Comparison of a Current Source and a Voltage source in Transmit SENSE

H. Nam[1], S. M. Wright[1]

[1]Electrical Engineering, Texas A&M University, College Station, TX, United States

INTRODUCTION: An RF power amplifier feeds power into a RF coil through matching networks and generates a transverse magnetic B_1 field. In the conventional voltage source configuration, the matching networks ensure maximum power transfer between the RF amplifier and the coil. Assuming the coil impedance is constant, the current delivered to the coil is directly proportional to the applied voltage. However, as the matching networks are designed for specific impedance transformation ratios, any change in the coil impedance changes the current delivered. In the presence of other transmit array elements, the impedance presented to the matching network becomes a function of the current amplitude and phase on each of those elements [1, 2]. Therefore, in order to be able to exercise accurate control over the amplitudes and phases of currents on each array element, it may be necessary to have an accurate knowledge of the mutual coupling, and take this into account in designing the RF pulse. This makes independent RF waveform transmission complicated. Alternatively, the use RF current sources driving non-resonant coils [3] has been shown to mitigate the effect of mutual coupling, and could prove beneficial in the design and application of RF pulses for transmit SENSE. Experiments show that a coil driven by the RF current source is much less sensitive to loading and an inter-element coupling than a conventional 50 ohm matched coil fed by a standard voltage source mode amplifier [4]. It makes independent current control on each array element of transmit coils possible thus gives the ability to create desired transmit field patterns in the presence of other coil [5]. In this paper we compare the current source with the conventional voltage amplifier and demonstrate the improved linearity of the voltage-to-current transformation. This could have significant advantage when using multiple transmit coils for Transmit SENSE.

THEORY: To compare a current source with a standard voltage source, a MOSFET model is used because of its popularity in signal amplification. Fig. 1 shows a large-signal equivalent circuit model of a MOSFET as a voltage source driving a 50Ω tuned coil. Drain current (i_D') is a function of gate-source voltage (v_{GS}) and the drain-source resistance (r_{DS}) is a function of i_D and v_{DS} [6]. Without other array elements, a constant voltage is applied across a coil and generates current. However in the presence of other array elements, coupling between elements detunes a coil and currents on other elements induce emf (v_{ind}) (Fig. 2). The output voltage and the drain-source resistance are affected by the induced emf. The change in the coil impedance and induced emf affect the gain of the voltage source. Thus the current on the coil is changed not only by the currents on other elements, but also by the performance of the voltage source. It indicates that the current on the coil is not linear with respect to the input voltage and the RF waveform doesn't follow the input voltage any more. That distortion due to other elements can be a significant problem to generate RF pulses for Transmit SENSE. Fig. 3 shows the circuit model of the MOSFET which behaves as a voltage controlled current source driving a non-resonant coil. The lumped element inductor and resistor represent the distributed inductance and series resistance of the coil. The variable capacitor is used to tune the coil to series resonance thus the MOSFET drives RF current through the low resistance coil. The induced emf in the current source is much smaller than that of the voltage source because of the non-resonant coil structure and thus the current change on the coil by other elements can be minimized.

METHOD: To show the linearity of the current with respect to the input voltage in the current source and the voltage source, we measured the current changes on a surface coil due to a nearby coil. A capacitor of large value (820pF, 100B series, ATC capacitor) was connected in series with the surface coil in order to measure the current. The voltage change across this capacitor indicates the current change on the coil. Connecting the capacitor in series with the coil doesn't change the coil impedance since the capacitor has a large value. First, the currents without other coil were measured by increasing the input voltage from 0.1V to 0.9V for the current source and voltage source. Second, same measurements were performed when other coil was driven by the voltage source and the current source with 0.5V input voltage. A vector voltmeter (HP 8405A) was used for the experiments and the operating frequency was 200.237MHz.

RESULTS: Measured currents in the current source show the linearity with respect to the input voltages (Fig. 5). That linearity gives the ability to generate the desired RF waveform in the presence of other transmit elements in Transmit SENSE. Unlike the current source, non-linearity of the voltage source indicates that RF waveform from one coil can be altered by other coils due to the mutual coupling and it can be a significant problem in Transmit SENSE.

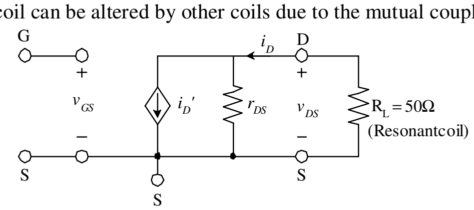

Figure 1. Large-signal equivalent circuit model of a MOSFET as a voltage source with a conventional 50Ω resonant coil

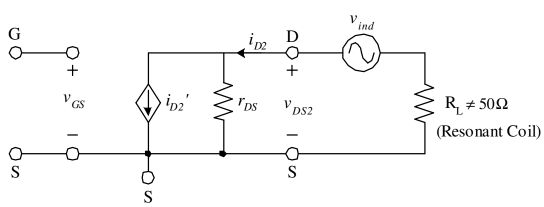

Figure 2. Large-signal equivalent circuit model of a MOSFET as a voltage source with induced emf due to the currents on other resonant coil elements

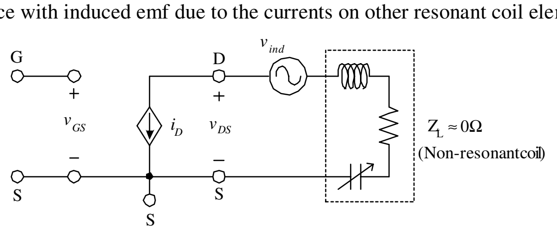

Figure 4. Equiivalent circuit model of a MOSFET as a current source with induced emf due to the currents on other non-resonant coil elements

CONCLUSIONS: The possible problem of the conventional voltage source configuration in Transmit SENSE has been demonstrated and the RF current source to avoid that problem has been presented. The improved linearity of the voltage-to-current transformation in the current source indicates that the current source may be beneficial for transmit SENSE applications as it is less sensitive to mutual coupling.

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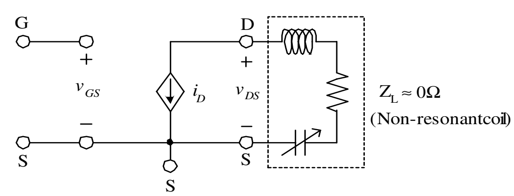

Figure 3. Equivalent circuit model of a MOSFET as a voltage controlled current source driving a non-resonant coil with a very low resistance

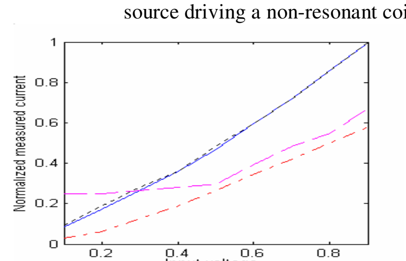

Figure 5. Measured current;
a) blue solid line: current source case without other coil
b) black dotted line: current source case with other coil
c) red dash-dot line: voltage source case without other coil
d) magenta dashed line: voltage source case with other coil

Acknowledgements: Support from the National Science Foundation (BES-0101059) is gratefully acknowledged.