Signal Vector Decoupling for Transmit Arrays

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Introduction: Transmit arrays and parallel excitation [1] have received a great deal of interest recently because of their potential to reduce multi-dimensional excitation times, lower SAR at higher field [2], and eliminate unsafe RF coupling with guidewires and other interventional or implanted devices [3]. By operating as dual transmit/receive arrays, the space requirements for whole body coils could also be eliminated. However, a major problem for transmit arrays is coil coupling. Transmit arrays typically use capacitive, transformer and overlapped decoupling methods, but the receive array method of reflecting the preamp impedance to effectively open circuit a coil is not possible. Current source methods using Cartesian feedback [4], high impedance network transformations [5], or transistor sources[6] all attempt to mimic preamp decoupling but the impedance mismatch potentially wastes the available power. If coil coupling were known, it can be included in TxSENSE computations[7]. Here, we show that coils can be decoupled by a properly chosen set of signal vectors. These vectors form a new basis set to independently excite each coil.

Theory: Consider an array of N transmit coils as in Fig. 1 in which the input shunt capacitors C_n are lumped with their transmit sources to form an equivalent Thevenin generator source G_n, while the remaining coil components are modeled by an N port impedance matrix **Z**. If port 1 is excited while ports n = 2 to N are open circuited, current flows in port 1 only, and open circuit voltages develop on all other ports. If the sources 2 to N and coil capacitors C_2 to C_N are now connected, current will now flow out of these ports. If these ports are now excited with Thevenin equivalent signals G_n equal to the port open circuit voltages, the remaining port input currents are zero. We satisfy this condition if we excite coil 1 with unit voltage, and the remaining coils by voltages:

$$V_n = \frac{Z_{1n}(1+j\omega C_n Z_n)}{Z_1+Z_{11}(1+j\omega C_1 Z_1)}$$

, where Z_n is the impedance seen by coil n to its amplifier, Z_{11} is the self impedance of port 1, and Z_{1n} is the mutual impedance between ports 1 and n. By repeating the process, we build the signal vector basis set. In practice, we do not attempt to measure all circuit parameters. Rather, for any coil pair, if one injects zero signal into one coil and a nonzero signal into the other, and vice versa, the current transducer ratios yield the necessary decoupling factors.

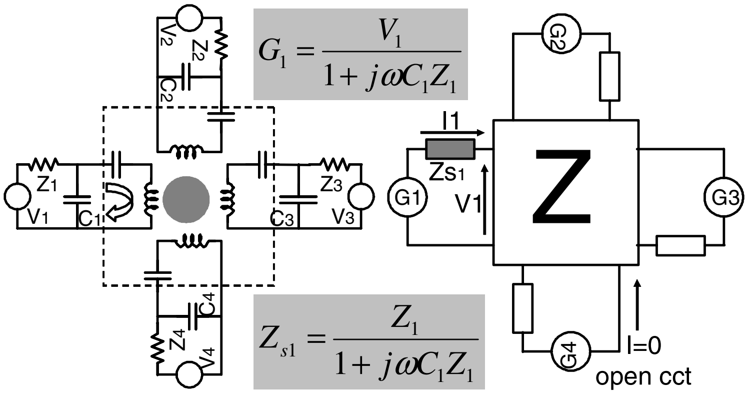

Figure 1: A N=4 element array can be modeled by absorbing the coil loops into an impedance matrix while the coil input capacitors are lumped into equivalent sources.

Methods: The open circuit condition can be detected by a current transducer in series with each resonant loop. We constructed four 6" by 3" 64 MHz transmit only coils incorporating toroidal current sensors (in effect a 1 cm short cct transmission line). Power and sensor signals were bifilar wound in the same cable trap balun (Fig 2). No attempt was made to geometrically decouple coils. A ganged array of amplitude/phase shifters provided the input signals to each coil. We did not directly solve for the signal vectors. Instead, we switched on a coil pair eg. 1 and 2, and excited each in turn with the other signal at zero. The ratio of coil 1's transducer signals (I2on/I1on) for these two cases directly gives the multiplier factor to reduce coil 1's loop current to zero. The process was repeated for pairs 2-3 and 2-4, the goal being to excite only coil 2. This ratio-metric method was performed by network analyzer and accounts for all mutual and self impedance terms, and transducer gains.

Results: Figure 3 shows the current transducer outputs for 4 coils. When coil 2 is activated, and 1,3 and 4 deactivated by PIN switches, one gets excitation on coil 2 only. If all coils are now activated with the correct decoupling vector except on 1, we create global coupling of signals. When this last error is corrected, simultaneous excitation again excites only coil 2.

Discussion & Conclusions: There are several ramifications to this work. Unlike the receive case, we have control over the signal sources. The decoupled coils appear open circuited. This means the amplifiers see only the input capacitor causing 100% reflected power. Consequently one could instead detect power reflection. The impedance matrix analysis demonstrates that a signal vector will always exist to cause current flow in a single coil. This is the same physical result as simply PIN switching a single coil. In B1 calibration, this justifies sequential activation of each coil, while the decoupling vectors can be determined electronically in under 1 ms. Finally, the method implicitly accounts for patient loading.

References:

[1] U. Katscher et al, MRM, 49:144-150, 2003,[2] Y. Zhu, 14th ISMRM p599: 2006, 2004,[3] G Scott, 14th ISMRM p128:2006,[4] D Hoult et al, JMR 171:64,2004, [5] Jevtic at al, 13th ISMRM, 324:2005, [6] Nam et al, 13th ISMRM 917:2005, [7] Pang et al, 13th ISMRM, 887:2005.

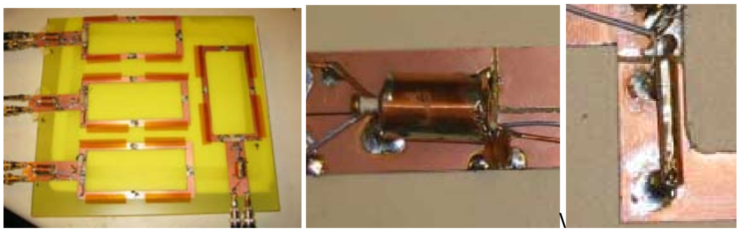

Figure 2: 4 coil transmit array with close-up showing bifilar balun and RF current transducer.

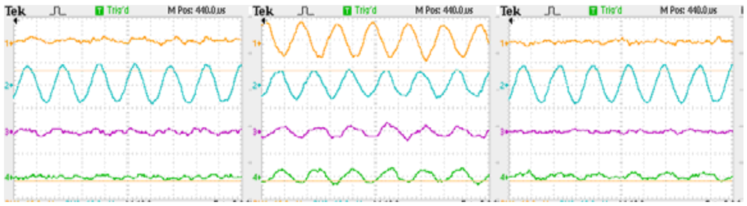

Figure 3: Current transducer output signals. Left: Coil 2 on, all others switched off. Center: Coil 1 set to zero causes global coupling with all coils enabled. Right: All coils enabled but with decoupling vector transmitted.