Modeling Low Magnetic Moment PIN diodes for MR Scanner Applications

R. Caverly[1], W. E. Doherty[2], and R. Watkins[3]

[1]Villanova University, Villanova, PA, United States, [2]Microsemi-Lowell, United States, [3]Department of Radiology, Stanford University, United States

ABSTRACT: Ultra Low Magnetic Moment (ULM) PIN diodes cause the smallest possible magnetic artifacts in high field MR Imaging. Designers of MR scanners often use CAD packages to simulate their designs but there are no models available in these CAD packages to simulate these important devices until now. A new model for PIN diodes used in MR scanners is presented and is applicable for devices used in higher field 7T, 9.4T and 11.7T scanners as well as both transmit control in high RF power MR scanners and passive blocking and detune functions. The model has been shown to accurately predict the operation of ULM diodes in these applications and is fully compatible with industry-standard simulators such as SPICE as well as it variants. The ULM PIN diode model is robust and can be integrated into system-level descriptions so that accurate simulations at all levels of the MR scanner system can be performed by developers of these systems.

MATERIALS & METHODS: The glass-encapsulated SOGO passivated [*1*] ULM PIN diodes exhibit low lead inductance and contact resistance, with metallurgical bonds used to attach the silicon chip to the pins on the cathode and anode sides of the chip. Other materials used exhibit extremely low magnetic properties as described in [2]. The SPICE-based model is unique in that it originates from the underlying physics governing the switching behavior rather than ad-hoc models. The model consists of two major parts; one part utilizes the standard PN junction SPICE model while the other is derived from the basic semiconductor transport equations (Figure 1) [3]. This foundation provides a framework that allows modeling of both static and dynamic switching characteristics and is valid for DC characterization as well. The model accurately characterizes the current-dependent carrier lifetime and the associated resistance flattening at higher DC currents.

The PIN diodes modeled in this work varied from high voltage, wide I-region devices for high power transmit control in MR scanners to narrow I-region devices suitable for RF blocking and for shunt resonant circuit detuning on the receive side. High power devices modeled include the UM5600, 7100, 7200 and 7300 series of high power devices (I-region widths greater than 2 Mil) and the UMX9989AP, a single (for ease of assembly in MR coils) anti-parallel pair of fast switching rectifier diodes with narrow I-regions (approximately 6 microns). These diodes are designed to turn on during the leading side lobe of the (SINC X) envelope for both 90^{O} flip angle pulse and the 180^{O} phase reversal pulse. The UMX9989AP is also used to protect surface coil receive modules from high power RF transmit pulses.

Figure 2 shows the results of the SPICE-based modeling on these four ULM PIN diodes. In the figure, the curves show the SPICE modeling results while the squares show measured data associated with the specified diode. The devices show the classic $1/I_{DC}$ behavior and the flattening of the resistance characteristic for currents higher than 10 mA. Figure 3 shows simulations of resistance as a function of DC current and frequency using the same SPICE-based model for a single UM9989 PIN protection diode. Included in the figure are the associated 1H Larmor frequencies for 1T to 11.7T. The modeling results show that even for modest diode DC biases of 10mA, the resistance is a function of frequency. This phenomenon is a direct result of the low carrier lifetime in these devices, a necessary requirement for rapid switching speed for receiver protection or tank circuit detuning.

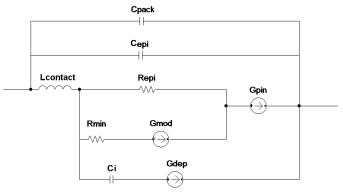

Figure 1. RF equivalent circuit of the ULM PIN diode [4].

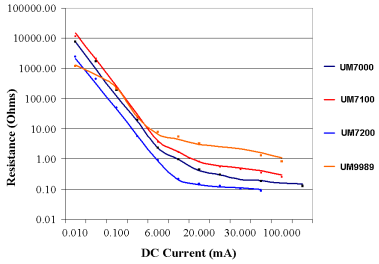

Figure 2. Curves show SPICE model results with associated measured data (zero applied magnetic field) on studied diodes.

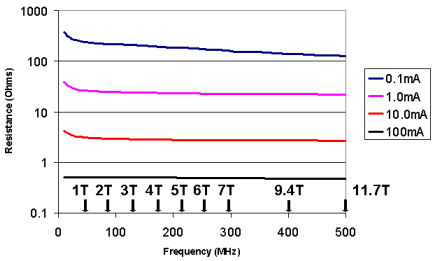

Figure 3. UM9989 resistance as a function of current and frequency.

RESULTS & DISCUSSION: A SPICE-based model is shown that accurately models both current and frequency behavior of ULM PIN diodes for MR scanners. High power thick I-region UM7XXX series diodes are shown to exhibit extremely low resistance values at high currents, providing low insertion loss at the high RF powers in transmitting, active detune and block switching applications. Thinner I-region UM9989 series diodes, used in higher field (B_o) scanners for passive coil detune and blocking functions in surface coils (i.e., diodes turned on by the applied RF signal), shows variable resistance at lower operating frequencies. The results show that RF coils may not be sufficiently detuned unless the bias current is set to a high value. The full SPICE models for the devices discussed here are detailed in "SPICE Modeling of Microsemi High Power PIN and Ultra Low Magnetic Moment Fast Diodes - Final Report" [4] which can be obtained by contacting the authors.

REFERENCES:

[1] "PIN Diodes with Low Magnetic Moment for Surface Coils in High Field MRI", R. Watkins and W. E. Doherty Jr., *ISMRM*, 2008.

[2] "PIN Diodes with Low Magnetic Moment for Surface Coils in High Field MRI", R. Goldfarb, PhD, NIST, Boulder, CO, P. Voskoboynik, W. E. Doherty, Jr, R. D. Joos, Microsemi Corporation, *Med Phys* 33 (12), December, 2006.

[3] "SPICE Modeling of Microwave and RF Control Devices", R. Caverly, N.V. Drozdovski, L.M. Drozdovskaia, and M. Quinn, *IEEE Proc. 43rd Midwest Symposium on Circuit and Systems*, 2000.

[4] "SPICE Modeling of Microsemi High Power PIN and Ultra Low Magnetic Moment Fast Diodes - Final Report", Microsemi Corp., 2008.