High Power, High Speed Control Device Models for MRI Applications

Robert H. Caverly, ECE Department, Villanova University, Villanova, PA 19085 USA

Introduction: Solid-state control elements are used throughout magnetic resonance imaging (MRI) scanners, being found in high power/high speed transmit-receive (TR) switches in single coil and coil arrays for parallel imaging as well as in receive coils for Q-spoiling as a method of patient and equipment protection.

Materials and Methods: PIN diodes are the traditional device for high power RF control in MRI scanners for both TR and receive coils [1-3], with FETs, recently GaN devices [4], making some inroads in some specialized applications. Accurate device models are important for the designer of these TR switches and coils so that various design approaches can be studied, with an optimal solution thoroughly investigated before prototypes are fabricated. Of special importance in device modeling is the temperature rise in the device during the high power slice-select pulse (SSP). Since the SSP can be of varying width and repetition rate (TR), determining the overall thermal rise, and subsequent inter-pulse cooling, can show if the control device is approaching burnout temperatures. Common junction temperatures of 150 to 175 ^{o}C are often cited as the upper limit to ensure device survivability. Malfunctioning devices such as PIN diodes due to thermal burnout can lead to burnout of sensitive LNAs as part of the TR switch chain, or to Q-spoiling failures that can jeopardize the patient by increasing the risk of burns. All of these also contribute to scanner downtime and potential increased costs. In this work, we focus on modeling the transient thermal (and linear) behavior of MRI transmit/receive circuits using SPICE-based simulators. Development work continues on an accurate PIN diode thermal and RF model (Fig. 1) where the thermal impact of the I-region (modeled as G_{mod}) and the PN junctions (modeled as G_{PN}) have been discussed [1-3] but are now applied to other circuits

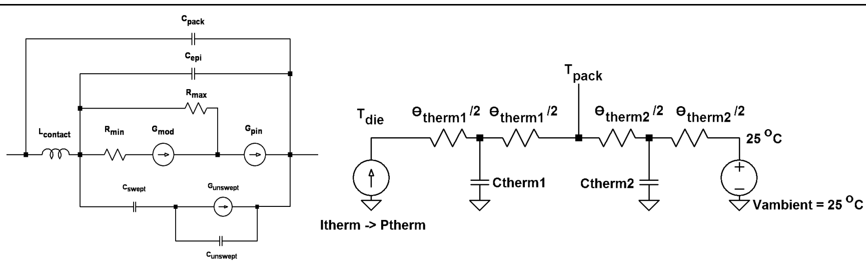

Figure 1. Electrothermal model based on a previous PIN diode isothermal model [3]; junction and I-region thermal behavior controlled using a two-pole Cauer thermal model [3]

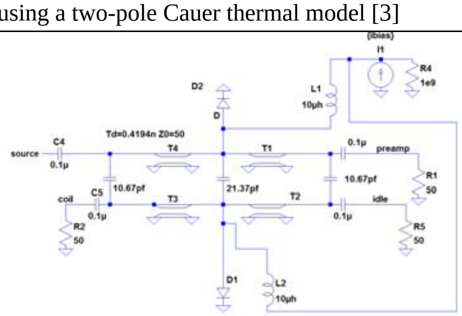

Figure 2a. SPICE schematic of linear balanced duplexer-based TR switch (^{1}H @ 7T)

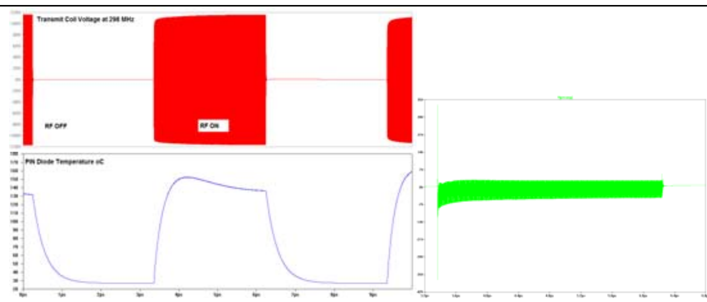

Figure 2b. SPICE simulated PIN diode receiver protection circuit response time/insertion loss and temperature rise and decay (blue) of the die and package in response to an applied SSP (red). The inset (green) shows preamp leakage for a 52 dBm applied pulse.

Discussion: This talk will focus on linear, nonlinear and thermal device modeling of PIN diodes in MRI applications. The detailed SPICE-compatible model will be presented, with several MRI applications (including the TR switch – Fig. 2) presented to show the utility of the model and its support for TR switch and Q-spoiling design.

References

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