High power, high efficiency on-coil current-mode amplifier for parallel transmission arrays

J. A. Heilman[1], M. J. Riffe[2], O. Heid[3], and M. A. Griswold[4]

[1]Physics, Case Western Reserve University, Cleveland, OH, United States, [2]Biomedical Engineering, Case Western Reserve University, [3]Medical Engineering Division, Siemens AG, Erlangen, Germany, [4]Radiology, Case Western Reserve University

Introduction

Parallel transmission [1] has been suggested as a method for improved RF transmission, since it allows for accelerated volumetric excitation and potential correction of B1 inhomogeneity in MRI. Many proposals to date use multiple high-power, single channel transmitters that make large-scale implementation cost prohibitive. In addition, the coils in the transmit array have poor isolation between coils due to the lack of preamplifer decoupling and require tuning of each element in the array. On-coil amplifiers have been suggested as an affordable alternative with the additional benefits of increased decoupling, lower loss, and reduced dependence of power and tuning on the load [2,5]. While these local transmitters have delivered very high quality results, they have only been implemented at relatively low powers (<50W) [2], partially due to the inherent efficiency limitations of a class-AB type amplifier configuration. In this abstract, we present a high-power amplifier topology for on-coil parallel transmission using local MOSFETs that can be driven by low power signals. This topology offers high efficiency, high power, high decoupling, vector control, and low cost, making it attractive for scalable parallel transmission arrays.

Theory

The design uses a current-mode class-D (CMCD) amplifier [3] topology (fig. 1). In comparison to classic class-D and -E amplifiers, the CMCD can achieve higher efficiency at higher output power due to the series incorporation of the FET drain-source capacitance, C_{ds}, into the coil loop, allowing zero voltage switching [3]. The transmit current in the coil is controlled uniquely by the gate voltage, and the symmetry of this configuration naturally suppresses the effects of coupled currents. Additionally, the coils are automatically detuned when both FETs are off, as both C_{ds} are then in series. Electric field coupling, which would disturb drain bias, is reduced with concentric shielding [4]. These two factors combine to create high isolation. The load is driven directly by the amplifier, and does not require matching to a 50Ω network [5].

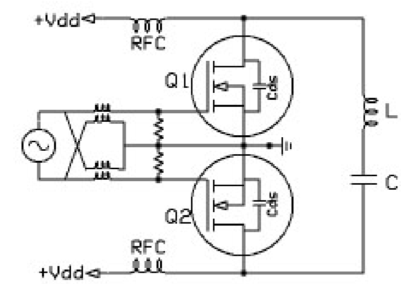

Figure 1 Current-mode class-D amplifier topology. The coil is represented by the series LC leg. The two chokes RFC act as current sources. Note that the drain-source capacitances Cds are in series with the coil.

Materials and Methods

The CMCD design was implemented on an array of surface coils of size 8.5x8.5cm with 12.5x12.5cm shield, tuned for 1.5T [4]. The coil terminals are attached between the drains of the two FETs, and tuned so that the circuit is series resonant when one of the FETs is switched on. Excitation at RF frequencies occurs by the alternate shunting of the applied DC voltage to ground as a FET is driven to saturation. A standard signal source was used as the input, amplified to around 5V to produce a gate voltage sufficiently high to saturate the FETs. Both FETs are driven out of phase for optimal efficiency, and was accomplished here using a 4:1 broadband balun.

Results and Conclusions

Pulsed power outputs of up to 1200W have been achieved with amplifier efficiencies over 85% into the 5 Ohm load observed on this coil. Upper harmonic suppression was >40dB, as seen in figure 2. We attained isolation between two adjacent, non-overlapping coils of 20dB due to coil detuning in the off state, i.e. when one coil is transmitting and the other biased but inactive. 6dB of isolation was observed between adjacent, non-overlapping resonant coils, and can be improved with overlap decoupling methods. We estimated output power versus load, with an increase of 10% from full load to no load without additional tuning or matching of the coil. Local heating has not proven to be a problem, even at high average output power, due to the high efficiency. Thus this work presents a competitive topology with high promise for parallel transmission arrays.

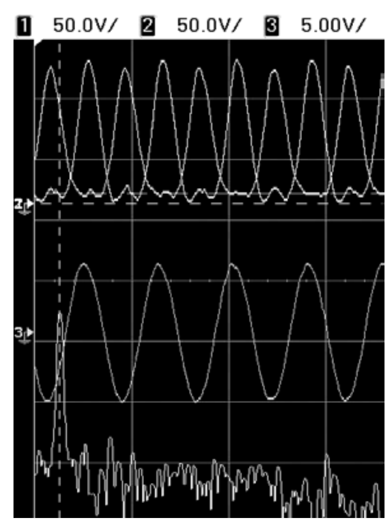

Figure 2: Generated RF waveforms. Upper traces are FET drain voltage waveforms, demonstrating the class-D performance of the coil. The lower trace is proportional to the power incident on a nearby coupling loop, with the spectrum (20dB/div by 100MHz/div) of that waveform showing spectral purity.

References

[1] Kobayashi H., *et. al.*, IEEE Trans. Mic. Th. Tech. **49**(12)2480-85 (2001)
[2] Katcher U., *et. al.*, Mag. Res. Med. 2003 Jan;49(1):144-50
[3] Kurpad K.N., et. al., Proc. ISMRM 2005:00016
[4] Lanz T, *et. al.,* Proc. ISMRM 2006:00216
[5] Heid, O. Deutsches Patent 10127266 (2003); US Patent 6683457 (2004)

This work was supported by Seimens Medical Systems, Erlangen, Germany