Demonstration of high efficiency on coil RF amplifier for 7 Tesla MRI

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Introduction For multi transmit MRI, particularly at high fields like 7 Tesla, it is highly desirable to place the RF amplifiers directly at the coil[1]. This avoids high cable losses and provides better control of current in the coil. There is, however, the problem of removing the excess heat of the amplifiers from the bore. This can be solved by using high efficiency class-E amplifiers. While these amplifiers are by nature not suited to amplify amplitude modulated signals, like MRI excitation pulses, a supply voltage modulator can be added to the circuit. Consequently, the RF waveforms have to be translated to DC power modulation. Since the RF amplitude modulation has similar properties as gradient waveforms, we have driven the RF waveform to additional gradient waveform boards. Therefore MRI system adaptation remains relatively small, while enabling the potential of incorporating a high number of on coil amplifiers. A low power demonstration circuit of a class E amplifier was driven by a Philips 7T MRI scanner, using the existing RF and gradient hardware. Images of a phantom and a volunteer were obtained, providing proof of principle.

Methods A class E amplifier (figure 1) was constructed, using a D1013UK FET as active element. Cshunt is the parallel equivalent of the source-drain capacitance of the FET. Since Cshunt is voltage dependent, Lres and Cres were experimentally optimized when driven at maximum power. Vcc was regulated by a class B modulator, capable of delivering 0..35V/2A. The system was connected to a Philips 7T console (figure 2), using an additional channel of the Gradient Chain Interface (GCI) as input for the modulator and an RF pre-amplifier for the RF signal. The RF signal contains no pulse amplitude information, only frequency and phase. The amplifier was directly connected to a 50mm loop coil and placed in the bore of the magnet. Using a Nova Medical headcoil as receive antenna, images were obtained from a spherical phantom (diameter: 120mm) and the wrist of a volunteer.

Results The efficiency of the class-E amplifier was determined in a test setup with continuous input signal and found to be in excess of 80% , the maximum output power was 14W in a 50Ω load. Figure 3 shows the RF input signal, the output of the modulator an the RF output signal as measured with a digital oscilloscope (Tektronics TDS3964B). It is clearly seen that the RF amplitude (middle trace) closely follows the desired pulse shape (upper trace), where no amplitude information is present in the RF input signal (lower trace) itself, demonstrating the functionality of the modulator. Note though that a feedback loop has not been incorporated yet.
In figure 4 the image of the sphere is shown, the black bands in the image demonstrate the capability of the amplifier to provide slice selective properties, which require amplitude and frequency modulation. While still at low RF power, 2D and 3D images were obtained in vivo (figures 5 and 6).

Conclusion The results demonstrate the possibility of using an on-coil class-E amplifier at 7 Tesla. The efficiency of the circuit is sufficient for using multiple amplifiers in the bore for multi channel excitation. In fact, the efficiency of an RF coil at this frequency is in the same range, hence the coil itself would be capable to cool the amplifier. While a class E amplifier requires a different driver circuitry, with relatively little effort it can be interfaced to an existing MRI system without extensive hardware modifications. Future work includes power up scaling and sampling of the RF signal for linearity correction[2] and on line quality control.

References 1. Gudino, N. et al, On-coil Multiple Channel Transmit System Based on Class-D Amplification and Pre-Amplification with Current Amplitude Feedback, MRM2012. 2. Stang, P. et al, An Envelope Tracking Transmit Array Amplifier, ISMRM 20: 2638 2012.

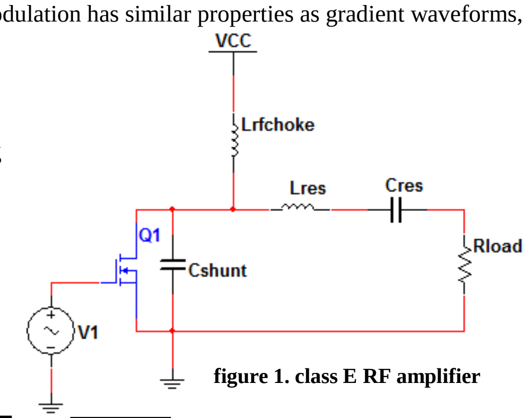

figure 1. class E RF amplifier

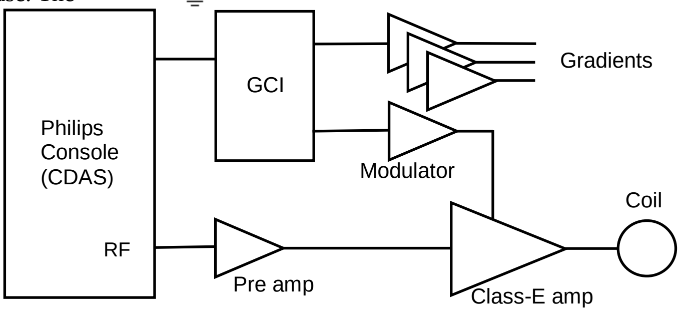

figure 2. Block schematic

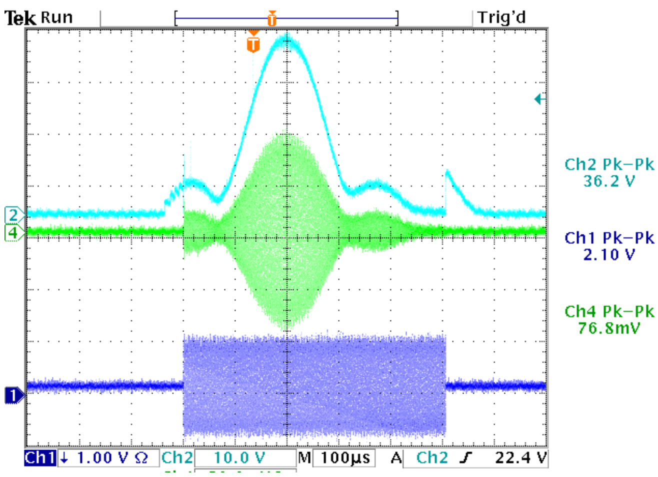

figure 3. Oscilloscope readout

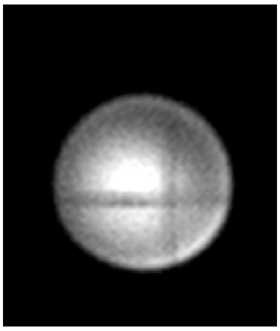
figure 4. One slice from three orthogonally acquired slices of a phantom. Note the saturated cross originating from the other slices, demonstrating accurate slice selection.

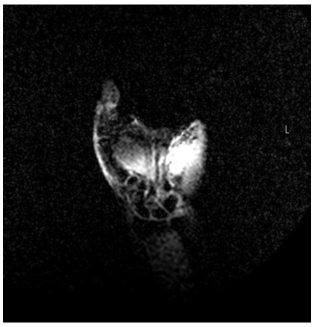
figure 5. 2D MRI of the wrist, using the local class E amplifier on a 5cm loop coil.

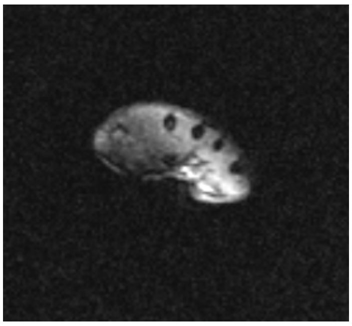
figure 6. 3-D MRI of the wrist, obtained at an isotropic resolution of 1mm