Optical power transmission can help to build receive coils without coaxial cables

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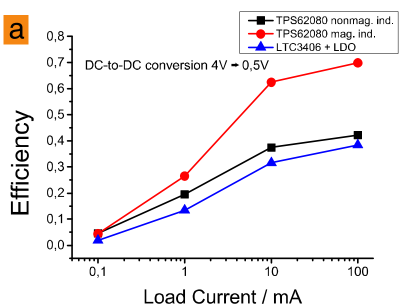
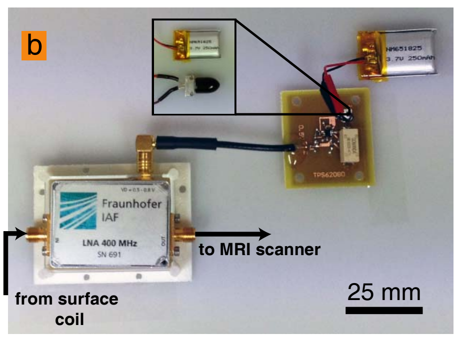
Introduction: The use of an optical fiber for power transmission (either using the same fiber, or a second one to transmit the receive signal from the magnet to the spectrometer) offers great possibilities for MRI (magnetic resonance imaging) receive coils. Parallel imaging is a rapidly growing area over the last few years, reaching to systems with up to 128 receive channels [1]. Using a large number of coils, the overall size and possible crosstalk of the corresponding larger number of cables increases and needs to be accounted for. Since optical fibers are non conductive they do not form ground loops and do not interact with the magnetic field too. They are also very easy to bend and require less space than coaxial cables. Besides higher safety and smaller size that an optical fiber offers compared to a coaxial cable, imaging applications could greatly benefit from using optical technology. The combination of fiber optics technology with a receive coil could lead to a system that would need only one fiber that is used both for powering the receive system and also optically transmitting out the magnetic resonance signal. In this abstract the use of optical power transmission was evaluated as a power source for switching DC-to-DC converters to replace an external lab power supply in order to get towards a fully optically connected receive coil.

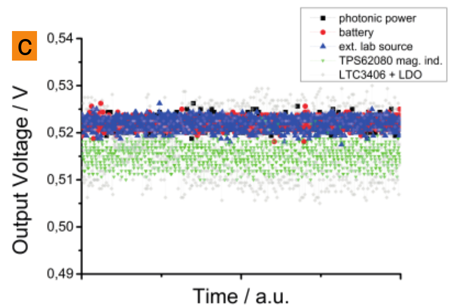
Methods: For converting optical power back to electrical power a photonic power converter (PPC) from JDS Uniphase Corporation (Milpitas, USA) was used, because it offers high electrical power while having a very small footprint. It provides 4 V output voltage and can deliver up to 125 mA of current (0.5 W of electrical DC power) from an optical fiber that is connected to a laser source outside the MRI scanner. After the PPC a power regulation circuit is needed to supply the needed regulated voltages for all further electronic devices (e.g. a low-power consuming low-noise amplifier (LNA)) of the MRI optical receive system. In order to increase the power efficiency (and not waste energy) a switching DC-to-DC converter is prefered, since it has less heating, therefore less noise in the regulated voltage is expected. As an alternative, the preamplifier can run of a nonmagnetic rechargable battery that would allow the system to run for several hours without external power supply. MRI experiments were performed on a Bruker AVANCE III MRI spectrometer (400 MHz) using standard imaging sequences and coil configurations. A commercial linear resonator (d=72mm) was used for transmission, while a circular Bruker surface coil (d=30mm) was used to record MR signals from a phantom of ionized water. Instead of the standard Bruker preamplifier we used a special low-power consuming LNA [4], which was solely powered from either the optical power transmission or a battery. The SNR values of the different setups were compared to the case when an external lab power supply was used.



a) Measurement of the efficiency for the DC-to-DC conversion from 4 V down to 0.5 V. Comparison between two different inductors (nonmagnetic and magnetic) and a circuit with an additional low dropout regulator (LDO).



b) Measurement setup with LNA, switching DC-to-DC converter and power supply from a battery. Inset: Size comparison of the photonic power converter (PPC) and the battery.



c) Measurement of output noise for the DC-to-DC converter depending on the used source. The noise of the lab source is the same as for the photonic power converter or the battery. Using a magnetic, more power efficient inductor leads to more noise. Using an additional LDO gave the most noise.

Results: Image SNR values for both optical power transmission and battery power supply (figure b) were measured with a spin-echo sequence. SNR values were determined from images recorded in the same way with the different setups. The mean of the signal intensity in a region close to the surface coil was compared to the standard deviation of noise outside of the water phantom. Results were compared to the case when a lab power supply was used to power the LNA. The values were 112 (with an external power supply), 110 (with a MR compatible battery) and 80 (with optical power transmission). The low SNR value for the optical power transmission stems from higher noise, the signal value was the same as in the other two cases. The position of the DC-to-DC converter and the PPC is critical, since the current switching of the DC-to-DC converter influences the receive cable and the PPC itself has a slightly magnetic casing. Measurements on the RF bench for gain and noise figure of the LNA showed that with the right positioning the noise figure will be unaffected. Using a nonmagnetic battery as a power source matched the performance with the lab power supply. Both preamplifier and battery can be used inside the scanner without problems if carefully positioned. Also the efficiency of the DC-to-DC converter was measured on the RF bench (see figure a). Here one can see that the use of a nonmagnetic inductor (Gowanda SMG5025), required for operation inside a high magnetic field, leads to a drop of around 30% in efficiency as compared to the same circuit with a state of the art small size magnetic core inductor. The reason is that the nonmagnetic inductor has a much larger DC resistance that leads to losses during switching operation. On the other hand, the noise of the output voltage, that was also measured (figure c), is the same in both cases (optical transmission and battery). It has the same magnitude of 2 mV, when compared to the lab power supply. The noise is even lower then compared to the case when using a magnetic core inductor.

Discussion and Conclusions: It was shown that optical power transmission or nonmagnetic batteries can be used as the power source inside a MRI scanner. In combination with a switching DC-to-DC converter this does not lead to increased noise in voltage levels and matches to using an external lab power supply. However, care has to be taken in the positioning of these additional components, as this can lead to higher noise in the receive signal. With these two sources (optical power transmission and battery) the output power and current is much higher as compared to our last work [2], where energy was harvested from gradient switches. 8 LNAs can be powered in parallel. Additionally the power is sufficient to provide an analog optical transmission for the receive signal as this only needs around 50 mW [3]. Thus a completely optically connected receive system (for one channel) can be built, that can be powered by optical power transmission, or alternatively without any external power connection via a battery.

References: [1] M. Schmitt et. al., Magnetic Resonance in Medicine, 59(6):1431-9, 2008. [2] J. Höfflin et. al., Proc. Intl. Soc. Mag. Reson. Med. 21 (2013) 728. [3] O. G. Memis et. al., Magnetic Resonance in Medicine, 59(1):165-173, 2008. [4] E. Fischer et. al., Proc. Intl. Soc. Mag. Reson. Med. 19 (2011) 1862.