Dynamic Modeling of Low Magnetic Moment PIN Diodes for MR Scanner Applications

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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 up until now, there have been no models available that show the behavior of the PIN diode in its ON and OFF state as well as in the switching transition between states. A new model for PIN diodes used in MR scanners is presented and is applied to a 1.5T coil. Both fast rectifier and higher power PIN diodes are simulated. The model shows 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: Glass-encapsulated SOGO passivated [1] ULM PIN diodes exhibit low lead inductance and contact resistance, low magnetic moment, and metallurgical bonds 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]. These devices have been extensively modeled using a novel SPICE-based based on the underlying physics governing the switching behavior. The model consists of three major parts; one part utilizes the standard PN junction SPICE model; the second describing the forward bias behavior is derived from the basic semiconductor transport equations [3]; and the third part models the voltage-dependent capacitance and conductance is the reverse bias state [4]. This foundation provides a framework for modeling both static and dynamic switching characteristics. The model accurately characterizes the level of blocking/detuning in MR imaging coils as well as their dynamic turn-on and turn-off characteristics. 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 UM7200 series of higher 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 1 shows the circuit schematic of the simulated MRI coil based on Roemer et al's coil model [5]. In the figure, the PIN diode under simulation and a DC driver circuit have replaced the fixed resistance often used in MR simulations. Figure 2 shows results of SPICE-based modeling using the UM9989 (fast rectifier) and UM7200 (higher power) series devices on the MR coil shown in Figure 1 for a 1.5T MR scanner. In the figure, the curves show the level of coil blocking/detuning exhibited by the PIN diodes as functions of the applied DC bias current. Note that the UM7200 provides greater than 40dB of blocking at 100mA than the 35dB of blocking for the UM9989 at the same bias level. Greater levels of blocking are provided by the UM7200 at higher current levels, with up to 47dB of blocking at 5A. Figure 3 shows dynamic simulations of the ON-OFF switching transient and the impact on the 64MHz RF signal for the MR coil circuit shown in Figure 1 using the UM7200 PIN diode. The model shows an approximate 10us ON-OFF delay and a 24us OFF-ON delay for the circuit simulated. These time delays are functions of the DC driver circuit.

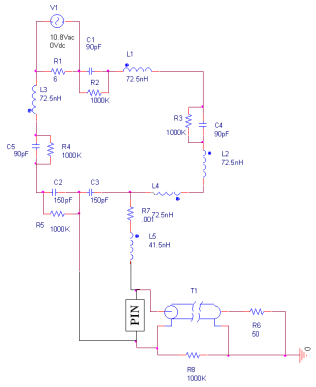
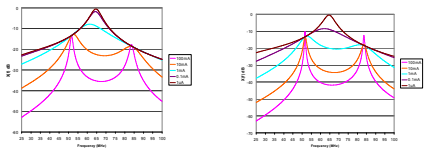


Figure 1. RF equivalent circuit of a coil circuit with ULM PIN diode for use in a 1.5T scanner [5].



UM9989 UM7200

Figure 2. Curves show SPICE model results of the blocking/detuning of the coil shown in Figure 1 as a function of DC bias current using the UM9989 and UM7200 PIN diodes. The better blocking/detuning exhibited by the UM7200 is evident at 64MHz in a 1.5T MR scanner.

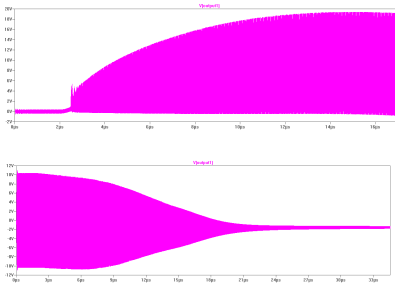


Figure 3. RF switching transient simulations showing the ON-OFF and OFF-ON delay for blocking/detuning using the UM7200 in 1.5T systems.

RESULTS & DISCUSSION: A SPICE-based model is shown that accurately models ON, OFF and transient state behavior of ULM PIN diodes for MR scanners. Higher power thick I-region UM7200 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 as well as robust blocking/detuning functions.. 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 less blocking capability but higher speeds. 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" [6] which can be obtained by contacting the authors.

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