General Signal Vector Decoupling for Transmit Arrays

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Introduction: Transmit arrays hold great potential for SAR and RF safety improvements by selectively localizing RF excitation volumes. Moreover these arrays can overcome RF inhomogeneity by B1 shimming. A major problem for transmit arrays is coil coupling. Passive decoupling typically employs overlapping or capacitor/transformer decoupling networks while active decoupling aims to convert a power amplifier to some form of current source [1-4]. Recently, two groups demonstrated the possibility of decoupled excitation by a proper choice of transmit signal vectors [5,6]. These vectors always exist and form a new linear basis set to independently excite each coil. Here, we extend the calibration theory to determine these vectors for transmit only and Tx/Rx arrays, and we report a complete MRI signal vector calibration test.

Theory: In the signal vector calibration process, the goal is to find the matrix **Z** relating coil loop currents I and amplifier output voltage V by V=**Z**I. Each column of **Z** yields a voltage vector that excites one coil with other coil currents nulled, effectively creating virtual open circuits. In practice we don't know the calibration between the current transducers Q and coil currents I, nor the scaling between the DAC vector D and amplifier output vector V. Even so, we still build an admittance matrix dataset $\mathbf{Y} = \mathbf{Q}\mathbf{D}^{-1}$ in which we build a matrix of all current transducer vectors **Q** for a scaled identity matrix **D** of N independent digital vectors each having a unique nonzero element. Other linear combinations are possible of course. The inverse $\mathbf{W}=\mathbf{Y}^{-1}$ is computed. Each column of **W** gives the digital vector that creates a unit current *transducer* output with all other transducers zero. Further each element W_{mn} differs from Z_{mn} by a ratio of transducer m and amplifier n calibration factors. By convention we renormalize each signal column by the diagonal values so the target DAC is unity. This approach works even with transmit/receive arrays. In transmit-only arrays in which a PIN switch can physically open circuit the resonant loop, the calibration can be simplified to a series of PIN-enabled 2 port calibrations between channel m and coil n. Any normalized off-diagonal element W_{nm}/W_{mm} can be independently found without a full matrix inversion by sensing transducer n and exciting coil m, then normalizing with sensor n output when excited by coil n and negating the ratio.

Methods: We use a simple 1:1 transformer in series with each resonant loop (fig 1a) to form an RF current transducer. We also constructed slotted-line style voltage/current sensors that can be inserted in series with the transmitter coax (fig 1b) to monitor complex power and also have the option to insert circulators (RF Lambda)(fig 1c) to dissipate reflected power. We constructed four 6" by 3" 64 MHz transmit-only coils arranged on a circular former (fig 1d) with no overlapping. A multi-channel vector modulator system[7], now with integrated vector analyzer ability, weighted the small signal RF from a GE Signa scanner to the four amplifier/coil channels and collected all transducer data. Calibrations were performed for the 4 port admittance method (all coils enabled) and with pair-wise PIN switched calibrations.

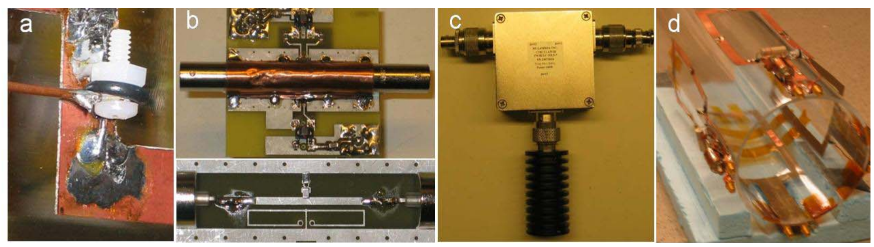

Figure 1: a) current transformer. b) complex power sensor c) circulator, d) coil array.

Results: Figure 2 (top row) shows coil excitations when only single coils were PIN switch enabled. In the middle row, significant coupling occurred with all coils enabled and only nonzero excitation on the target coil. In the bottom row, signal vectors computed by the admittance method were transmitted, yielding almost ideal decoupling. Bench test comparisons between pair-wise and full N port admittance calibrations yielded strikingly similar signal vectors with 30dB suppression being typical. The signal vectors provide a basis for analyzing coil interactions and decomposing the system into coils with 100% power transmission, with other channels appearing open circuited giving full reflection. This reflected power can be dissipated by circulators, but can be tolerated by the amplifiers as long as the RF transistor voltage/current safe operating zone is respected. All active decoupling methods will face this constraint. Circulators create an apparent amplifier output impedance of 50 ohms, which is incompatible with power amplifier decoupling[4]. Decoupling performance is dependent on the fidelity of the current transducers with accuracy limited by cross-talk. Even short circuit terminated RG58 cable shows a -40dB leakage near the array which can limit null accuracy.

Discussion & Conclusions: While useful for understanding transmit array circuit interactions, an intriguing question is whether explicit signal vector computation improves MRI B1 calibrations. For small tip-angle conditions, the coupled image data in Fig 2 should just be a linear combination of the signal vector excitations. For large tip angle excitations this will not be true. More importantly, since coil geometries are known, if current transducer and DAC/amplifier calibrations can be determined, it should be possible to compute B1 shimming signal vectors without performing time consuming MRI B1 field mapping for each array element. Finally, receiver decoupling may also be feasible but the price is degraded preamplifier noise factor if interacting coils are no longer well matched.

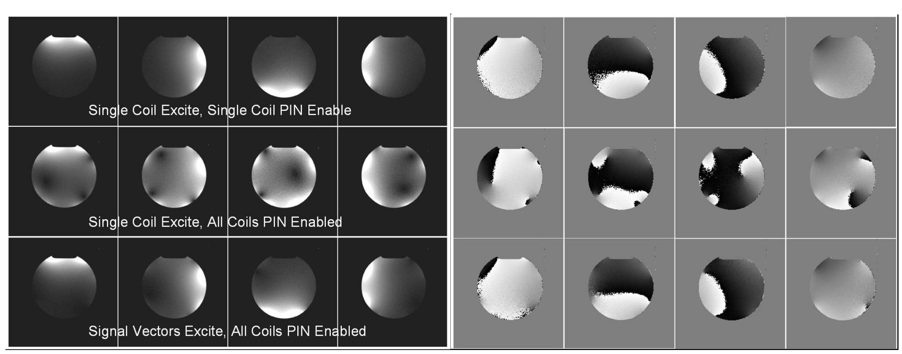

Figure 2: Magnitude and phase images. Top: PIN switched coils are individually enabled. Middle: Single coils excitation with all coils PIN enabled causes large coupling. Bottom: Signal vector transmission produces results almost identical to physically enabling single coils.

References:

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