Improved method and technique for monitoring SAR in transmit coils and arrays

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Target Audience: SAR and Safety Issues, Coil Designers

Purpose: With the advent of multi-channel transmitters, ultra-high field imaging and unique power-intensive techniques like Transmit SENSE, the need for real time power monitoring is becoming a more important need. Furthermore, recent studies have shown that current methods, namely just monitoring the forward and reflected power at the output of the amplifier is insufficient as coupling and mismatched or "broken" coils can change electric field and possibly SAR in multichannel transmit arrays[1-3]. Here we are proposing a three point method, monitoring the (1) forward, (2) reflected on the coax as well as, monitoring the (3) field at the coil. By monitoring the field at the coil, it is possible to account for coil coupling and mismatched or "broken" coils.

Methods: Figure 1 shows the basic set up for the SAR Monitor for a single coil. A narrow band, lumped element directional coupler was designed and built to couple a small amount of the forward and reflected power to the coil. These power levels are further attenuated using a pi-resistor network and then sampled and digitized using an LTC5587 power detector IC (Linear Technologies, Milpitas, CA) that's matched to a 50 ohm line using an L-matching network.

The forward and reflected power levels are communicated to a microcontroller, chipKIT Max 32 (Digilent Inc, Pullman WA) via a 3 wire interface. If the input power is greater than the allowable limits, there is significant reflection, or if the input powers are not equal in a multi-transmit array the microcontroller opens a λ/4 switch in the transmit line.

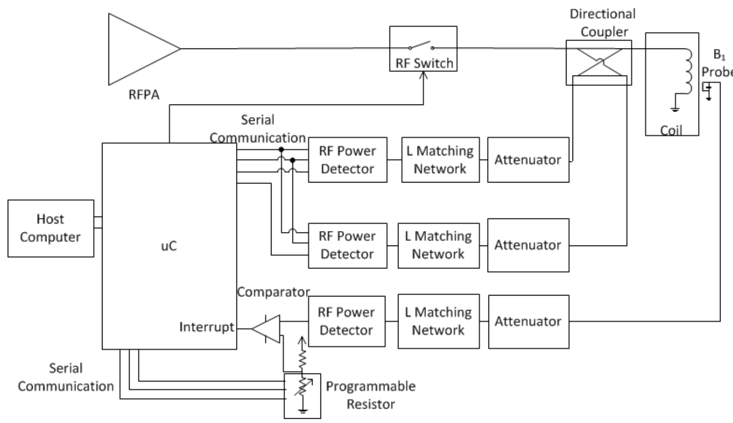

Figure 1: Block diagram of the SAR Monitoring System

The B_1 probe in figure 1 is a small tuned resonator near the coil head. A small amount of the energy is coupled to the B_1 probe and sampled and digitized also by an LTC5587 power detector IC (Linear Technologies, Milpitas, CA). However, unlike the forward and reflected power measurements, the pulse envelop is outputted to a high speed comparator; the SAR threshold limit is set via the programmable potentiometer; this can be set by the user at the beginning of the scan. The output of the comparator is tied to an external interrupt pin on the microcontroller and is continuously monitored. If the field generated by the coil is greater than the user defined limit, the microcontroller will open the λ/4 switch in the transmit line.

The λ/4 switch latches until the user resets it.

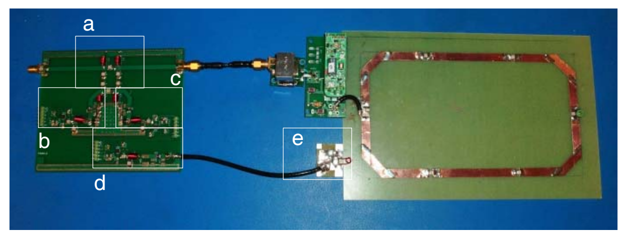

Figure 2: Prototype board containing: (a) directional coupler, (b) reflected power detector, (c) forward power detector, (d) probe power detector, (e) B_1 probe next to a loop coil. Not shown are the RF switch and microcontroller.

Results and Discussion: Figure 2 shows the SAR monitoring system for a single coil. The directional coupler is a -33dB coupler, with 0.15dB insertion loss and >25dB of isolation between the input and isolated channels.

The RF power detector IC was specifically chosen because it has 40 dB of dynamic range and its fast sampling rate (up to 500ksps), allowing for real time SAR and power monitoring. Furthermore, its 12-bit ADC resolution provides greater than 0.002dB/bit resolution; its SPI serial digital output is directly proportional the RF signal power, which allows for easy comparison between the forward and reflected power, as well as, between multiple coils in an array.

The B_1 probe is a parallel resonator tuned to the Larmor frequency at 3T (123MHz) and matched to a 50 Ω coax. In this configuration it is placed approximately 15mm above the coil which allows approximately -15dB of coupling between the coil and B_1 probe. Currently the user has to set the allowable SAR level at the beginning of the scan; however this can be automated if the patient position or location is known.

Conclusions: Here we have shown an improved method for power and SAR monitoring over the current techniques by additionally monitoring the field generated at the coil. This can provide additional information about efficiency of an individual coil or coupling between coils in an array, allowing for more accurate SAR measurement. While we have only shown it for a single coil, it is modular and can easily be built up for an array.

References: [1] Vernickel P, Leussler C, Wirtz D. et al. Proceedings of the 21st Annual meeting of ISMRM 2013; 2825. [2] Seifert F, Ittermann B. Proceedings of the 21st Annual meeting of ISMRM 2013; 2827. Hochman A, Villena JF, Silveira LM, et al. Proceedings of the 21st Annual meeting of ISMRM 2013; 2831