Imaging Study with Ultra-low Output Impedance RF Power Amplifiers

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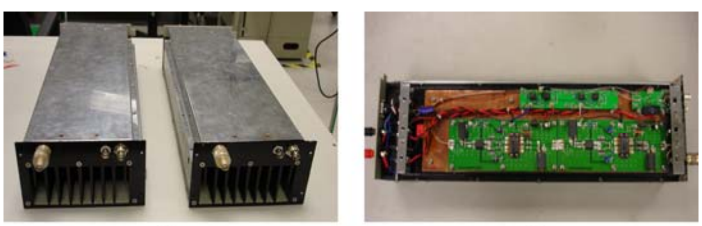
INTRODUCTION: Inductive coupling between element coils of a transmit array is one of the key challenges that parallel RF transmit faces. An ultra-low output impedance RF power amplifier concept was introduced to address this challenge and was shown to be effective in bench tests [1,2]. With the implementation of low source impedance at the output port of an amplifier, a concept analogous to the low input impedance preamplifier concept in parallel RF receive [3], coupling-induced corruptive current in the element coil driven by the amplifier is blocked by the high impedance present at the input port of the coil. The low source impedance can be achieved using a proper output-matching network at the final stage of an amplifier. Meanwhile the network can transform the input impedance of the coil into the optimum load of the MOSFET, hence maximizing the amplifier's available output power. A transmit coil array can be driven by the new amplifiers through $n\lambda/2$ cables, which enables the placement of the amplifiers in the equipment room (as opposed to near the imaging volume) and relaxes the compatibility requirements on power electronics and facilitated system integration. In this work, the feasibility of the present approach in a high field MR environment was evaluated. Imaging results indicated that, compared to the use of conventional RF power amplifiers, the new approach achieved significant improvement suppressing the effects of inter-element coupling, in agreement with bench test results.

METHOD: Two ultra-low output impedance amplifier prototypes were built for 3T MRI [2], as shown in Fig. 1. The configuration of their output stages are illustrated in Fig. 2. An inductor L_1 is used to resonate the drain-source capacitance of power MOSFET, and C and L are set to be series resonant at the working frequency. Since the drain-source resistance R_{DS} is usually very high, Z_{OUT} can thus be made very low as it is primarily determined by the series resonant circuit. Meanwhile, the value of C is chosen to transform the input impedance of the coil into the optimum load value specified for the MOSFET, to maximize the available output power [2].

Imaging experiments employing the two prototypes on a 3T clinical scanner (GE HealthCare, Milwaukee, WI) were conducted. As the approach supports relatively flexible placement of an RF power amplifier's power stage, the amplifiers were placed in the same equipment room as the stock amplifier was, with coax cables each of about 8.5 meters long connecting the amplifiers with their corresponding coils. This averted the need to make the amplifiers fully MR-compatible in the present investigation. In one set of imaging experiments a coil array consisting of two 8x8 cm^2 surface coils was placed above a cylindrical phantom (Fig. 3a), and was configured to perform parallel transmit and parallel receive. Each of the element coils in the array was connected to its corresponding RF power amplifier and RF signal receiver via a dedicated T/R switch.

MR images were acquired using a spoiled gradient echo sequence, with TE = 4.8 ms, TR = 34 ms, flip angle = 20°, matrix size = 256 x 160 and FOV = 24 cm x 24 cm. During transmit both amplifiers were gated on, where amplifier 1 had as input a 3ms RF pulse synthesized by the scanner system and output a peak power of up to 100W, and amplifier 2 had zero-amplitude pulse as input. In this case effects of coupling-induced corruptive currents on imaging mainly manifest in significant flip of spins that are located near element 2 but distant from element 1, in spite of zero input to the amplifier that drives element 2. Imaging results obtained with the use of two new amplifiers were compared to that obtained with the use of two conventional amplifiers. For parallel receive image reconstruction, phased array sum of squares combination was used.



a b

Fig. 1. Ultra-low output impedance amplifier prototypes

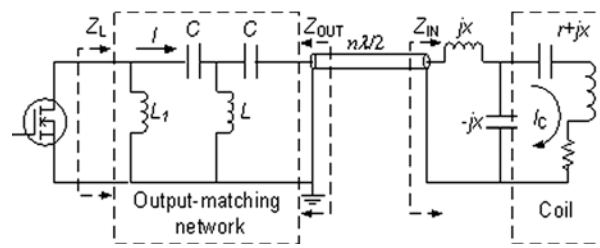
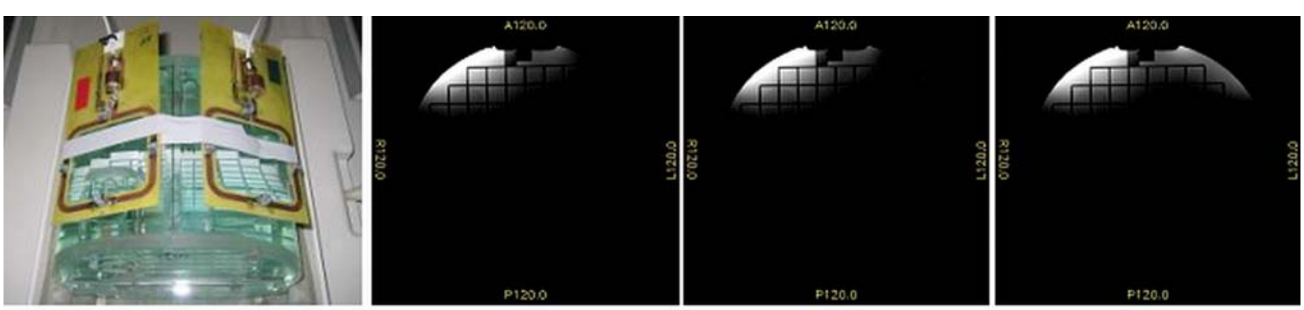


Fig. 2. The output stage of ultra-low output impedance amplifier

RESULTS: Fig. 3c shows an image that was acquired with the two element coils driven by two corresponding new amplifiers. The amplifier for element 1 (on the left) had a 3ms RF pulse as input and the amplifier for element 2 (on the right) had a zero-amplitude pulse as input. Fig. 3d shows an image that was acquired in the same way except that two conventional amplifiers were used in place of the two new amplifiers. A comparison of the two images suggests that use of the new amplifiers realized a significant reduction of coupling-induced current in element 2. The image intensity in the region that was near element 2 but distant from element 1 was reduced approximately by a factor of four with the use of the new amplifiers, in agreement with current measurements independently obtained in bench tests. The result shown in Fig. 3c was comparable to a reference result shown in Fig. 3b. The latter was obtained in the same way as the former was except that element coil 2 was connected, through a T/R switch and an 8.5m-long coax cable, with a short terminator, mimicking an extreme of the new amplifier optimization. Further improved results were obtained by reducing the coax cable length and moving the short closer to the input port of element 2. This was as expected as a reduction in cable loss would make the resonance circuitry at the input port more effective suppressing coupling-induced current in element 2.



a b c d

Fig. 3. **a**: A coil array consisting of two 8cm x 8cm surface coils was placed above a cylindrical phantom. MR images correspond to cases where element coil 2 (on the right) was connected, through a T/R switch and an 8.5m-long coax cable, with a short terminator **(b)**, an active new amplifier with zero input **(c)**, and an active conventional amplifier with zero input **(d)**.

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