

Technical Documents

Motion Control	5
Lighting	8
High Voltage IC.....	11
Class D Audio	13
Automotive	14
AC-DC and DC-DC	15
High Reliability	17
General Application.....	19
MOSFET	21
IGBT	23
Diodes.....	24
Package.....	25
Thermal.....	28

Motion Control Technical Documents

AN-978B - HV Floating MOS-Gate Driver ICs

International Rectifier's family of MOS-gate drivers (MGDs) integrate most of the functions required to drive one high side and one low side power MOSFET or IGBT in a compact, high performance package. With the addition of few components, they provide very fast switching speeds, as shown in Table II for the IR2110, and low power dissipation. They can operate on the bootstrap principle or with a floating power supply. Used in the bootstrap mode, they can operate in most applications from frequencies in the tens of Hz up to hundreds of kHz.

AN-985 - Six-Output 600V MGDs Simplify 3-Phase Motor Drives

Traditionally the functions described above have required discrete circuits of some complexity but International Rectifier's IR213X series six-channel gate drivers perform all the requirements for interfacing logic level control circuits to high power MOS-gated devices in high-side/ low-side switch configurations using up to six devices.

AN-1014B - Using The Current Sensing IR212X Gate Drive ICs

There are four single channel devices which incorporate current sensing. The IR2121 and IR2125 are low and high side drivers respectively, which have a high output drive (1A source /2A sink). The current sensing circuit for these two devices uses a timing circuit via the ERR pin to program the time between over-current detection and latched shutdown. The IR2127 and IR2128 are both high side drivers (IR2127-active high input/ IR2128 active low input), with a lower output drive (200mA source/420mA sink), and a more basic current sensing scheme. For applications where the output needs to be ON for long periods of time, or if the load has a reasonable impedance (>500Ω) the bootstrap capacitor voltage (V_{bs}) may start to droop. In this case a charge pump circuit may be needed.

AN-1044 – Plug N Drive™ Application Overview - Integrated Power Module for Appliance Motor Drive

These modules represent a sophisticated, integrated solution for 3 phase motor drives used in a variety of appliances, such as washing machines, energy efficient refrigerators and air conditioning compressor drives in the 250 Watt to 2 Kilowatt power range. They utilize NPT(non-punch through) IGBTs matched with Ultra-soft recovery diodes to minimize EMI generation. In addition to the IGBT power switches, the modules contain a 6 output monolithic driver chip, matched to the IGBTs to generate the most efficient power switch consistent with minimum noise generation and maximum ruggedness.

AN-1048 – Power Loss Estimation in BLDC Motor Drives Using iCalc

This note explains the power loss estimation spreadsheet prepared for brushless DC (BLDC) motor drivers. Steady state average power losses in the IGBT/ MOSFET switches and anti-parallel diodes can be reasonably and easily predicted, if certain operating conditions of the motor driver are known. This tool has been developed to cover the four most common drive strategies implemented for BLDC motors with trapezoidal flux distribution viz. 60° switching, 120° switching, PAM and hard switching. The switching in each of these strategies will be briefly explained, followed by an explanation of the loss calculation method for that strategy.

AN-1049 – Plug N Drive™ Storage and Assembly overview - Integrated Power Module for Appliance Motor Drive

This document provides note on items that require care when using Plug N Drive power modules. This document covers standard usage notes. Special usage notes, which only a certain power module has, may be indicated by another data. Be careful of this point.

AN-1052 - Using the IR217x Linear Current Sensing ICs

Linear current sensing ICs are designed to transfer current sense information from the high-side motor drive circuit to the low-side circuit, so that the information may be processed by ground referenced control circuits. The Analog input signal is actually a voltage which comes from the voltage drop across an external sensing resistor.

DN500 - Short-Circuit Protection for Power Inverters

Short-circuit protection on low- and medium-power inverterized motor drives is becoming essential to comply with safety standards. However, the implementation of such a feature can consistently increase board component count and system complexity when using traditional sensors and optocouplers. The IR2x14 and IR2x141 gate driver families are designed specifically to protect half bridge and three-phase inverter switches. Desaturation detection of the power switch is fully integrated, resulting in increased system reliability and drastically reduced part count and layout space. Moreover, this gate driver family features gate driving capability of up to 3A with anti-shoot-through and undervoltage lockout for both high- and low-voltage side.

DN501 - Accurate Current Sensing in High Voltage Motor Drives

Current sensing topologies vary according to many driving factors. In the appliance market, for example, the cost factor is dominant, while for the industrial market, performance is usually a key factor. Moreover, current levels discriminate between shunt-based current sensing that is often limited by the shunt thermal dissipation, and Halleffect topologies. The IR2x77 and IR2x771 linear current sensor families are suitable for shunt-based topologies, providing accurate current sensing in a very compact SOIC16 wide (10.5x10.65 mm²) package. Current is sensed directly in the phase at the shunt terminals. Noise cancellation and PWM ripple rejection are obtained as a result of a patented signal processing technique that allows a clean current signal to be generated and referenced to ground. Both PWM and analog output are available.

DN502 - Short-Circuit Protection for Three-Phase Power Inverters

The light industrial and appliance markets are becoming more and more demanding in terms of performance and safety features. These requirements are frequently at odds with the need for lower costs due to the higher circuit complexity required. The IR2x381 gate driver family is designed specifically to protect full inverter systems composed of a three-phase output bridge and brake, replacing at least seven traditional optocoupler gate drivers with one monolithic high voltage IC. Desaturation detection of the power switch is fully integrated, increasing system reliability and drastically reducing part count and layout space. Gate driving capability is up to 540mA. The full-featured design makes this device particularly well suited for motor drive applications.

DT92-6 - Current Sensing with The IR2130

The IR2130 High voltage MOS gate Driver IC provides a convenient and cost effective gate drive solution for applications requiring a three phase bridge configuration. It comprises three high side and three low side referenced drive channels and has been targeted at applications that include: WM AC Motor Drives, Six Step AC Motor Drives, and UPS. The IR2130 has features added to enhance its performance in these applications. These features include: Fault indicator output, Over current trip input, and Current signal amplifier. It is the use of this third feature, the current signal amplifier, that is the subject of this paper.

DT93-6B - Miniaturization of the Power Electronics for Motor Drives

This Design Tip discusses how the power electronics for a fractional HP AC or BL-DC motor drive (control IC drivers and IGBTs co-packaged in surface-mounted TO-220s) can be built in a volume not much larger than a pack of cigarettes to achieve the required level of power density.

DT97-3 - Managing Transients in Control IC Driven Power Stages

International Rectifier offers a broad range of control ICs from single channel to complete three-phase bridge drivers. All types employ high-integrity level shifting techniques to simplify control of power transistors from logic circuits. Our latest products further enhance this capability to drive power switches relatively displaced by up to 1200V.

DT98-2 - Bootstrap Component Selection For Control ICs

The V_{bs} voltage (the voltage difference between the V_b and V_s pins on the control IC) provides the supply to the high side driver circuitry of the control IC's. This supply needs to be in the range of 10- 20V to ensure that the Control IC can fully enhance the MOS Gated Transistor (MGT) being driven, some of International Rectifier's Control IC's include under-voltage detection circuits for V_{bs}, to ensure that the IC does not drive the MGT if the V_{bs} voltage drops below a certain voltage (V_{bsuv} in the datasheet). This prevents the MGT from operating in a high dissipation mode.

DT99-7 - Alleviating High Side Latch on Problem at Power Up

In a typical IR2xxx high voltage IC application with bootstrap power supply, the bootstrap capacitors are charged before the system becomes operational. In the process of charging up the bootstrap capacitor prior to establishing the high side supply voltage, if the high side output inadvertently turns on and stays on, it may cause a shoot through and may damage the IGBT devices. Even though the data sheet does not specify this power up transient case, the startup behavior is crucial for motor drive applications. In general, the high side outputs of most of our control IC products rely on the high side Under Voltage Lock out circuit (UVBS) during power up to stay low during the power up. Under a combination of certain overstress and startup conditions, however, the high side output can inadvertently turn on and such an operating condition must be avoided.

Lighting Technical Documents

AN-1013 - IR21571: Dual Lamp Series Configuration

Dual lamps connected in series is the popular conventional magnetic ballast retrofit configuration for the U.S. lighting market. The center lamp filaments are connected in parallel which results in six connections to the lamps from the output of the ballast. This retrofit configuration is accomplished using the IR21571 and some modifications to the ballast output stage. Through externally programmable components, the IR21571 affords flexibility of various features such as preheat time and frequency, ignition ramp characteristics, and running mode operating frequency. Comprehensive protection features protect the circuit against conditions such as lamp strike failures, filament failures, low DC bus, thermal overload, or ramp failure during normal operation. *This circuit switches off both lamps when one is taken out, and automatically restarts when both lamps are in place.*

AN-1019 - IR21571: Dual Lamp Ballast: Parallel Configuration

Driving two lamps in parallel results in lower voltage stress on the ballast output stage components, the wiring, and the fixture sockets. Additionally, the resonant L and C associated with the lamps will be less sensitive to component tolerances due to the lower running lamp voltages compared to the series configuration. For these reasons, the parallel configuration is becoming more popular. The IR21571 can be used in a ballast to control parallel lamp configurations. Through externally programmable components, the IR21571 affords flexibility of various features such as preheat time and frequency, ignition ramp characteristics, and running mode operating frequency. Comprehensive protection features protect the circuit against conditions such as lamp strike failures, filament failures, low DC bus, thermal overload, and ramp failure during normal operation. **Two variations of this circuit are included in this application note. The first one switches off both lamps when one is taken out, and automatically restarts when both lamps are in place. The second variation allows one lamp to remain running when the other is removed. When the lamp is reinserted, the ballast restarts in the pre-heat mode.**

AN-1020 - IR21571: T5 Lamp Ballast Using Voltage-Mode Filament Heating

T5 lamps are becoming more popular due to their lower profile and higher lumen/watt output. These lamps, however, can be more difficult to control due to their higher ignition and running voltages. A typical ballast stage using current-mode filament heating (filaments placed inside L-C tank) will result in excessive lamp voltage during preheat and excessive filament current during running. The output stage has therefore been modified for voltage-mode filament heating using secondary windings off of the resonant inductor. The result is a more flexible ballast output stage necessary for fulfilling the lamp requirements. The IR21571 Ballast Control IC is used to program the ballast operating points and protect the ballast against conditions such as lamp strike failures, filament failures, low DC bus, thermal overload or lamp failure during normal operation.

AN-1038B - Low Voltage DC Supply Dimmable Ballast for 1 x 36W T8 Lamp

It is possible to design an effective dimmable ballast based around the IR21592, that is powered from a low voltage DC supply instead of the AC line. A non-dimmable version based around the IR2156 is also possible using the same basic configuration as described here. The following example shows a ballast for a single 36W T8 lamp driven from a 30V DC supply. Lower supply voltages are possible, however the IR21592 control IC requires up to 13V supplied to the VCC pin before it will operate, also as the current is high large conductors are needed to keep losses at an acceptable level (for a 36W ballast operating from a 30V supply the input current is around 1.25A).

AN-1056 - 13W Integrated CFL using IR53H420

This application note is intended to be used as a development tool to speed up customers' time to market.

AN-1065 - Procedures to design 120VAC CFL solutions with the IR2520D

This application note (AN) is intended for helping the design of CFL ballasts, 120VAC input, using the IR2520D Ballast Control HVIC. The information enclosed will help in adapting the reference design IRPLCFL5U to different lamp types. Please refer to the IRPLCFL5U reference design and to the IR2520D datasheet for additional information on the design, including electrical parameters, state diagram and complete functional description.

AN-1066 - Procedures to design 220VAC CFL solutions with the IR2520D

This application note (AN) is intended for helping the design of CFL ballasts, 220VAC input, using the IR2520D Ballast Control HVIC. The information enclosed will help in adapting the reference design IRPLCFL5E to different lamp types. Please refer to the IRPLCFL5E reference design and to the IR2520D datasheet for additional information on the design, including electrical parameters, state diagram and complete functional description.

AN-1069B - Electronic Transformer Applications

For practical product designs based around the IR2161, the IRPLHALO1E circuit topology may not contain all of the required functionality. In this application note we have some additional circuit ideas that can solve some of the design problems that may be encountered.

AN-1072 - CFL Ballast with Passive Valley Fill & Crest Factor Control

In this application note we will try to find a trade off between high PF and low THD and costs. The goal of this design is to implement a 14W CFL ballast which conform to these specs:

- 1) Total Harmonic distortion (THD) < 30 %
- 2) Power Factor (PF) > 0.85
- 3) Lamp Current Crest Factor I_{pk}/I_{rms} (CF) < 1.7
- 4) Input: 220-240VAC
- 5) Cheaper than an active PF solution.

AN-1073 - Analysis of Different Solutions and Trade-off Cost vs. Power Factor Performance for Electronic Ballasts

Electronic lamp ballasts using an active boost type power factor front end, a Ballast Controller IC and 3 MOSFETs have superior reliability versus different solutions, but different solution can be lower cost, smaller, and use fewer components. This application note will show how to implement an electronic ballast with high power factor maintaining low cost and small size and will honestly point out the short coming of every implementation proposed versus the classical active power factor correction solution.

AN-1074 - A new Circuit for Low-Cost Electronic Ballast Passive Valley Fill with additional Control Circuits for Low Total Harmonic Distortion and Low Crest Factor

The goal of this design is to implement a low-cost linear ballast with good PFC, acceptable THD and low current-crest factor. The ballast will use Passive Valley Fill configuration to reduce costs compared to standard PFC. To overcome the disadvantage of the very high current crest factor, additional circuit has been used to modulate the Half Bridge frequency versus the bus voltage. The system will work at a minimum frequency when the bus voltage is low and increase the frequency while the bus voltage increases. This will stabilize the lamp power versus the AC line changes, improve the current crest factor and improve EMI because the operating frequency varies in a frequency range. The solution has been implemented for 2 different lamps: 36W and 58W T8.

AN-1075 - Obtaining Low THD and high PF without A PFC

This application note shows a method of obtaining a boosted bus voltage with a high PF and reduced THD, requiring only an additional inductor without the PFC control IC.

AN-1085 – Converting from IR2153(D)(S) to IRS2153D(S)PbF

The new IRS2153D(S)PbF replaces the existing IR2153(D)(S) advantageously by saving the need for an external bootstrap diode. It is based on the same core design and is pin-to-pin compatible, allowing minimum changes to the previous design. This application note describes the differences between the existing IR2153(D)(S) IC family and the new IRS2153D(S)PbF.

DT02-1B - Isolation method for 1-10V controlled ballast based on the IR21592

The light output of a dimmable ballast based around the IR21592 control IC, is determined from a DC control voltage between 0 and 5V that provides a reference for the closed loop lamp power control. At inputs below 0.5V the output will be at minimum, a preset power level below which the particular lamp that the ballast has been designed for, does not operate satisfactorily. This point will vary considerably between lamp types, depending on the length and diameter of the tube and also the cathode effectiveness. Above this the lamp power will increase linearly from the minimum level to the maximum. The minimum lamp power for which stable output can be achieved is typically 1% when using the IR21592 phase control technique.

High Voltage IC Technical Documents

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There are four single channel devices which incorporate current sensing. The IR2121 and IR2125 are low and high side drivers respectively, which have a high output drive (1A source /2A sink). The current sensing circuit for these two devices uses a timing circuit via the ERR pin to program the time between over-current detection and latched shutdown. The IR2127 and IR2128 are both high side drivers (IR2127-active high input/ IR2128 active low input), with a lower output drive (200mA source/420mA sink), and a more basic current sensing scheme. For applications where the output needs to be ON for long periods of time, or if the load has a reasonable impedance (>500Ω) the bootstrap capacitor voltage (V_{bs}) may start to droop. In this case a charge pump circuit may be needed.

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DT92-2 – High Current Buffer for Control ICs

Modules and other paralleled MOS-gated power transistors can present difficulties to gate drive circuits. International Rectifier's family of Control IC drivers can provide large peak output currents acceptable for most applications. However, when driving the extremely large loads of many paralleled devices, excess power dissipation in the MOS-gated drive section of the Control IC may become an issue when switching above the few tens of kilohertz range. The subject of this Design Tip is a current buffer to alleviate this problem.

DT92-4A – Simple High Side Drive Provides Fast Switching and Continuous On-Time

P-channel power MOSFETs are typically used as high-side switches in low power applications because of simpler gate drive circuitry. As power levels, either voltage or current, increase, the advantages of P-channel devices are quickly offset by their increased on-resistance, limited voltage range, increased cost, and increased complexity of the gate drive circuitry. By switching to an N-channel device, it is possible to improve on the P-channel's disadvantages, at the expense of increased gate drive complexity. For high power levels, the IGBT is extremely well suited for use as a high side switch, yet all currently available IGBTs are N-channel devices. Presented is a circuit that, with the use of an extra IC and a few passive components, solves the N-channel gate drive circuit issue.

DT94-1 – Keeping the Bootstrap Capacitor Charged in Buck Converters

This Design Tip shows examples of how the capacitor can fail to charge in a buck converter at: Start-up with no load, Start-up in battery charger applications, Stop/restart, or operation with low load. This Design Tip uses the IR2125 for illustration, but is applicable for all control IC devices.

DT97-3 - Managing Transients in Control IC Driven Power Stages

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The V_{bs} voltage (the voltage difference between the V_b and V_s pins on the control IC) provides the supply to the high side driver circuitry of the control IC's. This supply needs to be in the range of 10- 20V to ensure that the Control IC can fully enhance the MOS Gated Transistor (MGT) being driven, some of International Rectifier's Control IC's include under-voltage detection circuits for V_{bs}, to ensure that the IC does not drive the MGT if the V_{bs} voltage drops below a certain voltage (V_{bsuv} in the datasheet). This prevents the MGT from operating in a high dissipation mode.

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In a typical IR2xxx high voltage IC application with bootstrap power supply, the bootstrap capacitors are charged before the system becomes operational. In the process of charging up the bootstrap capacitor prior to establishing the high side supply voltage, if the high side output inadvertently turns on and stays on, it may cause a shoot through and may damage the IGBT devices. Even though the data sheet does not specify this power up transient case, the startup behavior is crucial for motor drive applications. In general, the high side outputs of most of our control IC products rely on the high side Under Voltage Lock out circuit (UVBS) during power up to stay low during the power up. Under a combination of certain overstress and startup conditions, however, the high side output can inadvertently turn on and such an operating condition must be avoided.

DT04-4 – Using Monolithic High Voltage Gate Drivers

The purpose of this paper is to highlight the most common subjects driving a half bridge power stage in motor drive applications (with monolithic IC gate driver) and to suggest appropriate solutions to solve the issues. In the following sections different topics are discussed: the sizing of some fundamental components, as bootstrap circuit and on/off gate resistors; the half bridge parasitic elements are presented with their effects and some possible solutions are proposed. In the end section some layout tips are presented. All the situations and the solutions proposed are, where it's not specified, for a typical IR monolithic gate driver with floating bootstrap supply.

Class D Audio Technical Documents

AN-1070 - Class D Amplifier Performance Relationship to MOSFET Parameters

This application note discusses key parameters to be considered in the selection of MOSFETs for class D amplifier and their relationship with amplifier performance such as efficiency, EMI, and THD. In addition, benefits and advantages of IR Digital Audio MOSFETs in class D audio amplifier are presented.

AN-1071 - Class D Audio Amplifier Basics

A Class D audio amplifier is basically a switching amplifier or PWM amplifier. There are a number of different classes of amplifiers. This application note takes a look at the definitions for the main classifications.

Automotive Technical Documents

AN-1032 - Fully protected H-Bridge IR 3220S Architecture and Typical Application

The IR 3220S is a fully protected Dual High Side Switch that features a whole H-Bridge control. With two additional Low Side MOSFETs, it limits the in-rush current of a DC motor, drives it in both directions and offers a braking mode without any external power management. Current protection (short-circuit) and Temperature shutdown(overload) give the IR 3220S the ability of meeting most of the Mechatronic's Customer Requirements. The High Side switches provide the direction capability and the H-Bridge protection. The Low Side MOSFETs bring the flexibility by offering the high frequency switching ability. Therefore, hard start-up of the motor is avoided and replaced by a smooth and stress-less speed ramp-up.

AN-1058 - Programmable High Side Current Switch IR3310/11/12

The IR331X devices suit for any application where the load current sensing is required. IR331X is fully protected, programmable current shutdown, over temperature shutdown and reverse battery protection. The current sensing features offer current readout accuracy, high frequency bandwidth, a versatile way to control the current shutdown and replaces the shunt resistor. The IR331X family features a reverse battery protection. In such condition, the current flows in the load and the body diode of the power MOSFET, so the power dissipation is much higher than in normal. In a power MOSFET the current can flow in both direction from drain to source or from source to drain. The system switches on the MOSFET in order to reduce power dissipation.

AN-1083 - Features of the Low-side Family IPS10xx

The new IPS10XX family of protected power MOSFETs consists of three terminal low side devices based upon the latest IR proprietary vertical technology P³ (Power Product Platform). IR protected MOSFETs are vertical power MOSFETs integrated with protection circuitry. The new IPS10XX family features logic level inputs, over-temperature shut down protection, over-current shut down protection, active clamp and diagnosis through the input pin. The new families are monolithic for $R_{DS(ON)}$ as low as 13m Ω , which allows faster response time for the over temperature protection and more accurate over current shut down. Compared to the previous low side family, the IPS10XX offers better protection, integrated with a more efficient power MOSFET and a diagnostic feature without the need of additional terminals. This application note explains the features included in the low side IPS family IPS10XX and provides suggestions on how to use these devices in the automotive environment.

AC-DC and DC-DC Technical Documents

AC-DC

AN-1018A - Using The IRIS40xx series Integrated Switchers

The IRIS40xx series are small IC's which contain a MOSFET and a switched mode power supply control IC in a single package. The devices are designed primarily for use in Flyback converter topologies.

AN-1024 - Flyback Transformer Design for the IRIS40xx Series

The IRIS40xx series of Integrated Switchers are designed primarily to be used in the quasi-resonant mode which means that the transformer will be operating in a discontinuous mode (The magnetic field is not continuous, it will return to zero when all energy in the transformer is transferred to the secondary side). In PRC mode the transformer will also generally be operating in a discontinuous mode, unless the minimum operating frequency is set very low (about 20kHz which would not generally be practical as this would require a larger core size). So this application note will cover the case for a discontinuous design only.

AN-1025 - Designing a Power Supply Using the IRIS40xx Series

Flyback Converter Power Supplies are very popular due to their simplicity, low cost, and ability to generate a number of outputs. Using the IRIS40xx series of Integrated switchers, and following the design procedures laid out in this application note and the other documents referenced, make the task of designing a basic power supply a simplified process. This application note gives step by step guidelines to guide you through designing your power supply.

AN-1077 - PFC Converter Design with IR1150 One Cycle Control IC

This Application Note describes the design methodology of a Continuous Conduction Mode Power Factor Correction circuit utilizing a boost converter and featuring the IR1150S PFC IC. The IR1150 is based on International Rectifier's proprietary "One Cycle Control" technique for PFC converter control. This application note presents a complete, step-by-step, design procedure including converter specifications and necessary design tradeoffs.

DC-DC

AN-1043 - Stabilize the Buck Converter with Transconductance Amplifier

In this application note, how to stabilize the buck converter with transconductance Error amplifier is discussed. The goal of the design is to provide a loop gain function with a high bandwidth (high zero-crossover frequency) and adequate phase margin. As a result, fast load response and good steady state output can be achieved.

AN-1046 - Dual Synchronous PWM Controller and LDO Controller In TSSOP Package Eases Multi-Output and Two-Phase Power Supply Solutions

Many applications like DDR memory, and set top boxes require at least two output voltages. And then there are some others such as graphics cards where the output power exceeds any single input power budget. Or, application when the current required is too large that two-phase solution should be used. International Rectifier's IRU3046, a monolithic dual synchronous PWM controller with a built-in linear regulator controller, offers unprecedented flexibility to configure these multiple types of power supplies.

AN-1047 - Graphical Solution to Two Branch Heatsinking Safe Operating Area

For Gen 1 iPOWIR devices, thermal resistance issues are avoided by carefully characterizing the package thermally at design time using infrared metrology and specially made iPOWIR devices with built in temperature sensors, and then specifying SOA appropriately. SOA was then based solely on PCB temperatures adjacent to the device.

AN-1053 - Power-up Sequencing Techniques Using **iP1201** & **iP1202**

There are three types of power-up sequencing: Sequential, Ratiometric, and Simultaneous. This application note will address how to implement these types of power-up sequencing with iP1201/2 designs. In all three cases, the input supply (V_{IN}) is held constant and the ENABLE pin is used to initiate the power-up sequence.

DN503 - Simple and Efficient Reverse Polarity Protection for -48V Communication Systems

Reverse polarity protection is required in many -48V wired and wireless communication infrastructure systems, with or without two-feed redundancy. Reverse polarity protection protects against accidental swap of ground and -48V feeds during system installation that could damage the system or bring down multiple systems in a central office. The reverse polarity protection can be implemented either on-board, or at the input of a custom, multiple-output redundant power supply.

High Reliability Technical Documents

AN-999 - International Rectifier's Total Dose Radiation Hardness Assurance (RHA) Test Program

For many years, IR has been the leader in radiation hardened MOSFETs. The design and processing of these devices has been carefully planned and implemented to result in a superior product. The thorough hardness assurance testing imposed on our product is an important component of this product line which has been overlooked by many in the industry. The philosophy behind the hardness assurance testing is based on the military requirements outlined in MIL-PRF-19500 and its associated detail slash sheets. IR has elected to exceed the military requirement and is currently using sampling plans as much as 2 times greater than is required.

AN-1016 - Hermetic Surface Mount Device (SMD), Its Advantages and Solutions to Assembly Integration

With the availability of low TCE (temperature coefficient of expansion) board materials, advances in materials, innovative SMD carrier designs, and maturity of the Power Module technology, the hermetic SMD devices can be now successfully and economically integrated in most of system designs. This article will focus on the new generation and more thermally efficient hermetic surface mount packages hereafter referred to as 'SMD'.

AN-1067 - Design Considerations When Using Radiation- Hardened Small Signal Logic Level MOSFETs

Balancing requirements when selecting materials and practices for production facilities is not an easy task. This application note provides more background information of thermal cycling and the potential impact of underfill, lead-free solder, insulated metal substrates (IMS) and conformal coatings when using MOSFETs in the DirectFET™ package.

AN-1068A – Considerations for Designs Using Radiation-Hardened Solid State Relays

Manufacturers of satellites, satellite launch vehicles, and tactical weapon systems face many challenges when designing electro-mechanical relays (EMR) into their systems. Some method of "cushioning" must be employed in order to prevent false relay operation when encountering shock and vibration. In addition, "hash filters" are sometimes necessary to debounce the contacts, thus adding space and weight. However, Solid State Relays (SSR) are immune to the shock and vibration levels normally encountered, and do not need contact filters. Hence, the use of Solid State Relays in place of the mechanical type leads to a more reliable end product.

AN-1078 - An Examination of Changes Imposed by Revised Hybrid Models When Calculating MTBF Values using MIL-HDBK 217F, Notice 1 & 2

Changes to the model incorporated in Revision F of MIL-HDBK-217 for estimation of hybrid failure rates result in a significant reduction of calculated MTBF values when compared to Rev E. Prompted by these reductions, a study was initiated which included a conversation with Seymour Morris of ROME Laboratory, who prepared the Rev F model created for hybrid microcircuits. MTBF calculations based on these models produce results that do not agree with those based on models presented in Revision E of MIL-HDBK-217. To illustrate this difference, calculated MTBF values are presented for the ART2815T DC/DC converter using MIL-HDBK-217F Notice 2 and using MILHDBK- 217E. In addition, calculations are presented including application of various adjustments to the hybrid circuit model factors. The values resulting from each of these calculations are summarized for comparison in Table I following. The adjustments employed in these calculations and a discussion supporting their use in the 217F element model are presented for review.

AN-1081 - Application Note for the IRUH Series of Radiation Hardened,
Ultra Low Dropout Linear Voltage Regulators

Within the series there are three slightly different groups of Ultra Low Dropout linear voltage regulators. Devices listed in group 1 and 2 are available in two different metal package styles, an MO-078 5-pin and an 8-pin flat pack. Devices in group 3 are available in the MO-078 package only. For the most part, the application information contained herein is applicable to devices in all three groups. However, there are some differences in construction between group types which lead to some differences in application information. These differences will be pointed out in each section as appropriate. Primary emphasis will be orientated toward Group 1, with differences in the other two groups, if any, following.

General Application Technical Documents

AN-101 - Choosing an Input Resistor for a Microelectronic Relay

The International Rectifier Photovoltaic Relay (PVR) devices are current-controlled microelectronic relays with a specified current which must be supplied for turn-on. Therefore, a current limit resistor is necessary when operating from a voltage source. This application note gives the procedure for determining the proper resistor to program the microelectronic relays to operate from any control voltage.

AN-944A - Use Gate Charge to Design the Gate Drive Circuit for Power MOSFETs and IGBTs

Gate Charge background, test methods, how to interpret the gate charge curve, how to estimate switching times, and how to compare different devices.

AN-948A - Linear Power Amplifier Using Complementary HEXFET Power MOSFETs

The class AB amplifier described in this application note uses a complementary pair of HEXFET power MOSFET devices as the output stage. This feature offers performance improvements over the equivalent bipolar output stage and allows a reduction in the complexity of the driver circuit, the output devices being driven by a single class A driver.

AN-1017B - The PVI - a New Versatile Circuit Element

The PhotoVoltaic Isolator (PVI), from International Rectifier, is a revolutionary component that can simplify many existing circuits, allow the creation of new designs, and achieve miniaturization and cost reduction. This article will explain the internal workings of the device, discuss its characteristics and give some application examples.

AN-1058 - Programmable High Side Current Switch IR3310/11/12

The IR331X devices suit for any application where the load current sensing is required. IR331X is fully protected, programmable current shutdown, over temperature shutdown and reverse battery protection. The current sensing features offer current readout accuracy, high frequency bandwidth, a versatile way to control the current shutdown and replaces the shunt resistor. The IR331X family features a reverse battery protection. In such condition, the current flows in the load and the body diode of the power MOSFET, so the power dissipation is much higher than in normal. In a power MOSFET the current can flow in both direction from drain to source or from source to drain. The system switches on the MOSFET in order to reduce power dissipation.

DT92-2 – High Current Buffer for Control ICs

Modules and other paralleled MOS-gated power transistors can present difficulties to gate drive circuits. International Rectifier's family of Control IC drivers can provide large peak output currents acceptable for most applications. However, when driving the extremely large loads of many paralleled devices, excess power dissipation in the MOS-gated drive section of the Control IC may become an issue when switching above the few tens of kilohertz range. The subject of this Design Tip is a current buffer to alleviate this problem.

DT92-4A – Simple High Side Drive Provides Fast Switching and Continuous On-Time

P-channel power MOSFETs are typically used as high-side switches in low power applications because of simpler gate drive circuitry. As power levels, either voltage or current, increase, the advantages of P-channel devices are quickly offset by their increased on-resistance, limited voltage range, increased cost, and increased complexity of the gate drive circuitry. By switching to an N-channel device, it is possible to improve on the P-channel's disadvantages, at the expense of increased gate drive complexity. For high power levels, the IGBT is extremely well suited for use as a high side switch, yet all currently available IGBTs are N-channel devices. Presented is a circuit that, with the use of an extra IC and a few passive components, solves the N-channel gate drive circuit issue.

DT92-6 - Current Sensing with The IR2130

The IR2130 High voltage MOS gate Driver IC provides a convenient and cost effective gate drive solution for applications requiring a three phase bridge configuration. It comprises three high side and three low side referenced drive channels and has been targeted at applications that include: WM AC Motor Drives, Six Step AC Motor Drives, and UPS.

The IR2130 has features added to enhance its performance in these applications. These features include: Fault indicator output, Over current trip input, and Current signal amplifier. It is the use of this third feature, the current signal amplifier, that is the subject of this paper.

DT93-1 – Testing High Power SCRs and Diodes

This Design Tip is designed to help field service repair personnel test high power SCRs and diodes using simple, portable test set-ups. International Rectifier's SCRs and diodes are rated for very high power levels. Testing the characteristics of these devices presents some problems unless the proper equipment is available.

DT94-5A – Using MOS gated Power Transistor in AC Switch Applications

Motion Control

The IGBT and the power MOSFET are not suited to switching AC waveforms directly. By placing co-packaged IGBTs in a series configuration, the problem of violating the conductivity modulation is solved.

DT95-1A – Replacing Mechanical Relays with IR's PVT412L Microelectronic Relay in Fax/Modem Designs

Here is information on how our PVT412L microelectronic relay (MER) will save time and money while improving performance and reliability in FAX/Modem designs.

MOSFET Technical Documents

AN-936A - The Do's and Don'ts of Using MOS-Gated Transistors

In this application note, some of the most common do's and don'ts of using HEXFET® power MOSFETs are described. The objective is to help the user get the most out of these remarkable devices, while reducing “on the job” learning time to a minimum.

AN-937B - Gate Drive Characteristics and Requirements for HEXFET® power MOSFETs

The HEXFET® is fundamentally different from the bipolar transistor. It is a voltage-controlled power MOSFET device. A voltage must be applied between the gate and source terminals to produce a flow of current in the drain. The gate is isolated electrically from the source by a layer of silicon dioxide. Theoretically, therefore, no current flows into the gate when a DC voltage is applied to it - though in practice there will be an extremely small current, in the order of nanoamperes. With no voltage applied between the gate and source electrodes, the impedance between the drain and source terminals is very high, and only the leakage current flows in the drain.

AN-940B - How P-Channel HEXFETs Can Simplify Your Circuit

P-Channel HEXFET Power MOSFETs offer the designer a new option that can simplify circuitry while optimizing performance and parts count. In principle, nothing can be done with a P-Channel MOSFET that cannot be done with an N-Channel *plus some extra gate drive circuitry*. The main advantage of a P-Channel device is circuit simplification in medium and low power applications. As explained in the next section, the P-Channel MOSFET has significant higher power losses that discourage its application in higher power circuits.

AN-941 - Paralleling HEXFET® Power MOSFETs

The three most important parameters from this point of view are: voltage, current and junction temperature. Voltage unbalances will be briefly examined in a qualitative way in the next section with other general considerations. The effects of current and temperature unbalances will be analyzed in the following sections.

AN-944A - Use Gate Charge to Design the Gate Drive Circuit for Power MOSFETs and IGBTs

Gate Charge background, test methods, how to interpret the gate charge curve, how to estimate switching times, and how to compare different devices.

AN-948A - Linear Power Amplifier Using Complementary HEXFET Power MOSFETs

The class AB amplifier described in this application note uses a complementary pair of HEXFET power MOSFET devices as the output stage. This feature offers performance improvements over the equivalent bipolar output stage and allows a reduction in the complexity of the driver circuit, the output devices being driven by a single class A driver.

AN-949B - Current Rating of Power Semiconductors

The current rating of an electrical device, be that a circuit breaker or a motor or a transformer, is the current at which the temperature within the electrical device reaches a value that may impair the reliability or functionality of the device itself. The manufacturer knows the temperature limits of the materials used in the device, but he does not know the temperature of the ambient in which the device will be used. So he makes an assumption on this temperature.

AN-955 - Protecting IGBTs and MOSFETs from ESD

International Rectifier has an outstanding ESD control program in place in its HEXFET manufacturing facility. This Application Note will discuss how HEXFET users can implement and benefit from similar ESD control programs.

AN-957B - Measuring HEXFET MOSFET Characteristics

This application note describes methods for measuring HEXFET Power MOSFET characteristics, both with a curve tracer and with special-purpose test circuit.

AN-986 - ESD Testing of MOS Gated Power Transistors

This note analyzes the behavior of MOS-gated power transistors undergoing an ESD test, without discussing the fundamental premise that a capacitive discharge is a meaningful simulation of an ESD event.

AN-1001 - A More Realistic Characterization of Power MOSFET Output Capacitance Coss

This design tip focuses on explaining the power MOSFET output capacitance Coss and how it actually affects the power conversion circuit.

AN-1005 - POWER MOSFET AVALANCHE DESIGN GUIDELINES

The purpose of this note is to better understand and utilize IR HEXFET™ Power MOSFETs, it is important to explore the theory behind avalanche breakdown and to understand the design and rating of rugged MOSFETs. Several different avalanche ratings are explained and their usefulness and limitations in design is considered.

AN-1040 - System Simulation Using Power MOSFET Quasi-Dynamic Model

The purpose of this note is to examine the Quasi-Dynamic model of power MOSFET and its effects on device thermal response.

AN-1050 – DirectFET Materials and Practices Application Note

In writing this document, the aim is to provide more background information on the potential impact of four factors:

1. Underfill
2. Lead-free solder
3. Insulated metal substrates (IMS)
4. Conformal coating

AN-1059 - DirectFET™ Thermal Model and Rating Calculator

The DirectFET™ encourages the removal of heat in opposing directions away from the die, so that cooling will occur both through the substrate pad connections (source/gate) **and** through the surrounding “Can”. The “Can” then dissipates heat to the ambient through the “Can”-to ambient thermal interface, which is maximized where a heat sink is used.

AN-1084 – Power MOSFET Basics

This application note discusses the breakdown voltage, on-resistance, transconductance, threshold voltage, diode forward voltage, power dissipation, dynamic characteristics, gate charge and dV/dt capability of the power MOSFET.

IGBT Technical Documents

AN-944A - Use Gate Charge to Design the Gate Drive Circuit for Power MOSFETs and IGBTs
Gate Charge background, test methods, how to interpret the gate charge curve, how to estimate switching times, and how to compare different devices.

AN-955 - Protecting IGBTs and MOSFETs from ESD
International Rectifier has an outstanding ESD control program in place in its HEXFET manufacturing facility. This Application Note will discuss how HEXFET users can implement and benefit from similar ESD control programs.

AN-983A - IGBT Characteristics
IGBTs are minority carrier devices, and have superior conduction characteristics, while sharing many of the appealing features of power MOSFETs such as ease of drive, wide SOA, peak current capability and ruggedness. A line of IGBTs from International Rectifier has switching characteristics that are very close to those of power MOSFETs, without sacrificing the much superior conduction characteristics.

AN-990 - Application Characterization of IGBTs
This application note covers some of the major issues normally encountered in the design of an IGBT power conditioning circuit. It is the companion to INT-983, "IGBT Characteristics."

AN-1045 - AC TIG Welding: Output Inverter Design Basics
A common use of *IR Standard Speed* IGBTs is in the output inverter stage of the AC TIG₁ welding machines. IR has designed application specific modules and the aim of this document is to provide information on how using them. Considerations and guidelines to connect several devices in parallel are also provided for very high current applications.

DT99-1 - Overshoot Voltage Reduction Using IGBT Modules With Special Drivers
A critical problem common to all power switching circuits is inductive energy storage in stray inductances within the circuit. At low power levels of a few Watts a fast turn-off transition results in ringing with an overshoot voltage proportional to the stored energy and the switching speed. At high power levels these overshoots pose a major problem in terms of adequate voltage margins to handle them and the additional cost of such devices. Higher switch voltage ratings also result in higher conduction losses and lower overall efficiency. We are thus faced with a dilemma, how to maintain high efficiency with fast switching speeds without creating huge overshoots with all their attendant problems.

Diode Technical Documents

AN-968 - Selecting and Designing In the Right Schottky Rectifier

International Rectifier offers a broad line of Schottky rectifiers with a variety of packages, rated currents, voltages and rated junction temperatures. These Schottky rectifiers are intended for use in a variety of power supply applications. This application note has the following purposes:

- Provide a familiarization with the foundations of IR's Schottky product range by reviewing the different packages, die sizes, and electrical characteristics of the various Schottky processes. Show how these all come together to form an overall product matrix that serves the design needs of virtually any power supply application.
- Review and explain the Schottky data sheet.
- Review the application performance trade-offs between different Schottky types, and give *Guidelines* that steer the user to the best choice of Schottky to meet given application requirements.
- Give design procedures to determine the worst-case design operating point, estimate the losses and select the heatsink for the Schottkys, in the the most common power supply circuits.
- Review the techniques for suppressing switching voltage transients and the fundamentals of snubber design.
- Present a comprehensive "Schottky Selection Guide for Power Supplies," that shows, at a glance, the different possible Schottky choices and performance trade-offs for a wide range of different power supply requirements, for the most common power supply circuits.

AN-989 – The HEXFRED™ Ultrafast Diode in Power Switching Circuits

This application note describes the benefits of using the International Rectifier 600-volt, 15-amp, ultra-fast recovery epitaxial diode (FRED) in power switching circuits.

DT93-1 – Testing High Power SCRs and Diodes

This Design Tip is designed to help field service repair personnel test high power SCRs and diodes using simple, portable test set-ups. International Rectifier's SCRs and diodes are rated for very high power levels. Testing the characteristics of these devices presents some problems unless the proper equipment is available.

Package Technical Documents

AN-994 - Maximizing the Effectiveness of Your SMD Assemblies

Herein is described the device mounting and heat sinking used and the test methods employed to measure Thermal Resistance of the various packages. Standard printed circuit boards were developed to which devices were solder mounted for measuring z thermal resistance. FR-4 material with 2 oz. Cu was used. Board dimension were 4.75 inches by 4.5 inches and backside of board had full metal pattern. Three different PCB metallization patterns were tested: one with 1 sq inch of Cu area, the second one with Cu trace minimized so as to cover only as much area as taken up by the Device Under Test (DUT) and necessary lead mounting pads (described as “modified minimum pattern”), and the last one is the “absolute minimum” pattern with the metallized area sized only as needed to mount each lead.

This application note applies only to surface mountable type devices. Through-hole devices such as TO-220, TO-247, Full-pak, etc are excluded and not covered by this note.

AN-997 - Mounting Guidelines for the SUPER-247

This Application Note will examine the subjects involved with clip mounting the SUPER-247 to heat sinks. Topics Covered:

- A breakdown of system thermal resistance.
- The minimum force for a good thermal contact and the maximum force allowable before device
- Parameter degradation.
- Wet and dry contact conditions and the effect on thermal resistance.
- The effect on thermal resistance of using an electrical isolator between the device and the
- heatsink.
- Typical clip types, how they work and the forces that they impart.

AN-1000 - Mounting Guidelines for the SUPER-220

This Application Note is intended to outline the thermal options available to designers with regard to interface materials, clip types and the contact forces required to give good thermal contact and the performance that they might expect from each. The following topics will be covered:

- A brief revision of thermal resistance and its effects on system performance.
- Clip mounting of SUPER-220 devices to heat sinks, suppliers and interface materials

AN-1011 – Board Mounting Application Note for 0.800mm Pitch Devices

International Rectifiers Wafer Level Package (WLP) devices combine the latest die design with new packaging techniques to occupy the smallest possible footprints. International Rectifiers WLP technology now includes the FlipFET™ range of HEXFET® Power MOSFET devices (in which modified die design places source, drain and gate bumps on the front of the die), and also the 1A FlipKY range of Schottky Diode devices (where the anode and cathode are both placed on the front of the die). The 0.5A range of FlipKY product is covered in AN-1079. To simplify board mounting and improve reliability, International Rectifier manufactures WLP devices to exacting standards. These high standards have evolved through evaluating many different materials and designs. Although such evaluations have yielded good results, the recommendations in this application note may need to be adjusted to suit specific production environments.

AN-1012 - Mounting Considerations For International Rectifier's Power Semiconductor Packages

It is important that power semiconductors are correctly mounted if full functionality is to be achieved. Incorrect mounting may lead to both thermal and mechanical problems. The aim of this Application Note is to describe good practice in the mounting of power semiconductors.

AN-1027 – ADD-A-Pak Module Mounting Instructions

This application note discusses the proper mounting and exchanger surface preparation, important to optimize the heat transfer from module to heatsink and maintain the contact thermal resistance value specified on the data sheet.

AN-1028 – Recommended Design, Integration and Rework Guidelines for International Rectifier's BGA and LGA Packages

This application note discusses optimization of the layout and mounting recommendations for IR BGA and LGA devices. Topics discussed include PCB layout placement, soldering, pick and place, reflow, cleaning and reworking recommendations.

AN-1029 - Optimizing a PCB Layout for an *iPOWIR* Technology Design

The design of the printed circuit board is a simple but effective means of optimizing the performance of an *iPOWIR* □ technology solution. In general, there are a number of issues that need to be considered when designing a power supply layout. This application note describes how to optimize PCB layout for thermal and electrical properties.

AN-1031 - Lead Bending Considerations for International Rectifier's Power Semiconductor Packages

This application note is intended to address the frequently asked packagerelated question of how the legs of through-hole packaged devices may be safely bent without endangering part reliability.

AN-1035 – DirectFET Board Mounting Application Note

The growing DirectFET range now includes different can sizes and device outlines. The main text of this application note contains guidance common to all devices. Then, in Appendix A, there is information on each combination of can size and device outline currently available. For more details about individual devices, and to find out their size and outline, refer to the relevant product data sheet and package outline drawing. To simplify board mounting and improve reliability, International Rectifier manufactures DirectFET devices to exacting standards. These high standards have evolved through evaluating many different materials and designs. Although such evaluations have yielded good results, the recommendations in this application note may need to be adjusted to suit specific production environments.

AN-1050 – DirectFET Materials and Practices Application Note

In writing this document, the aim is to provide more background information on the potential impact of four factors:

1. Underfill
2. Lead-free solder
3. Insulated metal substrates (IMS)
4. Conformal coating

AN-1060 – Bare Die: Handling and Storage

The purpose of this guidance note is to look specifically at the handling and storage of Bare Die products. A few precautions in the storage, handling, die mounting and wire bonding should help to minimize product introduction time and minimize production losses.

AN-1061 - Bare Die: Die Attach and Wire Bonding Guidance for setting up assembly processes

The purpose of this guidance note is to review and discuss some of the specific features of the die attach and wire bonding processes that may be used in the assembly of bare die. Some materials characteristics and requirements are also considered.

Note: This document does not claim to cover ALL aspects of the die attach and wire bonding processes. The aim of the document is solely to provide a general overview based on experiences with the supply and use of Bare Die Products.

AN-1079 - Board Mounting 0.5A FlipKY™

The 0.5A FlipKY™ package is a Schottky diode device delivered in the form of a wafer level package (WLP). This package has both the anode and the cathode on the same side of the die. The leadless nature of WLPs can offer significant advantages with regard to PCB area and thermal performance. The 1A range of FlipKY product is covered in AN-1011. A Pb-free version of the 0.5A FlipKY is also available in view of the legislation regarding the elimination of lead from electronic products. This document is designed to help the customer prepare for, and assemble 0.5A FlipKY in an effective manner.

AN-1080 – DirectFET™ Technology Inspection Application Note

International Rectifier's DirectFET technology facilitates dual-sided cooling of surface mounted power MOSFET devices. This doubles power and current densities, which in turn reduces component count and system cost. These benefits result from the presence of solderable contacts on the surface of the silicon die for connecting the gate and source to the printed circuit board (PCB). A copper clip attached to the back of the die provides the drain connection. Devices in the DirectFET range vary but, typically, there are three electrical connections (gate, source and drain) but seven or more mechanical joints (one gate pad, one or more source pads, and four drain pads — each of the two drain rails is divided into two pads). Figures 1 and 2 show this construction.

DT99-3 - Hand-Soldering SO-8 MOSFETs

Hand-soldering SO-8 MOSFETs to a printed circuit board (PCB) may cause damage if not done properly. This application note describes how to properly hand-solder SO-8 devices to PCBs.

Thermal Technical Documents

AN-972B – Thermal and Mechanical Considerations for Full-Pak Applications

This application note describes the three methods used for providing electrical isolation for plastic molded semiconductors:

Isolated heatsink inside the grounded enclosure

- Insulating mica or plastic film mounting to grounded heatsink
- Elastomeric thermally conductive insulation material, such as Sil-Pad® manufactured by the Bergquist Company

AN-1030 - Applying *iPOWIR™* Products In Your Thermal Environment

iPOWIR technology products provide a higher level of functionality than a MOSFET or an IC, but are not a complete power supply. With *iPOWIR* products, thermal Design is a simple process, because each *iPOWIR* product is fully characterized for power loss under expected operating conditions.

AN-1033 - Calculating Temperature Gradients In Power MOSFETs with the HEXRISE™ Program

This note is intended to assist with the application of the HEXRISE™ program in practical, real-life cases. To use this Program effectively, it is important to appreciate its scope and to be able to apply it to thermal calculations for heat sinking arrangements that extend beyond the immediate boundaries of the power semiconductor itself.

AN-1057 - Heatsink Characteristics

In many electronic applications, temperature becomes an important factor when designing a system. Switching and conduction losses can heat up the silicon of the device above its maximum Junction Temperature (T_{jmax}) and cause performance failure, breakdown and worst case, fire. Therefore the temperature of the device must be calculated not to exceed the T_{jmax} . To design a good Thermal Management solution, the T_j should always be kept at the lowest operating temperature. This application note covers the maximization of thermal management and heat transfer basics.

AN-1059 - DirectFET™ Thermal Model and Rating Calculator

The DirectFET™ is fundamentally thermally different from industry-standard, encapsulated power semiconductors. The DirectFET encourages the removal of heat in opposing directions away from the die, so that cooling will occur both through the substrate pad connections (source/gate) **and** through the surrounding “Can”. The “Can” then dissipates heat to the ambient through the “Can”-to ambient thermal interface, which is maximized where a heat sink is used.

DT94-17 – Thermal Resistance Characterization for New Surface Mount Devices

This Design Tip describes how International Rectifier characterizes thermal resistance for HEXFET power MOSFETs in the new SO-8, Micro8 and Micro3 packages.

DT99-2 - Estimating T_j of SO-8 Power MOSFETs

It is a fundamental industry need to accurately measure junction temperature (T_j) of power MOSFETs in an operating circuit. This application note discusses the various methods for accurate measurement.