A Versatile In-Line Sensor For Power Monitoring and Calibration of Transmit Arrays

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INTRODUCTION:
Parallel transmit arrays add substantial complexity to MRI scanner electronics and systems. At the same time, parallel transmit pulse designs demand ever-higher fidelity RF reproduction. As channel counts grow, accurate transmit path measurements are needed to verify system performance, maintain patient safety, and ease equipment serviceability [3]. We present a versatile transmit path monitor using an in-line vector RF current and voltage (I/V) sensor connected to a Medusa MRI Console. Our system enables a wide range of performance and diagnostic measurements at relatively low cost, including RF power deposition, coil impedance, loading, and tuning, and amplifier characterization. Our system is designed to be integrated into a scanner and operate before and during scans, making measurements whenever the RF transmit chain is active.

METHODS:
We implement a transmit monitoring solution at 1.5T (64MHz) using a RF I/V sensor board [1] and a multi-channel Medusa MRI Console [2]. On the sensor board, we employ a balanced pickup loop for current sensing, and a capacitor/resistor voltage divider for voltage sensing. The voltage sensing tap is placed at the center of the current sensor to preserve the I/V vector phase relationships. Both sensor outputs are matched to 50-ohms and designed to produce outputs -40dB below the power transmit signal. The sensor board may be placed anywhere along the power transmit path between the RF amplifier and the Tx coil, although placement near the amplifier is usually desirable to minimize cabling. The Medusa console is used to receive and demodulate the vector I/V signals from the sensor board. We operate the system in two basic modes: monitor (scan), and test (prescan). In monitor mode, Medusa passively receives and is limited to measuring forward and reflected power, and coil impedance or loading. In test mode, Medusa takes control of the RF transmit path and can also measure coil tuning and Q-factor. In parallel transmit arrays, coil coupling/decoupling can be determined by measuring impedance and/or reflected power.

As with any RF measurement circuit, calibration is required for best accuracy. We model the sensor as a 4-port network yielding a 4x4 s-parameter matrix that is highly symmetry owing to balanced design between ports 1 & 2. We also assume perfect matching at the small-signal sensor ports 3 & 4. Together, this reduces the calibration burden to a simple open/short/load procedure at the coil port, plus a 'thru' measurement from drive port to the sensor outputs. Fortunately, Medusa is capable of facilitating these calibrations and no additional hardware is necessary. The calibration need only be performed once per board, assuming the installation does not change.

RESULTS:
We tested our measurement system with a 300W RF power amplifier and a 6" x 3" surface coil. Instantaneous forward and reverse powers are readily determined from the I/V sensor outputs as Vf=(V+ZoI)/2 and Vr=(V-ZoI)/2 respectively. In Figure 2 (top), we measure the impedance and center frequency of our transmit coil in a 2MHz band and under a variety of load conditions. The results match those obtained from an HP 3589A Network Analyzer. Notably, our approach is sensitive enough to detect respiratory and cardiac rhythms as time-varying impedance changes in a chest surface coil, as has been observed in other work [4], Figure 2 (bottom). A doped-water phantom is also tested as a control.

DISCUSSION & CONCLUSIONS:
We have successfully demonstrated power monitoring and coil characterization using our transmit path measurement system. While measurement noise is low thanks to abundant signal in the transmit path, we find that accuracy can suffer due to parasitic effects. When calibrated to 50 ohms, the practical range of measurement is about 5 ohms to 500 ohms. Outside of this range, cable losses, stray coupling, and mediocre calibration can easily contribute to measurement error. For our application, these limitations are perfectly acceptable. Although we describe a system for on-line transmit monitoring, the same methods can be applied to receive coils and arrays in an off-line setting. One could imagine a multi-purpose coil-testing system built into the scanner, or as a separate unit, with the ability to quickly determine if a coil is damaged or degraded. Given the success of our single-channel system, we are fitting power monitors to our 8-ch transmit array to observe inter-coil effects and test coil decoupling methods using this in-line sensing approach in place of pick-up coils.

REFERENCES:
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[3] Krueger et al., Proc 16th ISMRM, p896, 2008.
[4] Graesslin et al., 'RF Safety for Parallel Tx Arrays', MR Safety Workshp, Lisbon 2008.

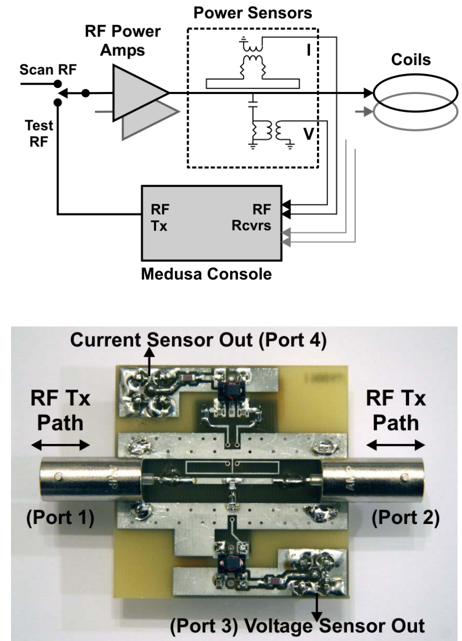

Figure 1 (top): Our power sensor produces vector I/V outputs which are measured by Medusa receivers. **(bottom)** Sensor with shield removed shows the voltage and current circuits.

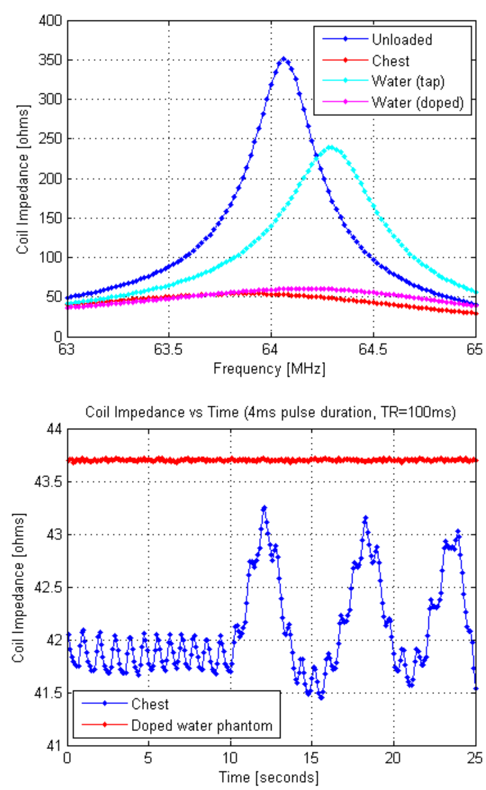

Figure 2 (top): Coil tuning and loading vs. frequency for various loads. **(bottom)** Coil impedance vs. time showing respiratory and cardiac rythms.