High-Field Actively Detuneable Transverse Electromagnetic (TEM) Coil with Low Bias Voltage for High Power RF Transmission

N. I. Avdievich[1], K. Bradshaw[2], A. M. Kuznetsov[1], and H. P. Hetherington[1]

[1]Radiology, Albert Einstein College of Medicine, Bronx, NY, United States, [2]MR Instruments Inc., Minneapolis, MN, United States

Introduction: Conventional schemes for active detuning of head sized volume coils require high negative bias voltages (>300V) to prevent distortion of RF pulses at power levels of 1-2 kW (1,2,3). Distortion of the RF pulses results in poor slice profiles and localization artifacts in slice selective imaging methods. To extend the power handling capacity and avoid using high DC bias voltages we developed an alternative method of detuning the volume coil. In this method the PIN diodes in the detuning circuits are shorted when the RF volume coil is tuned and negatively biased with -12 V when the coil is detuned. To preserve the high Q_U/Q_L ratio of the TEM coil we modified the method of Nabetani (4) by utilizing a high impedance (~200 Ω) lump-element λ/4 transformer.

Methods: An actively detuneable quadrature 16-element 4 T (170 MHz) TEM head coil was built as previously described (3). The RF coil had a cavity id of 38 cm, a 23.8 cm length with elements positioned at a diameter of 31.8 cm. The coil was driven in quadrature using two-port drive (1,3). To provide high impedance of the detuning circuits and, thus, to preserve high Q_U of the TEM coil a 200 Ω lumped-element λ/4 transformer replaces a 50 Ω coaxial cable transformer (4) (Fig 1). The detuning circuits are connected in parallel to each resonant element of the TEM. When the PIN diode is shorted the impedance of the trap Z_{trap} is given by $Z_{trap}=Z_0^2/R_{PIN}$, where Z_0 is a characteristic impedance of the transformer. With the resistance of the shorted PIN diode (R_{PIN}) equal to 0.5 Ω (at ~100 mA of current) and Z_0 = 200 Ω we obtain Z_{trap} = 80 kΩ. For comparison, Z_{trap} is only 5 kΩ when a 50 Ω transmission line transformer (4) is used. When the PIN diode is negatively biased, the detuning circuit provides an inductive load, forming a high impedance trap together with the capacitor of the TEM element. The final detuning circuit, which was further simplified, is shown in Fig. 1C. Values L_1 and L_2 were adjusted to provide the required inductive impedance when the PIN diode is negatively biased and highest resistive impedance when the PIN diode is shorted. The PIN diode driver provided a -12 V negative bias and a current of ~100 mA per diode.

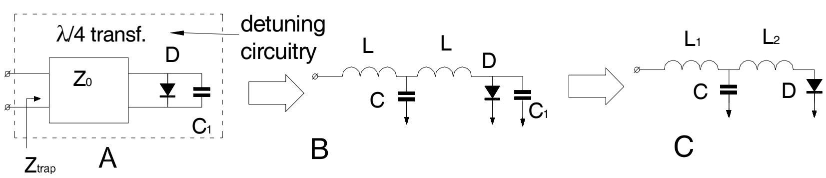

Figure 1 Schematic of the detuning circuit.

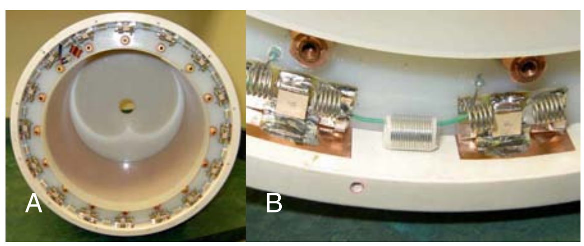

Figure 2 A) Picture of the actively detuneable head TEM coil with its front open to see the layout of detuning boards. B) Detailed picture of the detuning circuits.

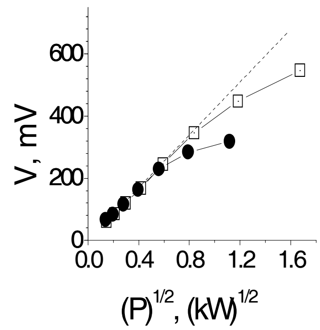

Figure 3 Dependence of the TEM coil performance ("old design" with high voltage bias) on the transmit RF power.

Results and Discussion: First, we tested the high negative bias voltage (–300 V) scheme described by Vaughan (1) to quantify the maximum RF power level achievable without RF amplitude distortion. Figure 3 shows the dependence of the voltage generated in a pickup coil positioned inside the loaded TEM resonator with the PIN diodes placed near the back wall (●) as in (1) or near the coil entrance (□), where capacitance of the elements was increased to decrease the dielectric losses (3). With the diodes positioned at the front of the coil, the output was linear with the square root of applied power up to ~1.5 kW after which it was significantly distorted. With the new detuning circuits in place the voltage generated by the pickup coil was linear up to 4kW (max. power of the RF amplifier). In the current design the power handling capacity is only limited by power rating of the intrinsic coil components. Thus, the detuning network described should support transmit powers of at least 10 kW. No increase (<±1 dB in power for a 90° RF pulse was measured when the coil was loaded with either a phantom (2.0 L sphere, 50 mM NaCl) or a head in comparison to the high bias voltage detuneable TEM coil. The ratio of Q_U/Q_L of the coil, loaded with a human head, was ~500/70, which provided a minimal decrease in SNR of ~5%. In contrast, use of a 50 Ω transformer as described by Nabetani et al (4) results in a Z_{trap} of 5 kΩ and Q_U of the TEM element of about 150, resulting in an SNR decrease of ~20%.

Conclusion: A new type of active PIN diode detuning network enabled a substantial increase in the power handling capacity for a head-sized TEM volume coil using a bias voltage of only -12V. By utilizing a high impedance (~200 Ω) lump-element λ/4 transformer the high Q_U/Q_L ratio of the TEM coil was preserved, thus, maintaining the transmit and receive efficiency of the coil. Incorporation of the detuning network did not substantially reduce (<1dB) the coil performance as compared to a detuneable TEM using the high bias voltage detuning network described by Vaughan (1).

References: 1) Vaughan JT et al, MRM 2002;47:990-1000. 2) Barberi EA et al, MRM 2000;43:284-289. 3) Avdievich NI et al, MRM 2004;52:1459-1464. 4) Nabetani A et al, Proc ISMRM 11, 2003, p 1574.