Evaluation of a modified passive clamp decoupling network at high frequencies

Chathura Kumaragamage[1,2] and Jamie Near[2,3]

[1]*Biomedical Engineering, McGill University, Montreal, Quebec, Canada,* [2]*The Douglas Brain Imaging Centre, Montreal, Quebec, Canada,* [3]*McGill University, Montreal, Quebec, Canada*

Target Audience. This abstract is intended for high-field (>7T) RF coil designers.

Purpose. Passive decoupling is typically used as a secondary mode of protecting the preamplifier, in the event active decoupling fails [2]. A passive decoupling network commonly consists of: two fast protection cross diodes on the coil loop to detune the circuit [1], or two cross diodes in shunt on the transmission line (Tx-line) to clamp the signal flow in the event of large coupling [3] (see Figure 1). However, non-ideal characteristics of diodes degrade performance at high frequencies (>300MHz). A high-frequency equivalent circuit model of a cross diode pair in the 'off' state can be represented [4] (Figure 2) by C_d, $1/R_d$, R_s, L_d the diodes capacitance, conductance, series resistance and inductance respectively. The diode capacitance C_d in the 'off' state leads to impedance mismatching (at Node A of Figure 1) at high frequencies, thus degrading the transmission coefficient (S_{21}), which can be improved by including a parallel tank (inductor capacitor) network, as shown in Figure 3(b) [5]. However, high frequency performance analysis of this modified cross diode topology is lacking in the literature, which we investigated in this work.

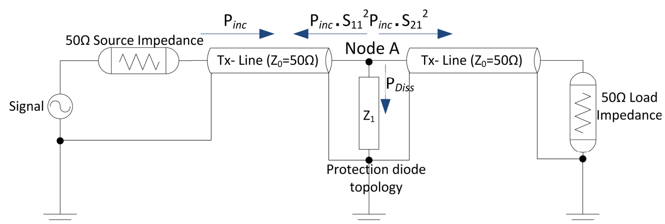

Figure 1. The diode topology placed in between a 50Ω Tx-lines, to the left is a signal source (RF coil) with 50Ω source, and to the right is the 50Ω load (the preamplifier).

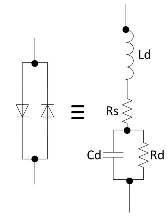

Figure 2. High frequency circuit model for a cross diode pair in the 'off'

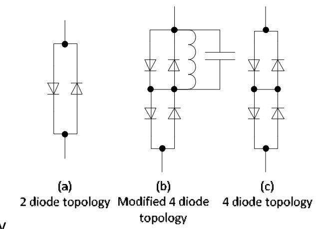

Figure 3. The three cross diode topologies to be investigated

Methods. The 'Off' state performance of three cross diode (UM9989) topologies was investigated (Figure 3): a) Commonly used two cross diode clamping b) A four diode clamping topology with a tuned tank circuit. The basis for using a tank circuit is to achieve a purely resistive load (>2kΩ) at resonance, to minimize impedance mismatches at Node A. Our intention was to evaluate a 2 diode setup with a parallel tank circuit [5]; which leads to a short circuit condition at DC. Therefore the proposed 4 diode topology was investigated. 3) A 4 cross diode clamping topology was also included to be compared against the modified 4 diode topology. These three topologies were evaluated, by complex impedance measurements obtained (in the form $Z_1 = Z \cdot e^{-j\theta_z}$ from 100-600MHz) with the S-parameter reflection method on an Agilent vector network analyzer (E5061B) with built-in impedance test kit. The impedance measurements were then used to calculate S-parameters [6] of the diode network modelled as a lossy 2-port network, when placed in between a Tx-line as illustrated in Figure 1 (P_{Diss} is power dissipated in the protection circuit). To retain the diodes in the off state during measurements, the RF power was set at 5.61mV (-32dBm), and was averaged 64 times to reduce noise. To improve measurement accuracy >300MHz: 1) A 50Ω RF resistor (FC0603E50R0BTBST1) was used for broadband load calibration. 2) A phase correction factor was computed offline by comparing phase measurements of a high-Q 1pF (ATC 100B series) capacitor with expected phase values calculated from equivalent series resistance (ESR) values extrapolated from the datasheet.

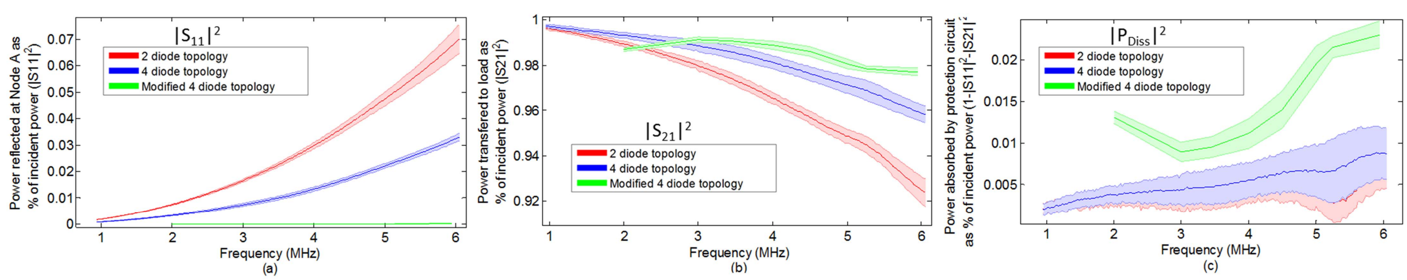

Figure 1. Reflection coefficient (S_{11}), Transmission coefficient (S_{21}), and Power dissipation in the protection load (P_{Diss}) vs Frequency for the protection circuits

Results. Results (based on five averages) in Figure 4a shows increased S_{11} at higher frequencies for the 2 and 4 cross diode topologies, but minimally affected the modified 4 diode topology. This results in increased signal transmission (S_{21}) for the modified 4 cross diode topology compared to the two regular cross diode topologies investigated. However, P_{Diss} data (Figure 4c) shows the modified 4 diode topology to be more 'lossy', even though it produced the highest S_{21}. Based on 201 impedance measurements throughout the frequency range investigated, the 2 cross diode model was approximated with the following values (L_d=0.9nH, R_s=0.6Ω, C_d=2.7pF, $1/R_p$=60µS, with a mean square error of 0.02% relative to the measurement).

Discussion. Signal losses due to parallel cross diode circuitry can be minimized by the tuned cross diode setup. The integrity of solder joints was identified to be crucial to achieving high Q characteristics, to minimizing S_{11}. The overall Q of the tank circuit improved when the diode capacitance was utilized in the tank without an additional parallel capacitor. At 200MHz, S_{21} of the modified 4 diode topology does not show an improvement, which can be attributed to the large required inductance, thus increasing inductor resistance, and reducing the Q factor. The S-parameters of the modified diode topology were acquired at 7 discrete steps since a different inductor is needed for each frequency measurement. The circuit model derived for the diode is in agreement with datasheet electrical parameters. These results indicate that the modified cross diode topology provides an efficient solution for passive decoupling at high-frequencies. The next step involves simulating a realistic surface coil (with resistances due to inductor material used) with the cross diode detuning circuit in the middle of the loop, and evaluating coil Q-factor with and without decoupling employed on the coil loop, thus providing a convenient and safe alternative to passive decoupling networks mounted on the receiver coil element.

Conclusion. Utilization of the modified 4 diode topology as a clamping passive decoupling network outside the coil environment, is beneficial for >300MHz MR applications to compensate for non-idealities of switching diodes.

References. [1] Mispelter J, et al. NMR Probeheads [Text], 2006 [2] Barberi E, et al, Magn Reson Med 2000; 43: 284-289 [3] Hoult D, Prog NMR Spectr 1978; 12; 41-47 [4] Natarajan S, Microelectronics analysis and design pp100-102 [Text] 2006, [5] Vaughan T, RF coils for MRI [Text] 2012. [6], Gustrau F, RF and Microwave Engineering [Text], 2012.