Preamp-like decoupling and amplitude modulation in CMCD amplifiers for transmit arrays

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Introduction

The on-coil current-mode class-D (CMCD) amplifier has been proposed as a scalable solution for multi-channel transmit arrays [1]. These switch mode amplifiers generate the narrowband MRI frequency through incorporation of the tuned coil as a filter. With properly chosen component values these amplifiers operate at near optimal efficiency since they can take advantage of zero-voltage switching (ZVS), wherein the FETs switch at a time when the drain-source voltage is zero, thereby incurring no loss by discarding charge stored on the drain-source capacitance C_{ds}. However, switching amplifiers general require an oversampled, digitally encoded input to produce a modulated output. Unfortunately, such digital inputs ruin the efficiency of the CMCD topology, since they switch many times per cycle and thus no longer operate in a ZVS mode. Additionally, tuning of the CMCD architecture can be difficult, especially in the presence of coupling, since the the filter is sensitive to bias voltage and neighboring coils. In this study, we present two improvements to the CMCD which address these issues. The first provides amplitude modulation without sacrificing ZVS by controlling the common mode current in the CMCD. The second is the addition of a parallel resonant filter that reduces the effects of C_{ds} on coil tuning, makes the most efficient operating frequency correspond with maximum power output, and introduces a detuning mechanism which is reminiscent of preamplifiers on receive coils.

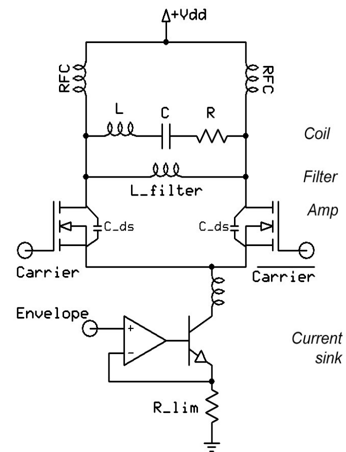

Figure 1: Schematic of CMCD amplifier, including filter inductor (L_{filter}) and current sink.

Theory

Amplitude modulation in a CMCD can be accomplished by recognizing that the current flowing through two FETs combines at their sources into a single common mode current, which only has a frequency content of the envelope and not of the RF carrier. Modulation can be implemented by limiting the common mode current using a current sink, as shown in Fig. 1. In this case, the carrier is narrowband (ie ideal for ZVS, thereby maximizing efficiency) and deviations from ZVS are limited to phase modulation of the carrier.

In order to address the issues of tuning and isolation, an inductor L_{filter} (Fig. 1), chosen to be parallel resonant with C_{ds} at ω_L, is attached from drain to drain. This creates a high impedance trap identical to a preamplifier decoupling circuit when the coil is active. It also ensures maximum current transfer to the series resonant coil.

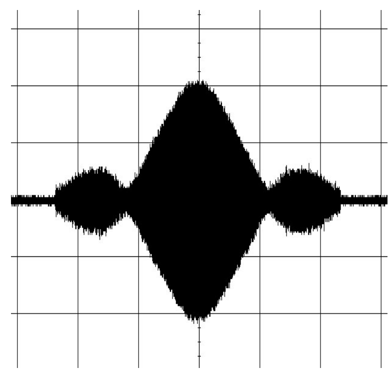

Figure 2: Characteristic sinc envelope, generated via modulation of common mode current.

Methods and Results

A voltage-controlled, linear current sink was introduced into the current return path of a CMCD amplifier, as shown in Fig 1 using a standard power BJT and opamp, and using an MRF275G for the FETS in the CMCD section. Figure 2 demonstrates sinc envelope, 1 ms long, with 64 MHz input carrier and a low frequency amplitude modulation. The effect of L_{filter} on detuning is observed by measuring retransmission of the coil when active. Figure 3 shows this effect, which suppresses resonance by 20dB at ω_L. This adds an improved isolation to neighboring coils similar to that found in preamplifier decoupling of receive coils.

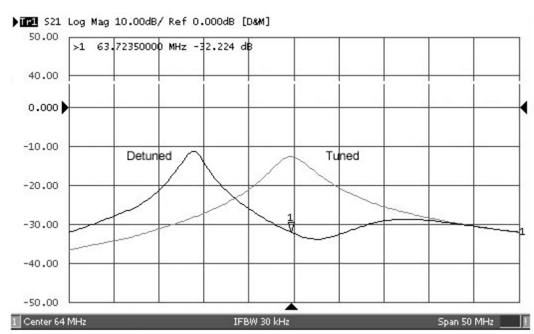

Figure 3: Demonstration of Lfilter effect on detuning: note 20dB suppression at 64MHz.

Discussion and Conclusions

We have presented two improvements to the CMCD amplifier that increase its applicability in multi-channel transmit arrays. Amplitude modulation is now possible without significant reductions in the efficiency of the amplifier and tuning and isolation of the coils is improved dramatically over previous implementations. These two improvements should allow for easier integration of transmit arrays into clinical scanning environments.

References: [1] J.A. Heilman et al, ISMRM 2007 #171

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