Optical Transmission System for High Field Systems

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Introduction: Interconnection problems between large number of coil elements and the scanner are critical, particularly in high field MRI. Moreover, SNR and RF safety issues are also significant concerns. Recent investigations on the analog optical transmission of MRI signals may alleviate this problem [1-3]. Although traditionally, the transmission of the MR signals is achieved by coaxial cables, in practice, an optical system with minimized losses and enhanced RF safety compared to coaxial lines can be feasible for high field MRI.
In this work, we introduce an optical RF transmission system for a 3T and a 7T system where the electrical MR signal is converted into an optical signal, carried using a fiber optic cable and then converted back to an electrical signal. In the system the detuning signal is also transmitted optically. Here, the details of the optical RF transmission system are shown and the experimental verification of the performance of the system is described.

Methods: The electrical-optical-electrical conversion system is composed of several components: a low noise amplifier (LNA) to increase the electrical signal from the coil, a laser circuit to convert the 123MHz or 300MHz signals to an analog optical intensity modulation, a fiber optic cable for transmission, and a photodiode circuit to convert the signal back to an electrical signal for processing. The transmit and receive coils are 10cm x 22cm loops on printed circuit board. Each loop is divided into eight equal length sections by capacitors and tuned and matched to a 1.9 L phantom (3.75g $NiSO_4x6H_2O$+5g NaCl per 1000g H_2O) load. The LNA for 7T was designed with BFP420 transistors and had a gain of 36.5dB and a noise figure (NF) of 0.8dB. The LNA for 3T was designed with BFP193 transistors and had a gain of 35dB and a NF of 0.8dB. The noise figures of the LNA's must be as low as possible, because they define the overall noise figure of the receive paths.

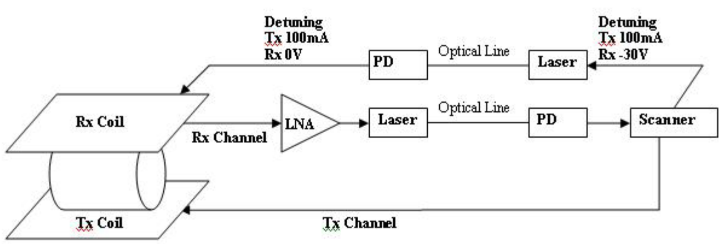

Figure 1: The optical system and the experiment setup for 3T and 7T systems

The electrical-optical-electrical conversion part of the receive path is the laser-photodiode cascade. The laser circuit drains 15mA provided by 4.3V nonmagnetic battery (MP 174565 from SAFT, Bagnolent, France) and the circuit is matched to the LNA's output impedance. The photodiode circuit detects the optical signal from the laser circuit and translates it to an electrical signal. The insertion loss and noise figure of the laser-photodiode cascade is 10.3dB and 18.5dB for 7T and 11dB and 17dB for 3T. The laser circuit was driven by the detuning signals from the scanner. The detuning network shown in Figure 1 produced 100mA during transmission and 0V during reception. The overall gain is 26.2dB for 7T and 24dB for 3T system. The spurious free dynamic range (SFDR) is 65dB for 100 kHz bandwidth and the overall noise figure is 0.9dB for both systems.

Results: To evaluate the performance of the optical transmission, three different conditions are considered. These are: 1) optical receive / optical detuning, 2) coaxial receive (optical part of the receive path replaced by a 10dB attenuator) / optical detuning, 3) coaxial receive / copper cable detuning (detuning signals from the scanner are connected directly to the coil). The experiment setup is shown in Figure 1 and results are in Table 1. The images are gathered by using a gradient echo pulse sequence with identical imaging parameters. The signal-to-noise ratio (SNR) values are calculated by the difference method [4] from the same region of interests on the images.
First and second setup gives comparable SNR values for the optical and coaxial receive paths. In Table 1, the results from second and third setup show a difference between two types of decoupling circuits for 7 tesla case. One possible reason for this is that the reverse bias of the PIN diodes that tune the receive coil is different between optical (0V) and copper cable case (-30V). Images obtained from the human calf with the optical transmission system and the coaxial systems show variation in SNR and are given in Figure 2.

	SETUP	SNR 7T	SNR 3T
1	**Optical Receive Optical Detuning**	**67**	**98**
2	**Coaxial Receive Optical Detuning**	**71**	**103**
3	**Coaxial Receive Cable Detuning**	**80**	**102**

Table 1: SNR values for 3T and 7T experiment setups

Discussion: The dynamic range is a critical issue for optical transmission systems. As mentioned by Gabr in [5], the dynamic range of the optical systems may not be sufficient for MRI signals. The optical transmission system can however be directly used with small coils which have potentially lower dynamic range compared to the volume coils. Moreover, we are working on covering the whole dynamic range needed by the means of nonlinearity compensation [6]. A further modification of the coil detuning circuitry is required in order to optimize the system to its final form and compensate the variation in SNR. Furthermore, optical lines cancel the coupling between neighboring channels and enhance RF safety. It is possible to scale the system for handling many channels by using multiplexing [3]. This also results in size reduction with reduced number of coaxial cables and interconnections.

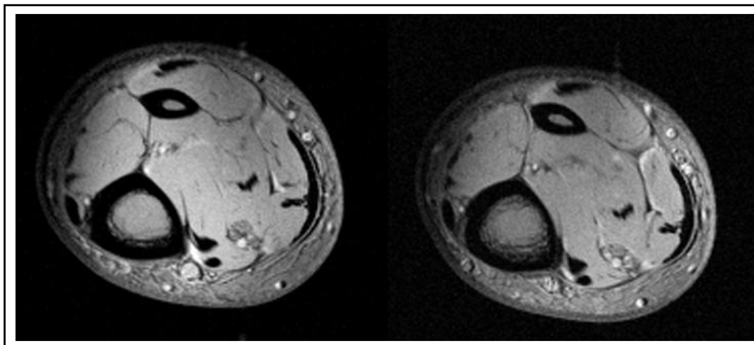

Figure 2: Axial images of human calf using 7T, coaxial system (left), optical (right) . Please note that the leg is moved slightly when changing the setup from optical to coaxial.

Conclusion: An optical transmission system for 3T and 7T systems is introduced. The system achieves comparable SNR performance with the coaxial cable in its dynamic range. We plan to improve the performance of the system by dynamic range compensation, improved SNR by optimization of the detuning circuit, and scaling the system for handling multiple channels by possibly using multiplexing.

References: [1] O.G. Memis, et.al., Magn. Reson. Med. 59 (2008) 165–173. [2] J. Yuan, et. al., J. Magn. Reson. 189 (2007) 130–138. [3] S. Biber,et. al., in: ISMRM 16th Annual Conference, Toronto, Ontario, Canada, 2008, p. 1120. [4] O. Dietriech, et. al.., Journal of Magnetic Resonance Imaging 26 (2007) 375-385. [5] R. E. Gabr, et. al.., Journal of Magnetic Resonance 198 (2009) 137-145. [6] K. Kose, et. al., IEEE Aerospace Electron. Syst. Mag. 5 (1990) 27–30.