it easy for power system architects to simulate and configure complete multi-module and multi-phase systems prior to implementation. This cuts time-to-market.

4-7. Aimtec's 1 watt dc-dc converter series is available in a compact single-inline SIP4.

Suited for deployment in distributed power and intermediate bus voltage architectures within the ICT (Information and Communication Technology), telecom, and industrial sectors, the module targets high-power and high-performance use in products such as networking and telecommunications equipment, servers, and data-storage applications, as well as industrial equipment.

Encapsulated Power Supplies

Encapsulated/sealed dc-dc power supplies are available in both single- and multiple-output versions,

4-8. The LTM4650 µModule is housed in a conventional ball-grid array (BGA) package.

like these from MinMax (Fig. 4-6). They come in SIP, DIP, SMT, and through-hole pin packages. Most of these modules deliver from less than 1W to over 300W, which is somewhat less than other non-brick packages. They are usually mounted directly on a printed circuit board.

A typical single-output plastic-encapsulated supply of this type rated at 1W. The Series accepts nominal input of either 3.3V, 5V, 12V, 15V, or 24V and produces outputs of 3.3V, 5V, 9V, 12V, 15V, or 24V. Isolation options are 1,000V or 3,000V. A five-pin SMD package measures 0.5 × 0.32 × 0.29 in.

Another plastic-encapsulated type is housed in a SIP package rated at 3W. Its nominal input voltages are either 5V, 12V, 24V, or 48V. Output voltages are either 3.3V, 5V, 9V, 12V, or 15V. The SIP package measures 0.86 × 0.36 × 0.44 in.

A sealed dc-dc power supply for COTS (commercial off-the-shelf for military applications) measures 2.4 × 2.3 × 0.5 in. It accepts a nominal 270V dc input and delivers either 3.3V, 5V, 12V, 15V, or 28V, with up to a 200W output rating. It has a mu-metal shield for low radiated emissions.

Aimtec's AM1SS-NZ series of unregulated 1 Watt DC-DC converters provides continuous short-circuit protection with auto recovery restart (Fig. 4-7). The restart feature will work continuously until the short-circuit condition is cleared, protecting the converter, the load, and the converter's input circuit from extremely high currents a short circuit can cause.

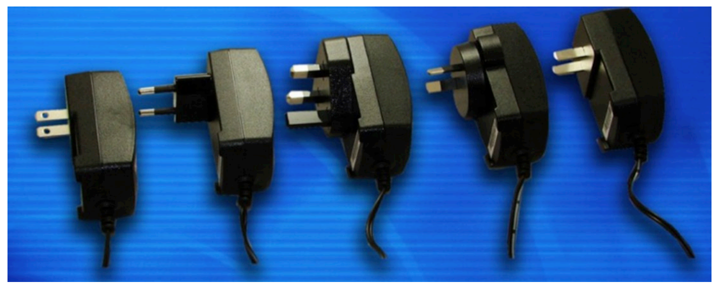
Supported input voltages of 3.3, 5, 12, 15, and 24VDC convert to single output voltages of 3.3, 5, 9, 12, 15, and 24VDC. Operating within an ambient temperature range of -40°C to +105°C (derating at 85°C), the AM1SS-NZ series is designed for versatility and can be integrated into a multitude of applications, such as digital circuits, low-frequency analog, or relay-drive circuits.

Available in a compact, single-inline SIP4 package (11.60 × 10.10 × 6.00 mm), the AM1SS-NZ is offered with an input-output isolation upgraded to 1500VDC for easy integration in industrial, telecommunication, and computer applications.

µModule

Power-supply packages continue to shrink by using semiconductor industry manufacturing techniques. The result is the µModule (power module) regulator that integrates switching controllers, power FETs, inductors, and all supporting components in a conventional ball-grid array (BGA) package (Fig. 4-8). The circuit requires only a few input and output capacitors.

The LTM4650 is a dual 25A or single 50A output switching mode step-down dc/dc converter. Operating from a 4.5V to 15V input, the LTM4650 supports two outputs each with an output voltage range of 0.6V



4-9. Phihong's energy-efficient 10W wall-mount adapter series is available in 5- and 9VDC outputs. The PSC12x Series consists of five versions: A, E, K, S, and C, each of which features a country-specific fixed-outlet plug. PSC12A adapters are equipped for use in the United States, Europe, United Kingdom, Australia, New Zealand, and China. PSC12x Series adapters are rated for operation from 0ºC to +40ºC.

4-10. Spellman Bertan High-Voltage Power Supply PMT30CN-1features: 500V to 7.5kV @ 1.9 to 4 Watts; modular design; stability and regulation; low noise and ripple; arc and short-circuit protected; and CE listed, UL recognized and RoHS compliant.

to 1.8V, each set by a single external resistor. Its high efficiency design delivers up to 25A continuous current for each output. The LTM4650 is pin-compatible with the LTM4620 (dual 13A, single 26A) and the LTM4630 (dual 18A, single 36A).

This µModule supports frequency synchronization, multiphase operation, burst-mode operation and output voltage tracking for supply-rail sequencing and has an onboard temperature diode for device-temperature monitoring. High switching frequency and a current-mode architecture enable a very fast transient response to line and load changes without sacrificing stability. Fault protection features include overvoltage and overcurrent protection.

The LTM4650 is housed in a 16mm × 16mm × 5.01mm BGA package.

AC Adapters

AC adapters are a cost-effective and relatively fast way to provide a power source for computer peripherals such as these from Phihong (Fig. 4-10). There are two types of dc output adapters: linear and switch-mode. The switch-mode adapter provides greater efficiency and smaller size, whereas the linear power supply adapter is less efficient and larger, but could be "quieter," that is, less radiated or conducted EMI. However, there are several adapters using the switch-mode topology that meet the FCC's EMI requirements

It is important to obtain an adapter that has high efficiency, which minimizes heat dissipation, resulting in an adapter that is small and reliable. Without this high efficiency, the resulting internal temperature rise would be potentially hazardous and a major reliability limiter. In many applications, the adapter may be placed in a confined space, or it may be buried under a pile of cable, so minimizing heat is essential.

AC adapters are a cost-effective power source to charge portable system batteries because the OEM does not have to design and qualify the supply. Typically, these adapters can power the unit as well as charge the associated battery.

The switch-mode adapter provides greater efficiency and smaller size, whereas the linear power supply adapter is less efficient and larger, but produces less radiated or conducted EMI. A high efficiency adapter minimizes heat dissipation, resulting in a smaller and reliable unit.

The California Energy Commission approved new energy saving standards in order to slow down the demand for electricity throughout the state. According to the CEC, the energy savings from the new standards over the next 10 years will enable the state to avoid building three large power plants.

On average, ENERGY STAR-approved models are 35% more efficient than conventional designs, and often are lighter and smaller in size. Many adapters have safety approvals from cUL/UL, TUV, SAA, CE, C-Tick, and CCC (except for 48V). Some provide no-load power consumption of less than 0.5W, as well as low leakage current with a maximum of 0.25mA.

High-Voltage Power Supplies

High voltage ac-dc power supplies offer regulated outputs for bench top or OEM use (Fig. 4-11). Typical applications include: spectrometers, detectors, imaging, electron beam systems, projection television, X-ray systems, capacitor charging, laser systems, and cathode-ray tubes.

Available high-voltage ac-dc power supplies have many circuit and system variations. There are single-phase supplies with switch-selectable 115/230Vac, three-phase 208V inputs, and most include power-factor correction (PFC).

The method for generating the high voltage is either with a conventional switch-mode power converter, or a resonant high-frequency inverter.

Power-supply enclosures are usually fully metal-enclosed units, 19-in. enclosed metal rack panels, or smaller modules intended for embedded applications.

High-voltage power-supply outputs can range from 1kV to over 100kV, from fractions of a milliamp to amperes, and output power from watts to kilowatts. Output polarity may be a fixed positive voltage, fixed negative voltage, or a reversible positive or negative voltage output. The output interface may be a high-voltage connector, or a captive high-voltage cable. The output voltage adjustment may be provided by a local internal potentiometer, or a ground-referenced signal for remote operation. Output monitors on some units monitor voltage or current, or both. Output ripple is usually rated in peak-to-peak in mV or peak-to-peak as a percent of output voltage.

Most supplies offer protection against arcs or output short circuits. Among the miscellaneous features found in these supplies are local and remote programming, fault indicators with safety interlock, overload protection, and an enable voltage signal input for remote control.

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CHAPTER 5:

POWER-MANAGEMENT REGULATORY STANDARDS

Regulatory standards must be met because international and domestic standards are required for the power-management section of the end-item equipment. These standards vary from one country to another, so the power subsystem manufacturer and the end-item system manufacturer must adhere to these standards where the system will be sold. Design engineers must understand these standards even though they may not perform standards certification. Understanding these regulatory standards usually poses problems for power-management subsystem designers.

- Many standards are technically complex, requiring an expert to be able to decipher them.
- Often, standards are written in a form that is difficult for the uninitiated to interpret because there are usually exemptions and exclusions that are not clear.
- Several different agencies may be involved, so some may be specific to one country or group of countries and not others.
- Standard requirements vary and sometimes conflict from one jurisdiction to another.
- Standards are continually evolving, with new ones introduced periodically, so it is difficult to keep pace with them.

What standards agencies are encountered at the product and system level?

ANSI: The American National Standards Institute oversees the creation, promulgation, and use of norms and guidelines that directly impact businesses, including energy distribution.

EC (European Community) Directives: Companies responsible for the product intended for use in the European Community must design and manufacture it in accordance with the requirements in the relevant directives.

EN (European Norm): Standard directives for the European community.

IEC (International Electrotechnical Commission): Generates standards for electrical and electronic systems.

UL (Underwriter's Laboratory): Safety approvals for electrical and electronics products within the United States. A UL approval can also be obtained through the CSA.

CSA (Canadian Standards Association): Safety approval required to use an electrical or electronic product within Canada. A CSA approval can also be obtained through the UL.

Telcordia: Standards for telecom equipment in the United States.

ETSI (European Telecommunications Standards Institute): Standards for telecom equipment.

Required safety standards for power supplies include EN60950 and UL60950 "Safety of Information Technology Equipment" based on IEC60950, containing requirements to prevent injury or damage due to hazards such as: electric shock, energy, fire, mechanical, heat, radiation, and chemicals. As of January 1997, the EC Low Voltage Directive (LVD) 73/23/EEC and the amending directive 93/68/EEC requires the manufacturer to make a declaration of conformity if the product is intended to be sold in the European Community.

Specific standards power-supply acoustics define maximum audible noise levels that may be produced by the product. The main contributor to the acoustic noise is usually the fan in a power supply with an internal fan.

ESD (Electrostatic Discharge) standards include EN61000-4-2 that tests immunity to the effects of high-voltage low-energy discharges, such as the static charge built up on operating personnel.

Power-Line Standards for Power Supplies

EN61000-3: Limits voltage changes the power supply under test can impose on the input power source (flicker test).

EN61000-4: Tests the effects of transients and determines the ability of the power supply to survive without damage or operate through temporary variations in main voltage. These transients can be in either direction (undervoltage or overvoltage).

EN61000-3-2: Limits the harmonic currents that the power supply generates onto the power line. The standard applies to power supplies rated at 75 W with an input line current up to 16A/phase.

EN61000-4-11: Checks the effect of input voltage dips on the ac input power supplies.

EMC Standards for Power Supplies

The most commonly used international standard for emissions is C.I.S.P.R. 22 "Limits and Methods for Measurement of Emissions from ITE." Most of the immunity standards are contained in various sections of EN61000. As of January1996, EC Directive 89/336/ EEC on EMC requires the manufacturer to make a declaration of conformity if the product is sold in the European Community.

Sections of EN61000 for EMC include:

EN61204-3: This covers the EMC requirements for power supplies with a dc output up to 200V at power levels up to 30kW, and operating from ac or dc sources up to 600 V.

EN61000-2-12: Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems

EN61000-3-12: Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16A and < 75A per phase

EN61000-3-2: Limits harmonic currents injected into the public supply system. It specifies limits of harmonic components of the input current, which may be produced by equipment tested under specified conditions

EN61000-4-1: Test and measurement techniques for electric and electronic equipment (apparatus and systems) in its electromagnetic environment.

EN61000-4-11: Measurement techniques for voltage dips, short interruptions, and voltage variations immunity tests.

EN61000-4-12: Testing for non-repetitive damped oscillatory transients (ring waves) occurring in low-voltage power, control, and signal lines supplied by public and non-public networks.

EN61000-4-3: Testing and measurement techniques for immunity requirements of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures.

EN61000-4-4: Testing and measurement techniques for electrical fast transient/burst immunity test.

EN61000-4-5: Recommended test levels for equipment to unidirectional surges caused by overvoltage from switching and lightning transients. Several test levels are defined that relate to different environment and installation conditions.

EN61000-6-1: Electromagnetic compatibility (EMC) immunity for residential, commercial, and light-industrial environments

EN61000-6-2: Generic standards for EMC immunity in industrial environments

EN61000-6-3: Electromagnetic compatibility (EMC) emission requirements for electrical and electronic apparatus intended for use in residential, commercial, and light-industrial environments.

EN61000-6-4: Generic EMC standards for industrial environments intended for use by test laboratories, industrial/medical product designers, system designers, and system installers.

Restriction of Hazardous Substances (RoHS) Affects Power Supplies

RoHS is a directive that restricts use of hazardous substances in electrical and electronic equipment. Designated 2002/95/EC, it is commonly referred to as the Restriction of Hazardous Substances Directive. This RoHS directive took effect in July 2006, and includes power supplies. Often referred to as the lead-free directive, RoHS restricts the use of: lead; mercury; cadmium; hexavalent chromium (Cr6+); polybrominated biphenyls (PBB) (flame retardant); and polybrominated diphenyl ether (PBDE) (flame retardant).

Electronic Waste Directives

RoHS is closely linked to the Waste and Electronic Equipment Directive (WEEE). Designated 2002/96/EC, it makes power-supply manufacturers responsible for the disposal of their waste electrical and electronic equipment. Companies are compelled to use the collected waste in an ecologically friendly manner, either by ecological disposal or by reuse/refurbishment of the collected WEEE.

Directives for Disposal of Batteries

Batteries are not included within the scope of RoHS. However, in Europe, batteries are under the European Commission's 1991 Battery Directive (91/157/EEC), which was recently increased in scope and approved in the form of the new battery directive, version 2003/0282 COD, which will be official when submitted to and published in the EU's Official Journal. This new directive explicitly highlights improving and protecting the environment from the negative effects of the waste contained in batteries.

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CHAPTER 6:

POWER SUPPLY SYSTEM CONSIDERATIONS

Overall design of the power-management subsystem involves several system-oriented issues. Adequate space must be available for the selected power supply. Make sure the power supply will fit in the space provided for it. Therefore, make sure the package type you want, such as open-frame, enclosed, brick, encapsulated, etc., will fit in the allocated space. In addition, make sure there is enough room adjacent to the power supply to allow it to cool if you are using natural convection cooling. If you are using forced air cooling, make sure that you have sufficient air movement around the supply.

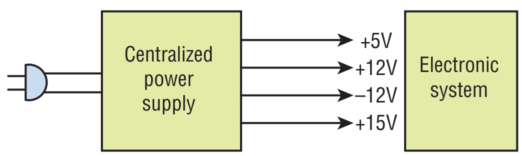
One aspect of space availability is the standards for size of rack-mounted power systems, such as 1U, 2U, 3U, etc. The term 1U defines one rack unit of height that equals 1.75 in. of rack height. A 2U rack mount height would be 2 x 1.75 in., or 3.5 in. high, and so on. The 1U, 2U, and 3U heights are maximum dimensions. Individual rack-mounted power supplies must be a bit shorter than the equipment's overall height to allow for the top and bottom covers. So a 1U-high enclosure-mountable power supply needs to be shorter than 1.75 in.; a 2U enclosure-mountable supply needs to be shorter than 3.5 in., and so forth.

Power Distribution

Distributing power in the end-item system depends on the type of power supply used. Five different distribution methods are possible:

Centralized Power Architecture (Fig. 6-1) accepts an ac power line input and produces one or up to five output voltages. As implied, centralized supplies operate from a central location and supply all the power for an electronic system. They are powered from the ac power line and produce a dc voltage output. They may provide one or multiple output voltages. These outputs then provide power to the specific circuits that require the various voltages. For most small, relatively low-power systems, centralized power distribution is usually the most cost- and performance-effective.

A typical centralized system is the type employed in desktop computers; that is, a single supply provides all the required voltages: +5V, ±12V. (Note: 3V is replacing 5V on many computers as the main logic voltage.) However, the centralized approach can suffer from lack of flexibility.



6-1. Centralized Power Supply Can Produce Multiple Voltage Outputs

If the system requires an additional low voltage, the power management subsystem must be redesigned by replacing the entire centralized supply or adding a voltage regulator derived from an existing output. If any existing supply voltage requires a higher current capability, the centralized supply must be replaced.

An advantage for the centralized power supply is the cost associated with powering a small to moderate size system. A single supply with multiple outputs can be more cost-effective than a distributed supply with multiple dc-dc converters.

To minimize power distribution losses, the centralized supplies should be located near the load. For safety and EMI reasons, it should be located as close as possible to the ac entry point, which is often a problematic tradeoff. Although centralized power works well for many applications, it is usually unsuitable for distributing high power at low voltages.

A drawback of the centralized supply is its transient response, which is the ability to react quickly to rapidly changing loads. Centralized power systems may have difficulty responding to transient loads and handling resistive voltage drops. Another potential problem is its characteristic of concentrating heat in one specific area.

Distributed Power Architecture (DPA) (Fig. 6-2) converts the incoming ac power to a secondary dc bus voltage, using a front-end supply. This dc bus voltage can be 12V, 24V, or 48V and is usually less than 60V. This bus voltage is distributed throughout the system, connecting to dc-dc converter modules associated with specific subsystems or circuit cards

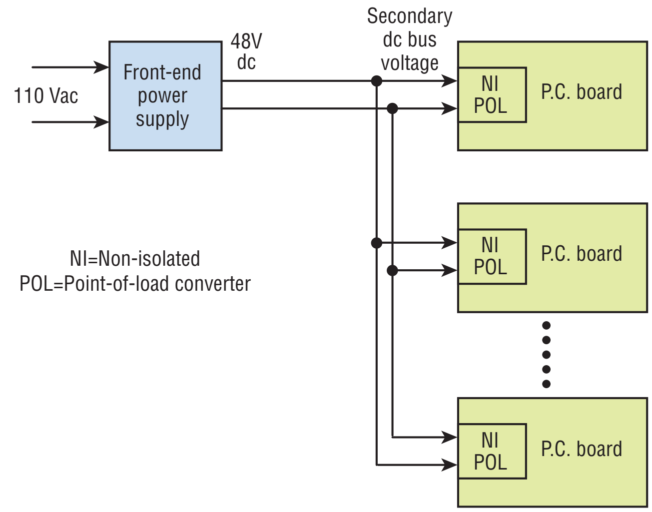
The most popular DPA voltage is 48V used by telecommunication systems. The secondary voltage is bused throughout the system, connecting to dc-dc converter modules associated with specific subsystems or circuit cards. You can locate the front-end supply either in a card cage or in a convenient place within the system. For non-telephone applications, the trend is to use lower intermediate bus voltages, ranging from 7V to 12V. This is because as the speed and complexity of the digital circuits and microprocessors increase, their internal spacings decrease, resulting in reduced input voltages for these devices. Therefore, the secondary buses power local dc-dc converters that output lower voltages. Higher-speed devices use lower voltages.

One common characteristic for front-end supplies is power-factor correction (PFC) that lowers the peak currents drawn from the ac line. This reduces the harmonic content fed back into the power line, which might otherwise interfere with other equipment connected to the same power line.

Among the features of most front-end supplies is the ability to work over a broad ac input voltage range, for example, 85 to 265Vac. Some front-end supplies may be paralleled to increase the available power. Some paralleled supplies may be combined in a 19-in. rack. Models usually include protection features for overvoltage, overcurrent, short-circuit, and overtemperature.

Optional on-board intelligence on some front-end supplies is the ability to communicate with the host computer. Transmitted data can include operational status, such as temperature, current limit, and installation location identification.

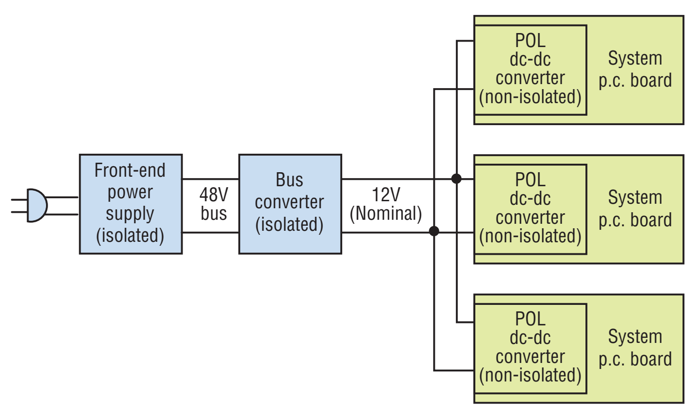
Intermediate Bus Architecture (IBA) inserts another level of power distribution between a front-end power supply and POL. An IBA (Fig. 6-3) employs an isolated bus converter that delivers an unregulated 9.6V to 14V to power to the non-isolated POL converters. As shown in Fig. 6-3, a typical bus converter delivers an unregulated, stepped-down voltage of 9.6 to 14V with a nominal 2000Vdc input output isolation. This converter is ideal for a loosely regulated 12Vdc Intermediate Bus Architecture to power a variety of downstream non isolated, point of load regulators. These modules are suited for computer servers, enterprise networking equipment, and other applications that use a 48V (+10%) input bus.



6-2. Distributed Power Architecture Employs Front-End Power Supply for Multiple POL Mounted on System P.C. Boards

Cost savings can be achieved in many applications by replacing multiple 48V in isolated dc-dc converters with low-cost, non isolated POL modules or embedded converters that are fed from the 12V bus converter rail. Implementing one central point of isolation eliminates the need for individual isolation at each point of load, allowing reduced costs, greater flexibility, and savings on board space.

Bus converters achieve high efficiency by limiting the input range and essentially optimizing for a single input voltage. Bus converters are designed for efficien-



6-3. Intermediate Bus Architecture Adds an Isolated Bus Converter

6-4. TDK-Lambda's medically certified DTM65-C8 external power supplies offer a class II input and do not require an earth ground connection and meets the stringent Level VI DoE standards for efficiency. It is housed in a rugged, vent-free IP21 rated enclosure, measuring 106 x 60 x 31mm. AC is applied using a standard IEC60320-C8 cable and DC provided through a four pin Power-DIN connector.

cy. Removing the entire feedback path (reference, error amp, optocoupler, etc.) liberates board area and power. Additional parallel MOSFETs may be added to lower on resistances. MOSFET duty cycles in the power train are set and maintained at 50%, and all components are optimized for the voltages they will actually experience and not the voltages they may experience. Also, for high efficiency most bus converters employ synchronous rectifier outputs.

Bus converter packages come in many sizes, from SIPs and SMTs to quarter-brick, eigth-brick and sixteenth brick modules.

AC Adapter's distribute power external to the end-item system. They plug into an ac power outlet to provide dc power via a cable and connector that plugs into the end item system. One of the widely used ac input power supplies (Fig. 6-4). They are a cost effective and relatively fast way to obtain a power source for computer peripherals and other electronic devices without going through power supply safety and EMI qualification tests.

All the OEM has to do is provide the appropriate connector within the associated equipment. Typically, many printers and scanners operate from these adapters that supply a regulated dc voltage. Laptop computers and other portable equipment use these adapters to power the unit as well as charge their battery.

It is important to obtain an adapter that has high efficiency, which minimizes heat dissipation, resulting in an adapter that is small and reliable. Without this high efficiency, the resulting internal temperature rise would be potentially hazardous and a major reliability limiter. In many applications, the adapter may be placed in a confined space, or it may be buried under a pile of cable, so minimizing heat is essential.

Battery-Based Power Distribution requires virtually all circuits designed "from the ground up." The power management subsystem design involves voltage regulation circuits operating from a battery whose output voltage naturally decreases with use.

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TABLE 6-1. COMPARISON OF POWER DISTRIBUTION APPROACHES FOR ELECTRONIC SYSTEMS

Power Distribution	Remarks
Centralized Power Architecture	•Usually most cost- and performance-effective for small, low-power systems. • Most of the heat is centralized in a single power supply. • Lacks design flexibility for adding voltages or current requirements.
Distributed Power Architecture (DPA)	• Changing load current or voltage usually requires only a POL change. • Failure of a single POL usually only affects a single function or p. c. board. • Heat is spread throughout the system.
Intermediate Bus Architecture (IBA)	• Achieves high efficiency by limiting input voltage range and usually operating open-loop, • Power train duty cycles usually maintained at 50% • All components are optimized for load voltage/current.
AC Adapter Power Distribution	• Does not require power supply safety and EMI qualification tests, which have been certified by its manufacturer. • Two types: linear and switch-mode. The switch-mode adapter provides greater efficiency and smaller size, whereas the linear power supply adapter is less efficient and larger, but could be "quieter," that is, less radiated or conducted EMI. • Usually limited 100 W, or less.
Battery-based Power Distribution	• Operates from Li-ion, NiCd or NiMH battery packs. • Provides high efficiency for maximum battery run time • Must have light weight, small physical size power supplies • Must be thermally efficient to prevent overheating.

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