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APPLICATION NOTE

Application Note AN-1220

Circuit Models for IR HiRel Solid State Relays

By

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I. INTRODUCTION

It is often the case that our High Reliability customers are looking for application support when using our Solid State Relays (SSR's). Previously, a mechanical device may have been used, or perhaps our radiation hardened MOSFETs were in use and supported by discrete circuitry to drive them. In the applications where our customers would like to utilize the added benefits of our SSR hybrids, IR would like to offer selected PSPICE circuit models for those parts in order to explore the operation of the parts under various extremes of temperature, radiation, and/or linear mode operation. Previously, AN-1068 [1] offered a general method for modeling the IR SSR, but as we have added products of various types over the years and customers have asked for more information, we would like to provide some typical circuit models that customers can readily use, and also they may modify them to suit their particular analyses. As is always the case with IR High Reliability (HiRel) products, the datasheet remains the definitive performance specification unless a customer purchases these products to a source control drawing or a Defense Logistics Agency Standard Microcircuit Drawing. In this document, two SSR's are described, one being a current driven relay with minimal circuitry (for fastest operation), and the other is a voltage driven relay with circuitry added for controlled rise & fall times.

II. DEFINITION AND APPLICABILITY

HiRel SSR's are used in a variety of applications, often limited only by the creativity of our customers. Our SSR products all contain at least one rad hard MOSFET and a photovoltaic (PV) device to provide a current-driven interface to the rad hard MOSFET. As such, these functional devices are much slower than directly driven MOSFETS due to the delays of the PV and the relatively weak drive of the PV output. In applications where a mechanical relay was the existing solution, an SSR would help to provide a solid contact without bounce (and therefore less noise) and with more control over the inrush from a power source suddenly connected to load capacitors. In these applications, our customers frequently need to check inrush current waveforms for the magnitude and duration of the current, not only for their own reasons but also to check the safe operating area (SOA) of the rad hard MOSFET for parametric boundary conditions as well as for linear mode operation conditions [2]. There is no substitute for the measurement of real hardware (and IR HiRel will support customers with samples of the parts in question, if the business environment is appropriate for such a request), but there are times when circuit models are more handy in terms of the analysis of extreme operating conditions required, variations in circuit parameters, simple trade studies in circuit designs, and any variety of other reasons.

III. THE FUNCTIONAL BLOCKS OF THE SOLID STATE RELAY

Every SSR from IR has at least one rad hard MOSFET in it. These MOSFETS have been supported in customer applications for years as PSPICE models available on our web site [3]. As customers have used and modified these MOSFET models for years, they may continue to do so for the SSR family. What is unique in this SSR family of hybrid circuits, and is the perhaps the most interesting focus of attention for this document, is the photovoltaic circuit in our SSR and how it affects the SSR performance. IR has a suitable source for optical parts to meet our HiRel requirements, and this source retains the design patents for their circuitry. As such, we cannot provide a perfectly detailed model for the part, but we can provide a model of the parametric elements which are controlled by our source control drawings and supported by the SSR datasheets (and DLA SMD). These parameters relate to the drive capability of the PV with respect to the rad hard MOSFET. Thus, as long as the drive circuit provides the PV drive as specified in the datasheet (typically 10mA), the performance parameters should be met. The circuit models presented will include the timing measurement circuit setup as described in the datasheet for each part, in order to present the customer with the most ease in its use.

Figure 1 shows the typical block diagram of our SSR (each datasheet will detail the specific diagram for that same part). In the diagram, there is a photodiode function, which may contain any number of diodes required to operate that particular SSR, and the output switch which will be a MOSFET that is either driven on or off. Details of the switch block as to which connection is the drain and which is the source is described in each datasheet, in order to allow proper alignment of the body diode. The MOSFET body diode allows the circuit to either block voltage from the load or block voltage from the source, depending on the desired orientation. (MOSFETs can conduct current in either direction when commanded on.)

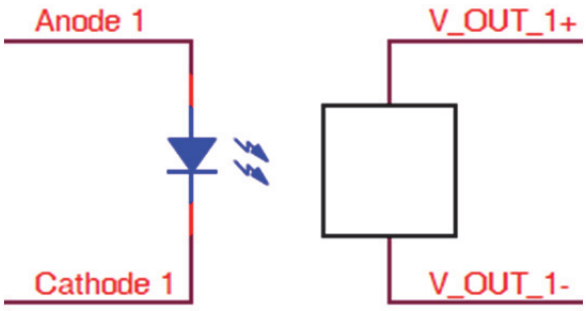


Figure 1: Typical SSR Block Diagram

Figure 2 shows more detail of the block diagram, and represents the item of interest in this document regarding the PV device. Specific examples of each SSR will reveal the final level of detail, but this diagram represents all SSR's from IR HiRel. Each specific SSR will have different devices (resistors, capacitors, etc.) on the output of the PV, and each specific SSR may have different drive circuits (direct current drive as designed by the user or logic driven inputs translated into a current drive by more resistors, MOSFETS, zeners, and an externally supplied voltage source). The various options in the SSR family are described in more detail in AN-1068 [1] and on the IR HiRel web site. This document shall simply expand on the typical circuit models for the SSR family as offered by IR HiRel for customers' use.

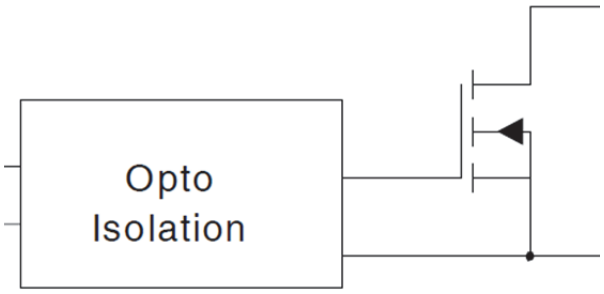


Figure 2: SSR PV device and MOSFET

IV. Specific Details of the RDHA701CD10A2NX SSR Circuit Model

This smaller, dual relay represents the minimum circuitry in our SSR family, and as what is likely the simplest circuit model, is a good place to start. As described in the part datasheet [4], this SSR is directly driven by current supplied by the user, and does not contain any additional circuit interface on the input to the PV device nor anything beyond what is standard with respect to the MOSFET drive circuitry.

Figure 3 and Figure 5 show the PV circuit models for this part. The PV LED on the input is represented by two diodes, and the particular operation of this voltage drop can be modified/modeled as per the product datasheet, which gives specifications for the various conditions of operation as specified for the SSR product itself as well as what IR controls through its source control drawing (SCD) when procuring the PV device. In order to provide customers with circuit models that represent typical extremes of circuit operation, a "strong" and a "weak" drive model were created. The PV device is affected by temperature, aging, and (to a lesser degree) radiation. These effects are combined into these two models, which can be imported into a user's simulation and used in the system circuit model to examine the effects of

- Rise time,
- Fall time,
- Turn on delay,
- Turn off delay,
- Safe operating area of the MOSFET,
- Application circuit inrush current,
- Application circuit's applied PV drive current (10mA in most cases),
- Voltage Spikes induced by parasitic inductance of application circuit,

and so on, limited only by the scope of concern of the circuit operation as defined by the user.

It is our intent to provide users with open source circuit models such as these so that if an analysis requires certain parameters to be modified for a specific analysis, the user may do so. IR HiRel has experience and proven capability with respect to worst case analyses for spacecraft power converters, but the intent here is not to do such an analysis but rather to provide our customers with as much information as we can in order that they may perform any analyses (worst case or otherwise) to support their own needs and requirements.

Figure 3 shows the schematic of the circuit model for the RDHA701CD102A2NX as created to emulate the behavior of its strongest capability to drive the internal power MOSFET. This "strong drive" means that the gain of the PV is at a maximum and the voltage output of the PV is also at a maximum. In most cases, this model will allow the user to evaluate the extremes of performance of the SSR with respect to the shortest turn-on time (maximum current from the PV to drive the MOSFET) and the longest turn-off time (maximum gate to source voltage to be discharged once the PV is no longer driving the MOSFET).

Figure 5 shows the schematic of the circuit model for the RDHA701CD102A2NX as created to emulate the behavior of its weakest capability to drive the internal power MOSFET. This "weak drive" means that the gain of the PV is at a minimum and the voltage output of the PV is also at a minimum. In most cases, this model will allow the user to evaluate the extremes of performance of the SSR with respect to the longest turn-on time (minimum current from the PV to

drive the MOSFET) and the shortest turn-off time (minimum gate to source voltage to be discharged once the PV is no longer driving the MOSFET).

Table 1 shows the relationship of how a strong or weak PV drive will affect the timing parameters of interest with an SSR. Not all IR HiRel SSR's have the same specified parameters since there are various options offered for each type (fast or controlled, current driven or buffered), but this table describes the effects for the entire set of parameters with respect to timing for all of the IR HiRel SSR's, not just the RDHA701CD10A2NX discussed in this section.

It is important to note that it is not always possible for IR HiRel to predict how our customers will use our devices, but in the event that the user's application does not actually make these aforementioned conditions a worst case for one of their parameter evaluations, this open source model allows for the user to modify the circuit conditions to make it their worst case.

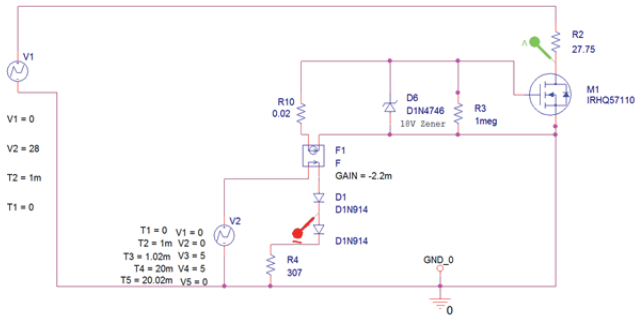


Figure 3: RDHA701CD102A2NX PV Circuit Model, Strong Drive

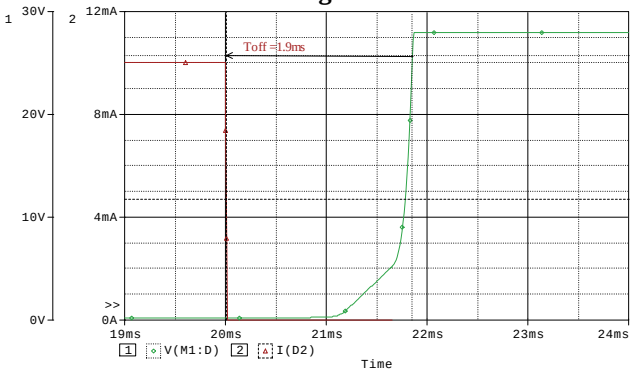


Figure 4: Simulated Turn Off Time for RDHA701CD102A2NX Strong Drive

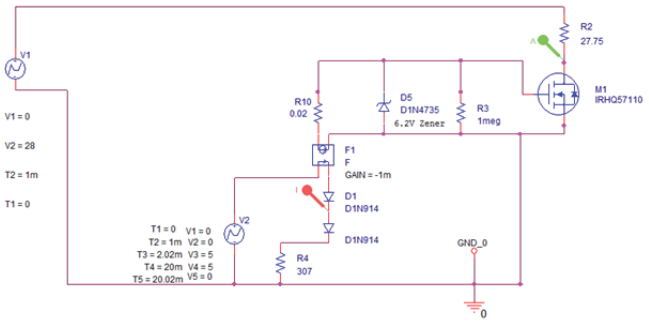


Figure 5: RDHA701CD102A2NX PV Circuit Model, Weak Drive

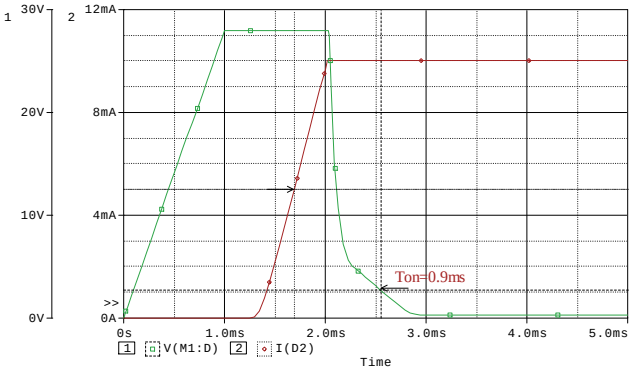


Figure 6: Simulated Turn On Time for RDHA701CD102A2NX Weak Drive

	Strong Drive	Weak Drive
t_{on}	min effect	max effect
t_{off}	max effect	min effect
t_r	min effect	max effect
t_f	max effect	min effect
$t_{on\ DELAY}$	min effect	max effect
$t_{off\ DELAY}$	max effect	min effect

Table 1: Effects of Strong and Weak PV Drive Capability

V. Specific Details of the RDHA701FP10A8QK SSR Circuit Model

This octal relay represents a more complex SSR from the product family. As described in the part datasheet [5], this SSR can be driven by a logic voltage supplied by the user, and contains additional circuitry for the voltage interface on the input to the PV device. It also has added circuitry on the output of the PV for control of the SSR timing (thereby slowing it down).

Similar to the method in the previous section, Figure 7 shows the schematic of the circuit model for the RDHA701FP10A8QK as created to emulate the behavior of its strongest capability to drive the internal power MOSFET. Figure 9 shows the schematic of the circuit model for the

RDHA701FP10A8QK as created to emulate the behavior of its weakest capability to drive the internal power MOSFET.

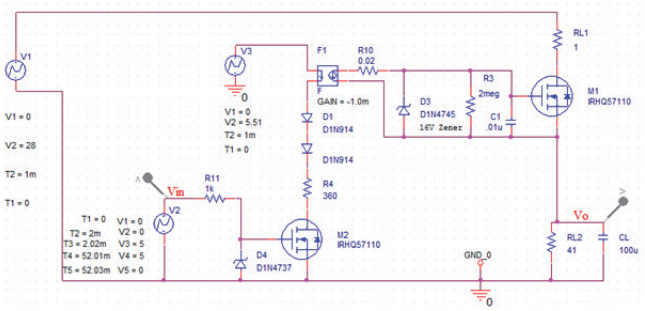


Figure 7: RDHA701FP10A8QK PV Circuit Model, Strong Drive

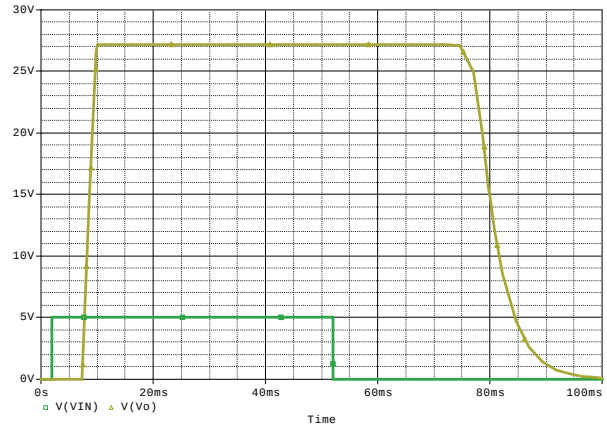


Figure 8: Simulated Turn Off Time and Delay for RDHA701FP10A8QK Strong Drive (t_f = 9.7ms, $t_{off\ DELAY}$ = 28.4ms)

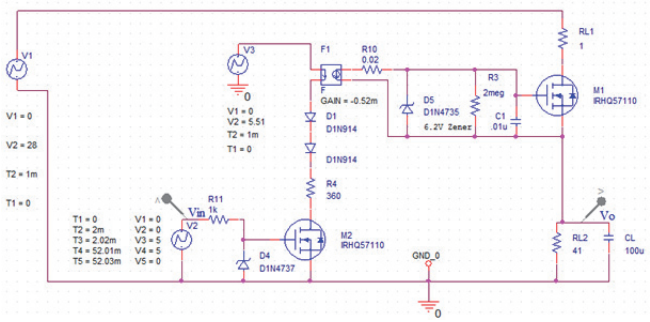


Figure 9: RDHA701FP10A8QK PV Circuit Model, Weak Drive

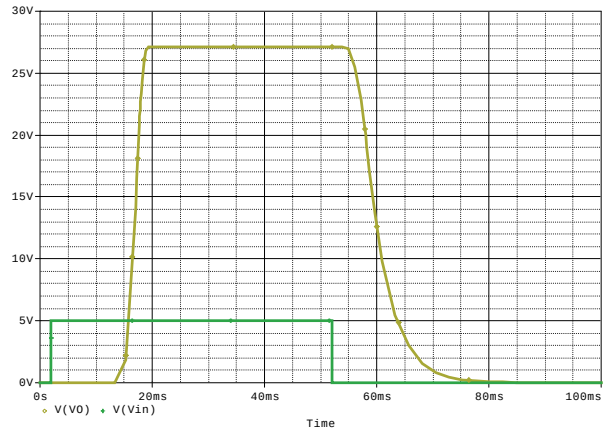


Figure 10: Simulated Turn On Time and Delay for RDHA701FP10A8QK Weak Drive (t_r = 2.8ms, $t_{on\ DELAY}$ = 7.6ms)

VI. An Application Example for the RDHA701CD10A2NX SSR

As an example of how these models can be applied towards typical applications, This section will describe the use of the dual SSR RDHA701CD10A2NX in an application circuit where it is used to dynamically load the output voltage of an IR HiRel Ultra Low Dropout Regulator, the IRUH3301.

Figure 11 shows the block diagram of the application in which an IR HiRel DC/DC converter creates 5V from a typical laptop power supply (which fortunately is within the range of the typical 28V bus), and that 5V is then used to supply the SSR with its logic drive and also to create two regulators point of Load voltages from separate ULDO's. The SSR is used to pulse the load on and off from the ULDO output voltage. A picture of the system is shown in Figure 12.

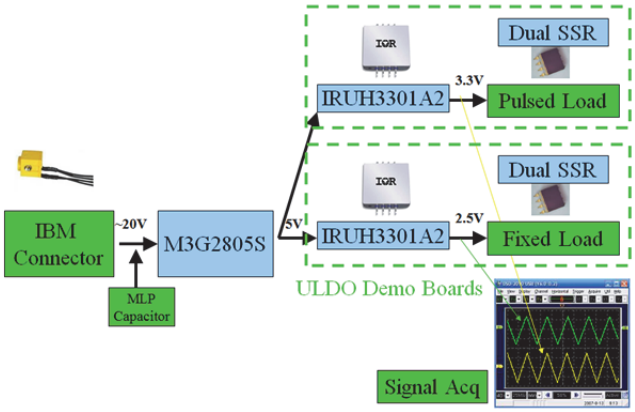


Figure 11: System Application for SSR with DC/DC Converter and Linear Regulator

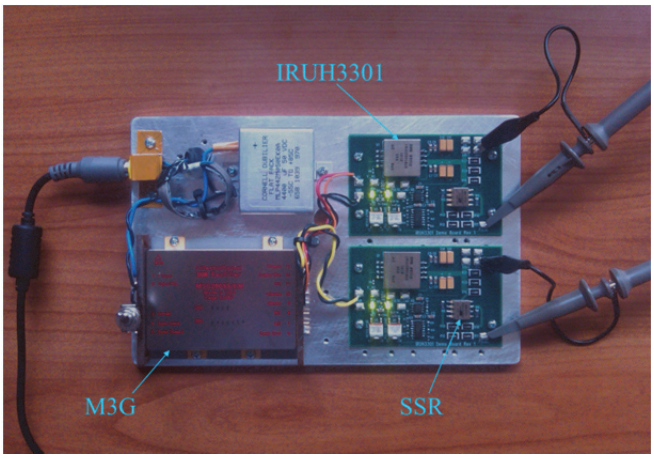


Figure 12: Picture of Application Circuit & System

The circuit diagram of the SSR with respect to its input voltage, drive, and output load is shown in Figure 13. Figure 14 shows measurements of this hardware, and then the circuit model of the SSR is shown in Figure 15 with the simulated results in Figure 16 for comparison, showing decent correlation to the measured hardware.

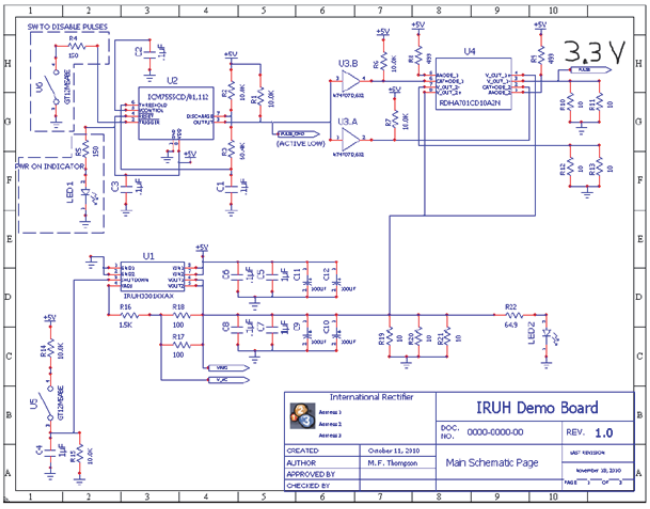


Figure 13: Schematic of Application Board with IRUH3301 Linear Regulator and SSR

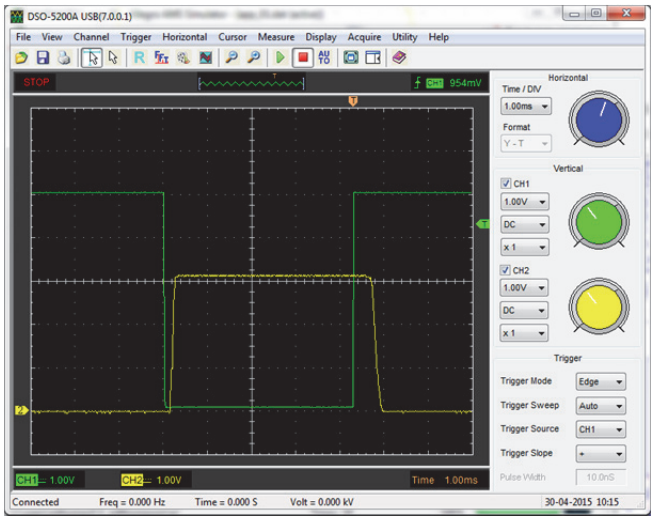


Figure 14: Measurements of Application Circuit Performance of SSR

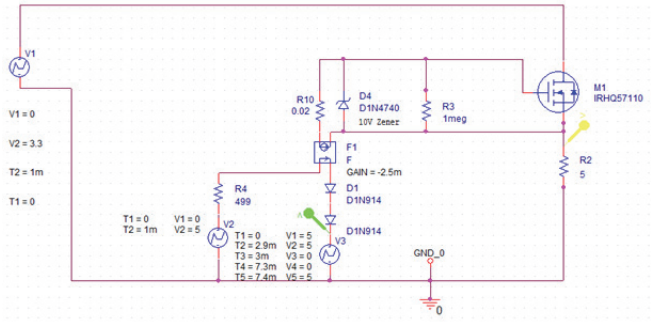


Figure 15: Circuit Model of SSR in Application Circuit

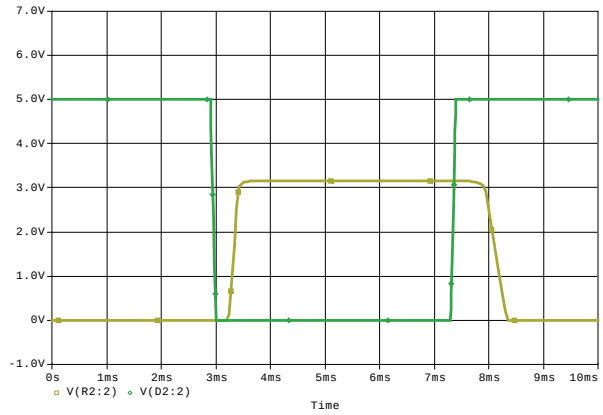


Figure 16: Simulation Results of SSR in the Application Circuit

VII. SUMMARY

This document provides a more detailed model of the IR HiRel SSR in order to facilitate the analyses of our customers with respect to typical circuit application, checking safe operating area, and as a tool for worst case analysis (whose

parameters can only be determined by our customers). It is IR's intention to provide as much support as is possible for our customers' applications, and sometimes that includes performing worst case analyses for our customers for our more complex hybrids (which can be quoted for price and lead time with quantities of flight parts as required by our Sales department). The main goal, which we shall leave to the customer to evaluate, is to provide a circuit model which can be modified for application conditions, and yet provides more detail than was previously provided. The models described in this document can be found on the IR HiRel web site [6].

REFERENCES

[1] Alan Tasker, "Considerations for Designs Using Radiation-Hardened Solid State Relays", International Rectifier Application Note AN-1068 Rev A, http://www.irf.com/technical-info/appnotes/an-1068.pdf, February 4, 2005

[2] Michael F. Thompson, "Linear Mode Operation of Radiation Hardened MOSFETS", International Rectifier Application Note AN-1155, http://www.irf.com/technical-info/appnotes/an-1155.pdf, October 14, 2009

[3] IR HiRel Web Site Circuit Model Library, http://www.irf.com/models

[4] IR HiRel Web Site, RDHA701CD10A2NX part detail page, http://www.irf.com/part/_/A~RDHA701CD10A2NX

[5] IR HiRel Web Site, RDHA701FP10A8QK part detail page, http://www.irf.com/part/_/A~RDHA701FP10A8QK

[6] http://www.irf.com/models/sim

Michael F. Thompson (IEEE M'05–SM'07) became a Member (M) of IEEE in 2005, and a Senior Member (SM) in 2007. Born in Pittsburgh, PA in 1972, the author received a Bachelor of Science degree from the University of Pennsylvania in Philadelphia, PA, USA in 1994, and a Master of Science degree (with a specialty in power electronics and controls) from the State University of New York in 1998.

He has worked for Lockheed Martin and Northrop Grumman. His design experience covers AC-DC, DC-AC, DC-DC power conversion at power levels that range from milliwatts to megawatts. He is familiar with the construction and characteristics of energy storage devices and the complexities of digital controls for power systems. Low noise output ripple designs and distributed power systems are of interest to him. He is presently working for International Rectifier HiRel as a Principal Engineer in applications for the Eastern United States and is based out of his office in Maryland.