Suppressing Transmit Coil Load Change Effects with Ultra-low Output Impedance RF Power Amplifier

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INTRODUCTION: Current variation in a transmit coil due to load change can be substantial in a setup using a conventional RF power amplifier. Recently an ultra-low output impedance RF power amplifier concept has been introduced for improving the inter-element isolation of a transmit array in parallel RF transmission [1-3]. The capability of an ultra-low output impedance amplifier in further suppressing load change-induced current variation is explored in this work. The amplifier, when connected to drive a transmit coil with L-type input-matching network, acts approximately as a current source, suppressing current variation due to load change as well as EM coupling. Meanwhile, the output-matching network of the MOSFET transforms the input impedance of the coil into the optimum load of the MOSFET, hence maximizing the available output power. Results from experimental evaluations and a comparison with a 50Ω-source case are presented.

THEORY: Fig. 1 illustrates the output stage of the ultra-low output impedance amplifier (DC path not shown) and the configuration when it is applied to drive a transmit coil. The power MOSFET in Fig. 1 can be modeled as a voltage-controlled current source, as show in Fig. 2. To minimize the output impedance Z_{OUT}, an output-matching network is employed, in which an inductor L_1 is used to resonate C_{OSS}, 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 [3]. The present amplifier-coil configuration in effect represents a way to realize current source. The output-matching network of the MOSFET scales its input current I by a factor of $1/\omega C Z_{in}$, which is further amplified x/r times through the input-matching network on the coil. The current running in the coil can be expressed as Eqn. 1, which suggests that r, the load of the coil, has no impact on the current in the coil, as the current I is primarily controlled by the gate voltage of the MOSFET. In addition to this current source property, Eqn. 1 shows that the present configuration is able to drive the current in the coil beyond the current rating of the MOSFET, consistent with the observed high power capability of the ultra-low output impedance amplifier [3]. Note also that the current in the nλ/2 cable can be significantly lower than that in the coil, which facilitates management of cable loss if the coil is some distance away from the amplifier.

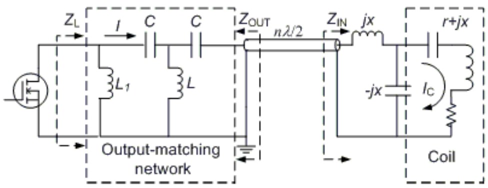


Fig. 1. The output stage of ultra-low output impedance amplifier

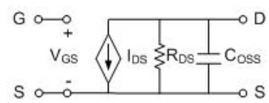


Fig. 2. Equivalent circuit model of MOSFET

$$I_C = \frac{x}{r}\frac{1}{\omega C Z_{in}} I = \frac{x}{r}\frac{1}{\omega C \frac{x^2}{r}} I = \frac{1}{\omega C x} I \qquad (1)$$

METHOD & RESULTS: An ultra-low output impedance RF power amplifier prototype was developed to work at 128 MHz (Fig. 3). It was consisted of three amplification stages, and the final stage was built with a high power MOSFET (ARF475FL, 900 W peak, Advanced Power Technology) based on the design shown in Fig. 1. The device was set to operate in Class AB and the bias current was set to 200 mA with a 150V DC drain-source voltage. The bias voltage was applied in pulse mode, as triggered by an external gating signal. With a 50-Ω load connected and a 3ms hard pulse at 1% duty circle as input, the gain of the final stage was measured to be 17 dB as the amplifier was driven to output 500W power, while all output harmonics were observed to be within acceptable ranges.

The current variations due to load change when a coil was driven, respectively, by the prototype amplifier and a 50Ω source were experimentally evaluated. An 8x8 cm^2 surface coil was placed above a phantom (1.33g/L NaCl, 0.66g/L CuSO4), as illustrated in Fig. 4, and was tuned and matched to 50 Ω when the distance between the coil and the phantom was 5 cm. This coil-to-phantom distance was set to various values to introduce load change in the subsequent evaluations. First a network analyzer (Agilent 4395A) with 50Ω source impedance was used to drive the coil directly (Fig. 5a), and then the new prototype amplifier was used instead with a 10W output power (Fig. 5b). In each driving source case the current running in the coil was measured through a small butterfly sensing coil placed across a segment of the coil, and the current measurements were normalized by the corresponding value taken when the coil-to-phantom distance was 5 cm. The results summarized in Fig. 6 suggest that, as the distance increased from 2 cm to 9 cm, the S11 of the coil correspondingly varied within a –44 dB to –7 dB range, and with the 50Ω source the current increased from –6.1 dB to 2 dB. In comparison, with the ultra-low output impedance amplifier the current varied within a ±1dB range, demonstrating a significantly improved robustness against load change.

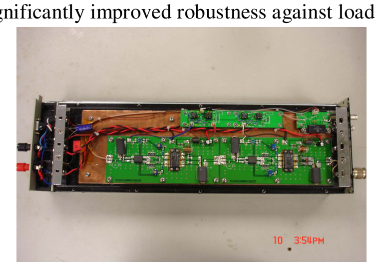
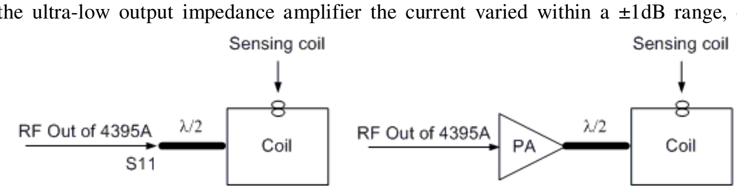


Fig. 3. Ultra-low output impedance amplifier prototype



(a) (b)

Fig. 5. Measurement setup when the coil was driven by (**a**) 4395A and (**b**) prototype amplifier

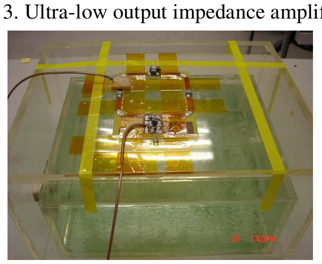


Fig. 4. Surface transmit coil and phantom

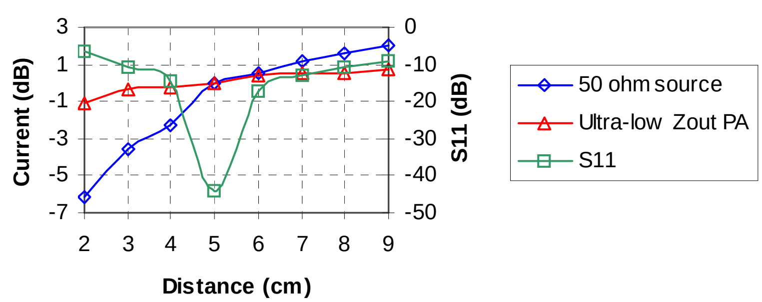


Fig. 6. Normalized current vs. the coil-to-phantom distance

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REFERENCES: [1] Y. Zhu, MRM 51: 775-784, 2004. [2] U. Katscher, et al., MRM 49:144-150, 2003. [3] X. Chu, et al., Proc. ISMRM. p. 172, 2007.