SAFETY REGULATIONS FOR MEDICAL DEVICES MANDATE ISOLATED POWER SUPPLIES AND I/O LINES. THE GOAL OF THESE REGULATIONS IS SIMPLE: DON'T ELECTROCUTE THE PATIENT. YOU CAN USE A VARIETY OF TECHNIQUES, INCLUDING TRANSFORMERS, OPTOISOLATORS, AND ADVANCED ISOLATION ICs.

Medical devices demand stringent isolation techniques

BY CHARLES H SMALL • CONTRIBUTING TECHNICAL EDITOR

According to DataBeans (www.databeans.net), medical electronics constitute a small but profitable part of the industrial-semiconductor market. In 2005, medical electronics represented 8% of the $25.9 billion industrial-semiconductor market, or about $2.1 billion. The medical-electronics industry is growing at a yearly rate of 11%, making it the fastest growing segment in the industrial-semiconductor market. The market segment is expected to exceed $4 billion in revenue by 2011.

DataBeans divides medical electronics into three major categories: diagnostics and therapy, home, and imaging. The diagnostics-and-therapy segment contributes roughly 48% of revenue, with the home segment contributing 37% and imaging contributing 15%. As a result of medical care and treatments increasingly moving away from clinical settings and into homes, the home market is growing the fastest at 12% average annual growth, followed by imaging at 11%, and diagnostics and therapy combined at 10%.

The insurance industry is instigating major changes in how patients receive medical care. To reduce costs, hospitals and clinics treat patients for a much shorter time than in the past. Insurance companies can save billions by moving treatment and monitoring to the home, and the increasing use of medical electronics in the home has created multiple opportunities for semiconductor suppliers.

COMMERCIAL SUPPLIES

One way to get an isolated power supply is to simply specify a commercially available medical supply. For example, GlobTek's 350W, 4×8-in. power supplies suit medical applications. The GT(M) 200P350 series delivers as much as 350W of continuous output power, and devices

AT A GLANCE

- Safety regulations mandate isolated power supplies and I/O lines. The goal is simple: Don't electrocute the patient.
- You can use transformers, optoisolators, and advanced isolation ICs to achieve your goals.
- Commercial isolated power supplies for medical applications are widely available.
- You can design your own power supply and submit it for certification yourself.

have regulated output voltages of 3.3 to 48V in 0.1V increments with remote sense available. Efficiency specifications are typically 85%. The supplies feature an aluminum U-channel chassis with optional top cover and are rated for 200W convection cooled or as much as 350W with forced air. The supplies have a dc power-good signal and current-share capability. A feature that is important for European markets is active PFC (power-factor correction) to IEC (International Electrotechnical Commission) 3000-3 2 Class A. The supplies accept 90 to 264V ac and have a Class B EMI filter as well as built-in protection for overcurrent, short circuit, overvoltage, and overtemperature. Footprint sizes start at 196× 107×46 mm, and devices meet UL (Underwriters Laboratories and TUV (Technischer Uberwachungs-Verein, or Technical Surveillance Association) 60950/ 60601.1 standards. They comply with EMC (electromagnetic-compatibility) directives for consumer electronics and FCC (Federal Communications Commission) Class B applications. All models carry UL, DEMKO (Danmarks Elektriske Materielkontrol), PSE (Product Safety Engineering), and CE (Consumer Electronics) logos with reports that an independent certified laboratory generates.

Another supplier of medical-grade power supplies is Condor, which offers the GSM25 series of 25W medical switchers. The company claims that the devices are the industry's smallest 25W switchers, measuring 2.5×4×0.86 in. Conducted EMI exceeds FCC Class B and CISPR (The IEC's International Special Committee on Radio Interference) 11 Class B. Overvoltage protection is standard, and the supplies meet medical standards UL2601-1, IEC60601-1, and CSA (Canadian Standards Association)-C22.2 No. 601-1. Output voltages are 5V main with ±12, ±15, or 12V, and −24V secondary voltages. Input voltage is 90 to 264V ac and 47 to 63 Hz single phase.

Leakage current in the ground-wire connection is 50 µA (nominal)/78 µA (fault condition) measured per UL2601-1 at 132V ac/60 Hz and 94 µA (nominal)/156 µA (fault condition) measured per IEC-60601-1 at 264V ac/50 Hz. All models include built-in EMI filtering to meet the following emissions requirements: conducted emissions EN55011 Class B, FCC Class B; static discharge EN61000-4-2, 6-kV contact, 8-kV air; RF field susceptibility EN61000-4-3, 3V/m; and fast transients/bursts EN61000-4-4, 2 kV, 5 kHz.

Power-One offers the ESM ac/dc modular power-supply series. The devices' input-voltage range is 88 to 264V ac at 47 to 63 Hz. Earth leakage current per EN60601-1 at 250V ac, 60 Hz specifies 300 µA for the ESM4B, ESM4C, ESM-6C, and ESM6D supplies. The ESM4 and ESM6 series of modular ac/dc power supplies' leakage currents conform to IEC601-1. The ESM4 series is available in 400 and 600W configurations, both providing as many as eight outputs from a 2.56×5×10.63-in. chassis. The ESM6 series is available in 600 and 1000W versions, both providing as many as 12 out-

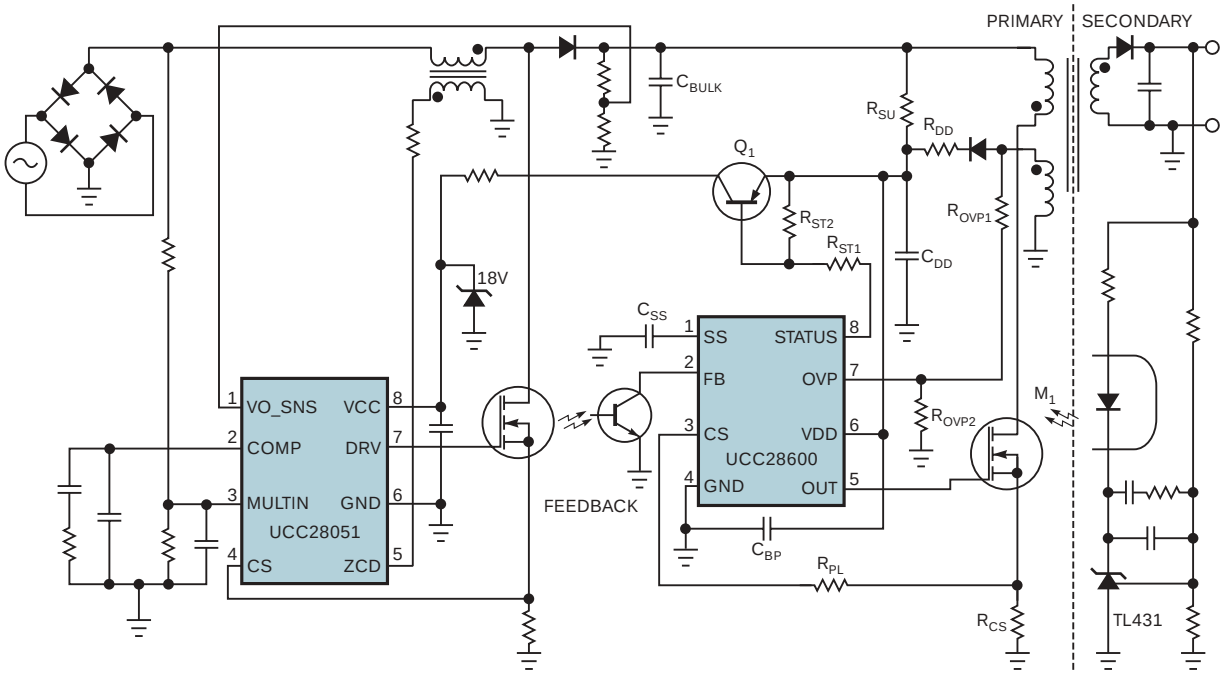
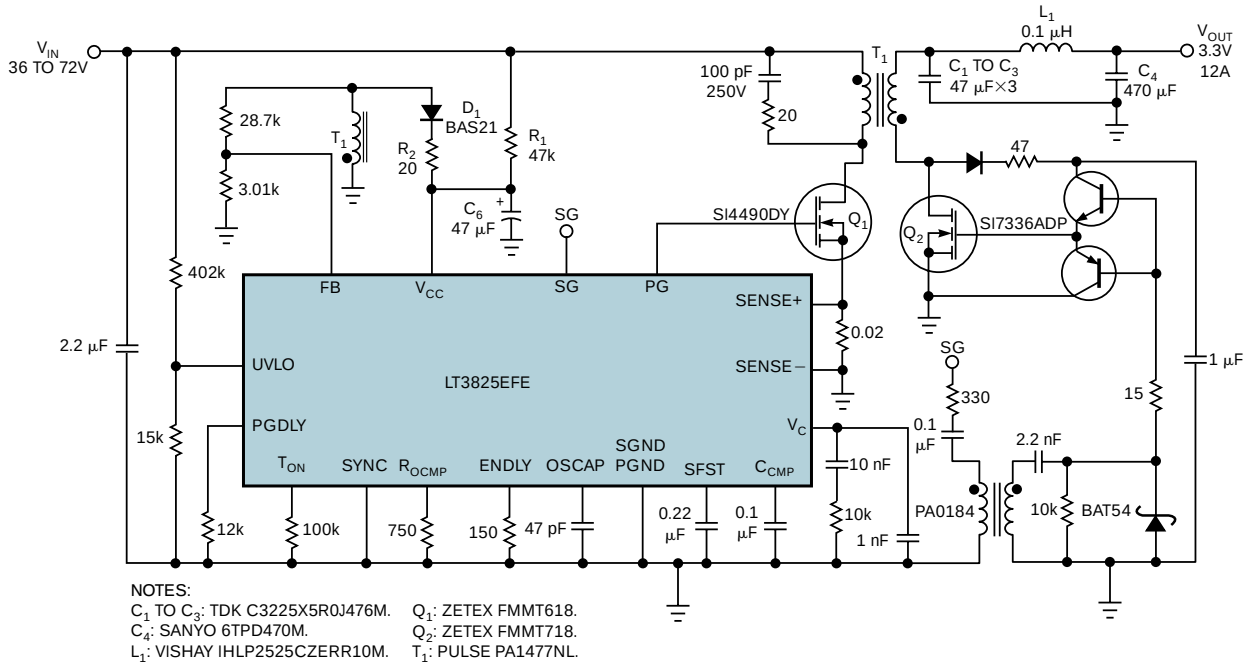


Figure 1 An optoisolator provides voltage feedback for this power-supply circuit. Note the input power-factor-correction circuit that Europe mandates for products that draw more than 60W.



NOTES:
C_1 TO C_3: TDK C3225X5R0J476M.
C_4: SANYO 6TPD470M.
L_1: VISHAY IHLP2525CZERR10M.
Q_1: ZETEX FMMT618.
Q_2: ZETEX FMMT718.
T_1: PULSE PA1477NL.

Figure 2 This transformer-isolated power-supply circuit employs transformer feedback for device powering and feedback voltage.

puts. You can configure five single-output and two dual-output modules in series or parallel to provide outputs of 1.45 to 58V dc.

ROLL YOUR OWN SUPPLY

Of course, you can design your own power supply and submit it for certification yourself. The Texas Instruments UCC28600 PWM controller has "green"-energy features to meet stringent worldwide energy-efficiency requirements. The UCC28600 integrates energy-saving features with high-level protection features. The UCC28600 incorporates frequency foldback and burst-mode operation to reduce the operation frequency at light load and no load (Figure 1). The UCC28600 is available in eight-pin SOIC and PDIP packages that operate from −40 to +105°C.

Texas Instruments also offers 1W, unregulated dc/dc converters in miniature packages that feature 3-kV isolation. The DCH01 family of plug-in power modules operates from a 5V input and provides single voltages of 5, 12, and 15V and complementary dual-output voltages of ±5, ±12, and ±15V. The modules, which suit medical instrumentation, provide as much as 85% efficiency and meet UL60950 specifications with 3-kV rms isolation and EN55022 Class B EMC performance. Supporting an operating-temperature range of −40 to +85°C, the modules can power TI's ISO721 and ISO721M high-speed digital isolators. In addition, the DCH01 provides highly effective point-of-load power conversion and ground-loop elimination for noise-sensitive applications.

The DCH01 uses reliable pc-board construction and comes in an industry-standard 20×8×10-mm SIP-7 package that is lead-free and ROHS (reduction-of-hazardous-substances)-compliant. The DCH01's open-frame design enhances reliability by eliminating the potting you commonly find in competitive products. The DCH01 series costs $4.25 (1000).

Not all isolated-power-supply ICs require an optoisolator. The Linear Technology LT1725 monolithic switching-regulator controller targets use in the isolated-flyback topology. It drives the gate of an external MOSFET and is powered from a third transformer winding. These features allow for an application input voltage limited only by external power-path components. The third transformer winding also provides output-voltage-feedback information, such that an optoisolator is unnecessary. Its gate-drive capability couples with a suitable external MOSFET to deliver load power that reaches into the 10s of watts.

The LT1725 has a number of features absent from most other switching-regulator ICs. By using current-mode switching techniques, it provides excellent ac- and dc-line regulation. Its unique control circuitry can maintain regulation well into discontinuous mode in most applications. Optional load-compensation circuitry allows for improved load regulation. An optional undervoltage-lockout pin halts operation when the input voltage is too low. An optional external capacitor implements a soft-start function. A 3V output is available at as much as several milliamps for powering primary-side application circuitry.

Targeting applications requiring more output current, the Linear Technology LT3825 isolated switching-regulator controller finds use in medium-power flyback topologies (Figure 2). A typical application is 10 to 60W with input voltage limited only by external power-path components. A third transformer winding provides output-voltage feedback. The LT3825 current-mode controller regulates output voltage based on sensing secondary voltage through a transformer winding during flyback. This setup allows for tight output regulation without the use of an optoisolator, improving dynamic response and reliability. Synchronous rectification increases converter efficiency and improves output cross-regulation in multiple output converters. The LT3825 operates in forced continuous-conduction

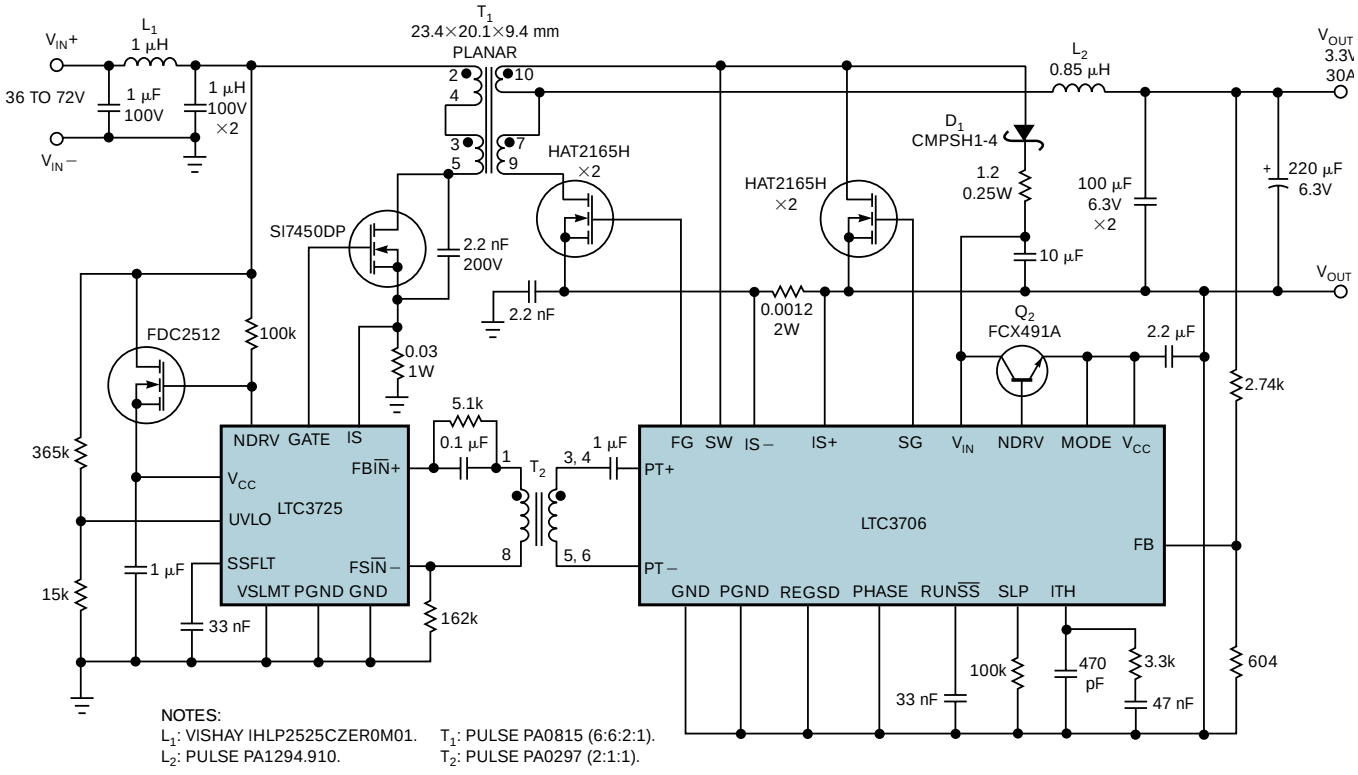


Figure 3 The LTC3706 secondary-side synchronous controller and its companion smart gate driver, the LTC3725, make it possible to create an isolated forward converter with the simplicity and performance of a buck regulator.

mode, which improves cross-regulation in multiple winding applications. Users can program and externally synchronize the switching frequency. The part also has load compensation, undervoltage lockout, and soft-start circuitry.

The circuit in Figure 2 shows an isolated, synchronous, 48 to 3.3V flyback waveform at a 12A supply. Instead of using a parts-intensive secondary-side voltage reference and error amplifier to drive an optocoupler, it uses the primary bias winding on the flyback transformer, T_1. Proprietary feedback circuitry inside the LT3825 reads the reflected output-voltage information on this winding during the flyback pulse. The circuit then compares this voltage with a precision internal reference and obtains an error signal. You use the error signal to modulate the on-time of Q_1 in such a way as to regulate the output voltage. An important benefit of this technique is that output-voltage information instantly arrives at the controller after the switching cycle ends. In a conventional optocoupler-based design, delays of 10s to 100s of microseconds occur in the optocoupler alone, severely limiting the converter's transient response.

According to Linear Technology's Kurk Mathews, buck-converter designers have long benefited from the simplicity, high efficiency, and fast transient response that the latest buck-controller ICs make possible. These ICs feature synchronous rectification and polyphase interleaved power stages. Unfortunately, these same features have been difficult or impossible to implement in the buck converter's close relative, the forward converter, often used in isolated medical applications. The LTC3706 secondary-side synchronous controller and its companion smart gate driver, the LTC3725, make it possible to create an isolated forward converter with the simplicity and performance of a buck regulator. Many isolated supplies place the controller IC on the input (primary) side and rely on indirect synchronous-rectifier timing and optoisolator feedback to control the output (secondary). The circuit in Figure 3 offers a more direct approach using fewer components. The secondary side uses the LTC3706 controller, and the primary side uses the LTC3725 driver with self-starting capability. When you apply an input voltage, the LTC3725 begins a controlled soft-start of the output voltage. As the output voltage begins to rise, the LTC3706 secondary

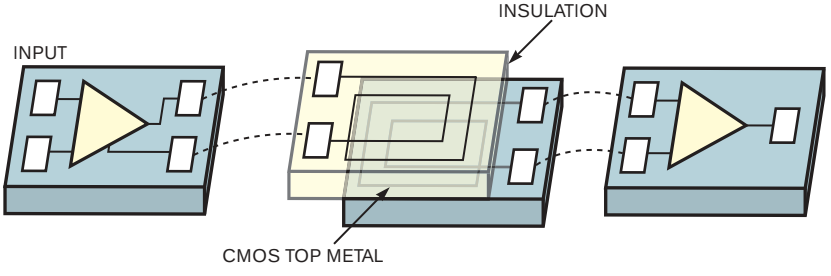


Figure 4 Analog Devices' iCoupler transformers are planar structures that use the CMOS metal layers as well as a gold layer fabricated on top of the wafer passivation.

controller quickly powers up via T_1, D_1, and Q_2. The LTC3706 then assumes control of the output voltage by sending encoded PWM gate pulses to the LTC-3725 primary driver through signal transformer T_2. The LTC3725 then operates as a simple driver, receiving both input signals and bias power through T_2.

ISOLATED I/O

In a variety of medical systems, designers face the challenge of signaling data between two points and preventing the flow of electrical current. The solution to this problem is to employ a galvanic-isolation device, which allows signals to travel between the two points but prevents the flow of electrical current.

In addition to providing isolation in the feedback loop of a power supply, optoisolators can also isolate I/O lines. Avago Technologies' fastest optoisolator is the HPCL-7723, which runs at 50 Mbps and exhibits maximum pulse-width distortion of 2 nsec and a propagation delay of 20 nsec. Avago offers single-, two-, three-, and four-channel devices. The HCN-Wxxx series comes in a wide-body package that withstands a minimum isolation voltage of 5 kV rms for 1 sec per UL 1577.

A GALVANIC-ISOLATION DEVICE ALLOWS SIGNALS TO TRAVEL BETWEEN THE TWO POINTS BUT PREVENTS THE FLOW OF ELECTRICAL CURRENT.

Analog Devices bases its iCoupler isolation technology on chip-scale transformers rather than the LEDs and photodiodes that optocouplers use. By fabricating the transformers directly on-chip using wafer-level processing, you can integrate iCoupler channels with each other and other semiconductor functions at low cost. The iCoupler transformers are planar structures that use the CMOS metal layers as well as a gold layer fabricated on top of the wafer passivation (**Figure 4**). A high-breakdown polymide layer underneath the gold layer insulates the top transformer coil from the bottom. CMOS circuits connected to the top and bottom coils provide the interface between each transformer and its external signals.

The circuitry encodes input-logic transitions using 1-nsec pulses routed to the primary side of a given transformer. These pulses couple from one transformer coil to another, and the circuitry on the secondary side of the transformer detects them. This circuitry then re-creates the input digital signal at the output. In addition, a refresh circuit at the input side ensures that the output state matches the input state even if no input transitions are present.

The ADuM240x product family is Analog Devices' first with an isolation rating greater than 2.5 kV rms. These quad-channel isolators are pin- and specification-compliant with the ADuM140x family but provide double the isolation rating at 5 kV rms. Targeting medical and other safety-critical applications, the ADuM240x isolators are certified to a working voltage of 250V rms (reinforced insulation), according to medical-equipment standard IEC 60601-1. They are

also approved for working voltages reaching 500V rms, per the more general standard EN60747-5-2. These quad-channel isolators are available in three channel configurations, each with three performance grades. The ARW grade supports data rates to 1 Mbps, the BRW grade supports data rates to 10 Mbps, and the CRW grade supports data rates to 90 Mbps. All models operate from 2.7 to 5.5V over −40 to +105°C.

Texas Instruments offers a two-member family of high-speed digital isolators, featuring on-chip capacitors to enable faster data transmission with higher signal integrity. These capacitive isolators, which combine the fastest data rates with high reliability, provide six-orders-of-magnitude higher magnetic immunity than inductive devices, and they use 60% less power than high-performance optocouplers.

The ISO721 and ISO721M provide data transmission and circuit protection with isolation of as much as 560V of operating voltage or 4-kV peak overvoltage transient. The ISO721M suits applications that require fast digital-data transmission with low system noise. The ISO721 is more flexible and robust for transmitting data in noisy environments. The devices meet the standards for isolators set by UL 1577, IEC 60747-5-2, and CSA Component Acceptance Notice 5A.

By using on-chip, high-voltage capacitors, the TI isolators transmit data as much as three times faster and use less power than commonly used high-performance optocouplers. In addition, TI's capacitive technology offers immunity from external magnetic fields that frequently occur in the industrial environment and can distort signal integrity. These devices also offer high immunity against data corruption due to fast voltage transients, providing a minimum protection level of 25 kV/μsec.

TI's isolators use a semiconductor-grade silicon-oxide dielectric. This stable insulator provides proven reliability and long operational life. These requirements are critical in industrial applications, in which voltage surges can otherwise degrade device lifetime. At typical operating voltage, each device's life expectancy exceeds 25 years.

The ISO721 features TTL inputs with a noise filter, a 100-Mbps transmission speed, a typical propagation delay of 17 nsec, 2 nsec of jitter (typical), and support for 3 or 5V signals. The ISO721M, on the other hand, has CMOS inputs without a noise filter, a 150-Mbps transmission speed, a typical propagation delay of 10 nsec, and jitter of 1 nsec (typical). The device supports 3 or 5V signals. The ISO721 and ISO721M devices come in an eight-pin SOIC package and cost $1.65 (1000). An evaluation module is available. EDN

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Avago Technologies
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