An Integrated Multi-Channel RF Transmitter for Continuous Arterial Spin Labeling with Multiple Label Coils

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Introduction: Arterial spin labeling (ASL) permits the quantification of cerebral blood flow and perfusion. Continuous ASL (CASL) using separate RF coils for labeling and imaging are not limited by magnetization transfer (MT) effects and allow for easy territorial mapping of the supplying arteries if small labeling coils are placed directly over the respective arteries. Reports in literature so far only describe territorial mapping with single coils [1] or simultaneously switched multi-coil setups [2]. Here we present a setup for an independent multi-channel RF transmit array that is interfaced with a standard clinical scanner so that the RF switching is completely controlled by the scanner hardware, allowing for independent switching of multiple transmit coils.

Methods: CASL requires the use of independent labeling and imaging coils if MT effects are be avoided. In our setup the labeling coils are triggers by three independent external triggers (Osc0, Osc1, ExtTrig) supplied by the sequence program. Two signals are electrical TTL signal (Osc0, Osc1), the third signal is optical (ExtTrig). The electrical signals are transformed to optical signals inside the hardware cabinet of the scanner to minimize RF noise. The length of the scanner signals indicate the duration of the labeling pulses. On the control board the optical signals are converted to TTL signals to the switch box and Quarter wave unit. The switch box consists of a pair of pin diode switches to gate the RF signal in each channel. The RF signal is then amplified using a high gain, low cost amplifier. The quarter wave unit is supplied with +12V (imaging), -12V (Labeling) from the control board with high output currents (>100mA). The quarter wave unit consists of two $\lambda/4$ transform-pin diode sets. The large output currents (100mA) are used to switch the pin diodes in the quarter wave unit and the pin diode on the labeling coil. The quarter wave unit is used to gate the RF output signal and to prevent any RF signal from the body transmit coil flowing back into the device. The labeling coils consisted of a single 5 cm diameter loop coil (tuned 123.25 MHz, matched 50Ω) with a pin diode to detune the coil during imaging. A fuse was added to the coils for patient safety to prevent any localized RF hot spots due to coupling with the body resonator. The high frequency signal was supplied by an RF synthesizer that was slaved to the scanner synthesizer with a 10MHz control line. The output of the synthesizer was distributed equally to the three independent switch boxes via a 3-way power splitter. The device was evaluated using phantom and volunteer measurement on a 3T MR scanner (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany). The volunteer measurements were performed in accordance with the local institution's ethic committee. Single-shot gradient echo planer imaging was used (128x128 matrix, FOV=210x210mm, TE=33ms, TR=2s, Labeling Time (LT)=10ms, Post-Labeling Delay Time (DT)=5ms, Gradient=0mT/m, Pixel Bandwidth (Bw)=2kHz) on a phantom to confirm the functionality of the device. For the volunteer a single-shot gradient echo planer imaging (64x64 matrix, FOV=210x210mm, TE=28ms, TR=4.8s, LT=2.7s, DT=700ms, Gradient=2.3mT/m, Bw=1.5 kHz) was repeated 10 times and averaged. The RF amplitude and LT were set as to not compromise clinical SAR limits mandated by the FDA. The RF power output between the three coils was balanced to within 1db. The coils were placed on the volunteer's neck above the left (LC) and right (RC) carotid arteries and the vertebral arteries (VA).

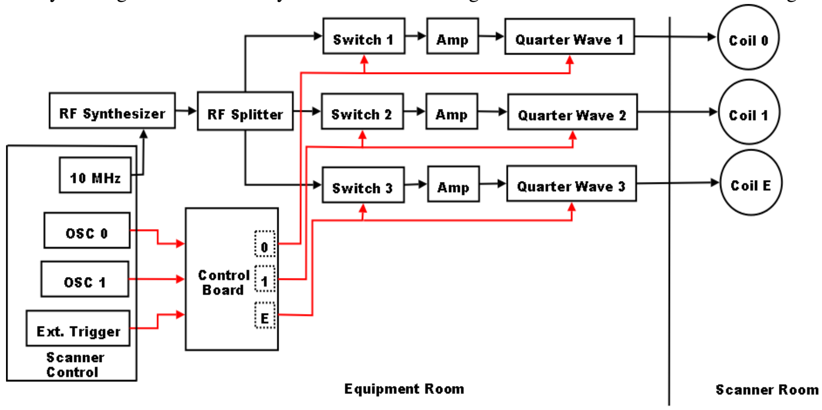

Figure 1 A schematic of the multi-channel approach used in the experiment. The red lines indicate signal control signal lines. The RF path is indicated by black lines.

Results and Discussion: Figure 2 depicts the result of the phantom and corresponding coil in a representative single slice of a volunteer image. The pattern in the phantom is the result of inhomogeneous excitation of the surface coil. Each pair of black and white stripes corresponds to a full revolution of the magnetization vector. Comparing the depth of the outer black stripe in A, B, and C indicate equality in RF power output. In the volunteer, A and B represent ipsilateral hemisphere perfusion from the RC and LC respectively, and C represents perfusion from the vertebrobasilar artery. D represents perfusion from the carotid arteries. E and F represent perfusion from the RC and LC respectively with VA. G represents total perfusion from LC, RC, and VA. All perfusion weighted images from the respective coil(s) are in agreement with expected normal physiological conditions.

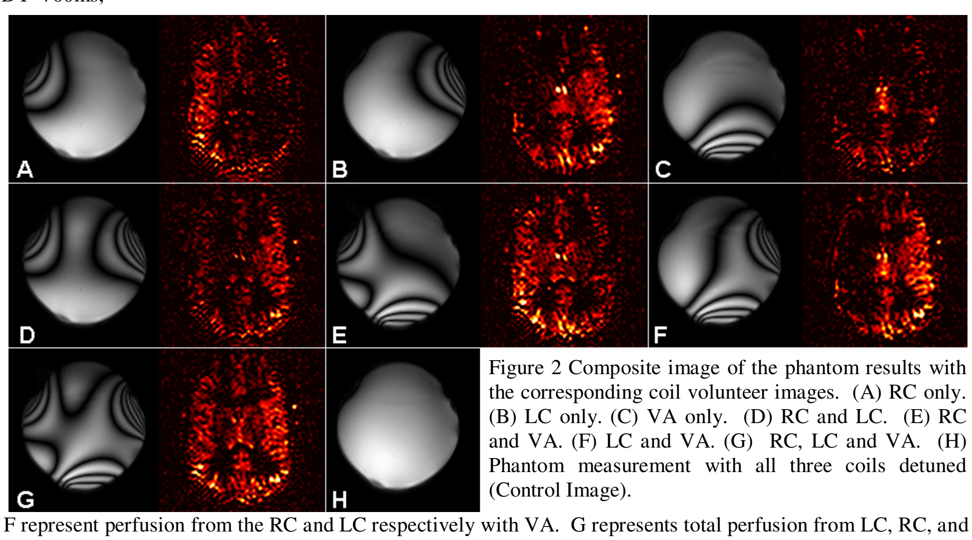

Figure 2 Composite image of the phantom results with the corresponding coil volunteer images. (A) RC only. (B) LC only. (C) VA only. (D) RC and LC. (E) RC and VA. (F) LC and VA. (G) RC, LC and VA. (H) Phantom measurement with all three coils detuned (Control Image).

Conclusion: We developed and implemented a multi-channel transmit array for performing independent multi-coil territorial CASL experiments. We successfully tested the transmit array in phantom and volunteer measurements. Phantom measurements demonstrated equivalent excitation and the volunteer measurements verified the ability to label targeted supplying arteries. The label coils are connected to individual low cost low power RF amplifiers creating a cost effective multi-channel transmit array. The RF output (label paradigm, labeling duration) of the label coils is completely controlled from the scanner console, making the device user friendly, a very important feature in the employment and acceptance into routine clinical implementation.

References: [1] Greg Zaharchuk et al, *Magnetic Resonance in Medicine* 41:1093-1098 1999 [2] Xiaodong Zhang et at, *NeuroImage* 34:1074-1083 2007

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