Multi-Channel MOSFET Amplifiers for Parallel Excitation in 7T Animal MRI System

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Audience: Those interested in RF circuit design and multi-channel TX systems.

Purpose: Parallel excitation using multi-channel transmit arrays is capable of addressing the problems of RF field inhomogeneity at ultrahigh magnetic fields and providing a fast and efficient approach to performing selective excitation[1,2,3]. Given its compact size and high RF power output capability, on-coil MOSFET RF amplifier offers advantages for practical implementation of parallel excitation[4,5]. In this work, we developed a multi-channel transmission system with compact MOSFET amplifiers for 7T animal MRI scanner. Its performance was evaluated experimentally.

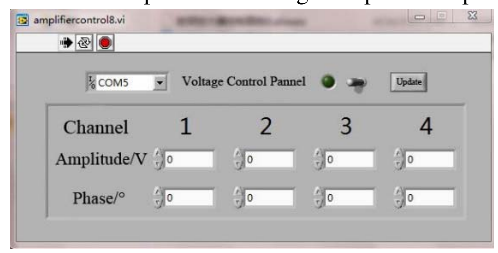

Fig 1. Graphic user interface (GUI) on PC for controlling the amplitude and phase of each transmission channel.

Methods: The multi-channel transmission system is composed of a multi-channel RF controller and 4 independent RF power amplifiers. The PC Graphic User Interface (GUI) and the Digital Analog Converter (DAC) constitute the RF controller. The phase shifter, attenuator and the two-stage amplification constitute the RF power amplifier. The PC GUI (developed by LabVIEW, National Instruments) is used for setting the phase and amplitude of each channel. The signal from a PC is converted into analog voltage of 0-10V by the 12-bit DAC (DAC7678, Texas Instruments) with 8 output channels. The voltage-controlled phase shifter (JSPHS-42+, Mini-Circuits) and attenuator (MVA-2000+, Mini-Circuits) have phase shift ranging from 0° to 200° and attenuation ranging from 2dB to 43dB with control voltage of 0-10V. In the two-stage power amplification, the first stage uses power transistor (MRF321, 10W rated, M/A-COM) and the second stage uses power MOSFET (MRF177, 100W rated, M/A-COM). Class A operation is adopted for the amplifier to acquire high linearity. We used ADS (Advanced Design System, Agilent Technologies) and Altium Designer (Altium Company) for the schematic design and the PCB (Printed Circuit Board) design respectively.

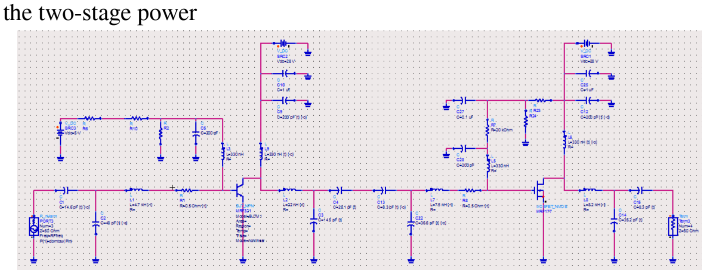

Fig 2. Schematic of the two-stage RF power amplifier using MOSFET.

Results: The above mentioned PC GUI for 4-channel control as an example is shown in Fig 1. Fig 2 shows the schematic of the power amplifier design. The amplifier performance is simulated in ADS. Using the second stage amplifier as an example, the simulation results at 300MHz are: stability factor K=1.46, auxiliary stability factor B_1=0.84, S_{11}=-44.2dB, S_{21}=13.8dB, VSWR=1.01 (Fig. 3). The amplifier is tested with network analyzer. The center operating frequency of the amplifier is 300MHz. Under this frequency, the power gain for the first stage, second stage amplifier and the whole amplifier is 9.0dB, 9.1dB and 18.7dB respectively (Fig. 4). One channel of the power amplifier is shown in Fig 5. The 4-channel power amplifier consists of 4 power amplifiers mentioned above.

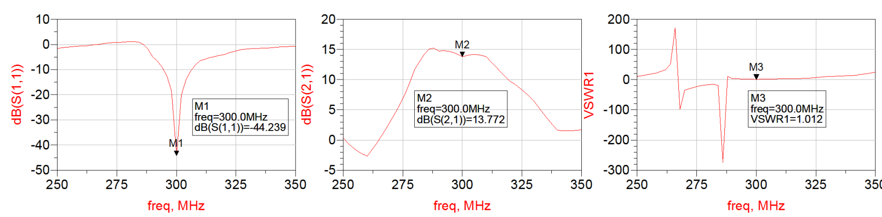

Fig 3. Simulation results: S11, S21, VSWR of the second stage MOSFET amplifier.

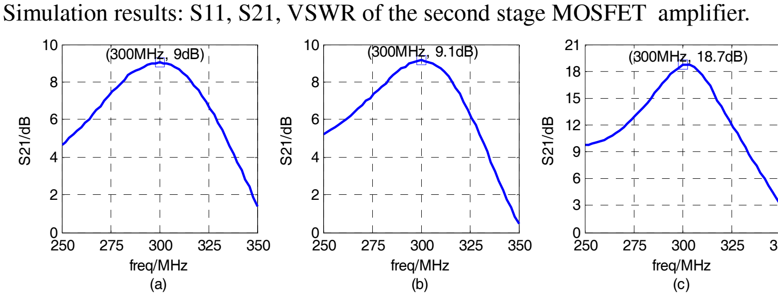

Fig 4. Power gain (S21) of (a) the first stage amplifier, (b) the second stage amplifier, and (c) the whole amplifier vs. operation frequency.

Discussion and Conclusions: The design of a multi-channel transmission system with compact MOSFET amplifiers for 7T animal MR Imaging system is presented. In the simulation of the second stage power amplifier, K>1 and B_1>0, showing that the amplifier is unconditionally stable at 300MHz; S_{21}=13.8dB, S_{11}< -20dB, VSWR$\approx$1, showing that the amplifier has high power gain (S_{21}) and negligible reflected energy loss. In the bench test, the power gains of the first, second stage and the whole amplifier are at high level, demonstrating the sufficient amplification capability of the transmission system at 300MHz for small animal parallel transmission applications at 7T. The test and simulation results have difference because the component parameters of the real amplifier have unavoidable differences from the schematic design, due to limitations in the experiment conditions. By fine tuning the parameters of the amplifier circuits, further improvement of amplification gain can be expected.

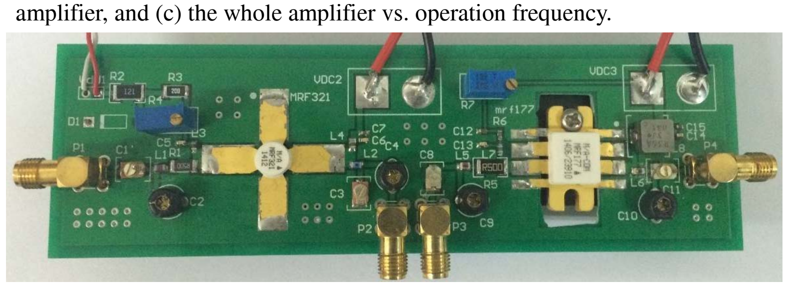

Fig 5. Photograph of one of the MOSFET RF power amplifiers developed for 7T small animal imaging system.

References:

1. Childs AS, et al, MAGMA. 2013;26(4):401-10; 2. Katscher U, et al. MRM. 2003;49:144–150; 3. Zhang X, et al, OMICS J Radiol. 2012;1:e110; 4. Heilman JA, et al, ISMRM 2007 (Abstract 171); 5. Gudino N, et al, MRM 2013; 70:276-289.