Broadband Multi-Channel Optical Interface for On-Coil Switch-Mode RF Amplification

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

Purpose: On-coil Current-Mode Class-D (CMCD) amplification offers several advantages for practical implementation of parallel RF transmission (pTX) [1]. To generate shaped RF pulses with high efficiency, while avoiding cable cross talk, the amplifier is fed by separate optical signals: the RF carrier and the encoded envelope. In previous work [1,2] these signals were generated by a multiple output data-timing generator in synchrony with, but otherwise independent of, the scanner. The goal here was to develop an interface that allows for flexible integration with a commercial MRI system. An interface for pTX applications based on vector modulation has been previously demonstrated to drive remote (not on-coil) linear amplifiers [3,4]. Here we present a two-channel modular interface to drive on-coil CMCD amplifiers that allows easy expansion to any number of channels and flexible integration with commercial scanners over a range of field strengths.

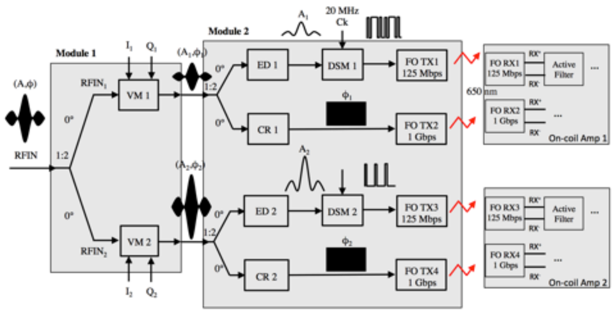

Figure 1: Schematic diagram of the modular interface

Methods: To add flexibility to the system and to be able to control CMCD amplifiers as well as conventional linear and quasi-linear RF amplifiers, the interface was designed as two separate modules (Fig. 1). The first module has as main components a 1:2 power splitter and two vector modulators (ADL5390, Analog Devices), and generates RF pulses with independent amplitude and phase control through the in-phase (I) and quadrature (Q) baseband control signals generated by a PCI board (PCI-6723, National Instruments) installed in a peripheral computer. The second module has a carrier recovery (CR) circuit formed by a high-speed comparator (ADCMP572, Analog Devices) in a zero-detection configuration and a high bandwidth envelope detection (ED) circuitry (ADL5511, Analog Devices) followed by an on-board sigma-delta (ΣΔ) modulator (AD7401, Analog Devices) with 20 MHz sampling frequency. Both the carrier signal and the modulated envelope were transmitted digitally through fiber optic (FO) transceivers (Fiberfin) to control an on-coil amplifier. The analog envelope was recovered through active filtering with a 100 kHz cutoff frequency. The interface was connected to the RF_{IN} accessible on different scanner systems (Siemens 7T and 11.7 T and Bruker 11.7 T)

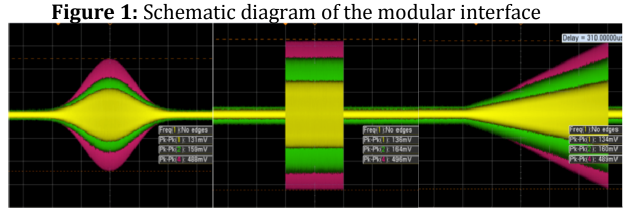

Figure 2: Shaped RF pulses with various amplitude and phases at the output of Module 1 (green and yellow) compared to RF input signal (in magenta).

Results: Figure 2 shows examples of 500 MHz RF pulses at the output of Module 1. RF pulses as short as 10 us were modulated and transmitted with negligible delays (~10 ns). Figure 3 shows the detected envelope before (a) and after modulation, optical transmission and demodulation (b) and the recovered carrier signal as measured on Module 2 (c). Note that the recovered carrier presents out-of-band noise due to the high gain of the comparator. Therefore the optical transmitter was only enabled during the RF pulse to eliminate potential noise during MR signal reception. The resulting dynamic range of the envelope signal after on-board modulation, optical conversion and demodulation at the fiber RX side was ~33 dB, close to maximum dynamic range of the IQ vector modulator implemented on this prototype (35 dB). The effective envelope signal bandwidth, measured at the output of the demodulator, was close to 100 kHz. We were able to recover the carrier signal at the output of the fiber RX across the 64-500 MHz frequency range (and higher) with minimal changes in amplitude (Fig. 4). Table 1 shows phase and attenuation values for the specified I and Q input values over one-hour interval.

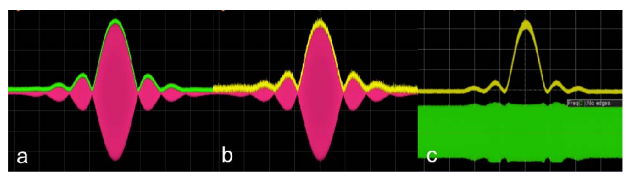

Figure 3: Envelope detection before and after modulation optical transmission and demodulation & carrier recovery.

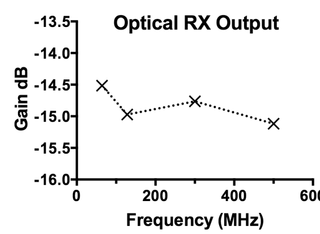

Figure 4: Gain of the carrier signal at the optical RX side referred to the amplitude of the input carrier signal.

I(V)	Q(V)	Phase (degree)	Amplitude (-dB)
0.15±0.03	0.72±0.04	179.13±0.06	12.68±0.01
1.07±0.03	0.72±0.04	11.8±0.00	19.13±0.01
0.76±0.03	0.76±0.03	139.3±0.00	31.99±0.02
0.19±0.04	0.99±0.00	91.27±0.55	16.1±0.00

Table 1: Phase and amplitude values for different I and Q values

Discussion and Conclusions: We have demonstrated a simple and low cost (~US$200 per channel) interface to control pTX arrays driven by on-coil CMCD amplifiers. In this first prototype we recovered the envelope and the carrier information from the single RF_{IN} of the scanner system and control amplitude and phase independently for each channel. For more complex pTX applications, different RF envelope signals could be also synthesized by the PCI-6723 board and sent synchronous with the scanner to the high bandwidth IQ control signals of the modulator. To prepare the signals for optical transmission, the RF carrier was "digitized" at the output of the comparator, while the envelope was encoded by the ΣΔ modulator. This simple on-board signal encoding showed accurate phase and amplitude control.

References:

1. Gudino N, Heilman, JA, Riffe MJ et al. Magn Reson Med. 2013 Jul;70(1):276-89.
2. Heilman JA., Gudino N, Riffe MJ et al. Proc. ISMRM, 2009 (Abstract 3027).
3. Feng K, Hollingsworth NA, McDougall MP et al, IEEE Trans Biomed Eng. 2012;59(8):2152–2160.
4. Hollingsworth NA, Moody K, Nielsen J et al. Proc. ISMRM 2013 (Abstract 2744).