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A direct modulated optical link for MRI RF receive coil interconnection

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Abstract

Optical glass fiber is a promising alternative to traditional coaxial cables for MRI RF receive coil interconnection to avoid any crosstalk and electromagnetic interference between multiple channels. A direct modulated optical link is proposed for MRI coil interconnection in this paper. The link performances of power gain, frequency response and dynamic range are measured. Phantom and *in vivo* human head images have been demonstrated by the connection of this direct modulated optical link to a head coil on a 0.3 T MRI scanner for the first time. Comparable image qualities to coaxial cable link verify the feasibility of using the optical link for imaging with minor modification on the existing scanners. This optical link could also be easily extended for multi-channel array interconnections at high field of 1.5 T.

Keywords: Direct modulation; Radio frequency (RF) coil; Signal-to-noise ratio (SNR); Dynamic range

1. Introduction

In recent years, RF arrays with multiple coil elements ranging from 32, 64 to 96 have been successfully demonstrated [1–3]. However, with the rapid increase of coil numbers, the crosstalk between coaxial cables and connectors becomes more serious and deteriorates the image qualities. Greater risk of RF burn due to the cable ground loops is also a threat to patience safety. In additional to these electronic problems, mechanical bulk and stiffness of the cables represent a limitation on the ease of operation.

Baluns and cable traps are usually conventional solutions to some of the electromagnetic (EM) problem. However, patterns of shield current on the cables are much dependent on their placement, length, grounding and coupling to the magnet environment. Therefore, absolute characteristics of shield currents become difficult to be predicted accurately. Accordingly, the placement of cable traps should also be optimized for each specific setting.

Optical glass fiber could be a promising alternative to coaxial cables for the MRI coil array interconnection to avoid EM problems completely. Because there are only optical signals transmitted, glass fiber is naturally immune to electromagnetic interference. And for the same reason, all earth grounds can be removed from the coils. Also, optical fiber has very broad bandwidth to carry a huge amount of data, analog or digital ones, with very low attenuation to maintain the signal intensity during transmission. Small cross section, light weight and mechanical flexibility of fiber make it easy to handle with. Costs of optical elements and devices are greatly reduced during these years.

A suitable optical link for MRI coil interconnection is expected to have an adjustable power gain to control the signal intensity. A flat frequency response over a wide frequency range is also desired to make the optical link possible for use at different field strengths. And low noise figure (NF) is required to avoid introducing much noise during optical transmission and reception. In addition, MRI signals often have very wide dynamic range. Therefore, a very large linear range is required for an optical link to transmit signals with the same amplification. Meanwhile, intermodulation terms should be also minimized to avoid distortion.

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A fiber-optic link always includes three primary components of an optical transmitter, a glass fiber cable and an optical receiver. In transmitter, the optical output is modulated by the input RF signal. This modulated optical signal is transmitted through the fiber and converted back into the electrical RF signal in the receiver. Optical modulation method determines the overall link performance. There are usually two modulation methods: direct modulation and external modulation. The architectures of a direct modulation link and an external modulation link are illustrated in Fig. 1(a) and (b), respectively. In general, a direct modulated optical link has simpler structure than an external modulated one. By eliminating the expensive optical modulator such as Mach–Zehnder modulator, the cost of a direct modulated optical link could reduce by more than 80% without sacrificing overall optical link performances [6]. The detail comparison between direct and external optical modulation has been demonstrated by authors in the previous work [6]. An external modulated optical link used for MRI coil connection has been demonstrated by Koste et al. [7]. In this paper, we focus on the analysis of the direct modulation method for MRI and demonstrate the first use of a direct modulation optical link at 0.3 T low field MRI to verify its applicability.

2. Methods

2.1. Link structure overview

An analog direct modulated optical link was built and the structure of the optical transmitter and the receiver are shown in Fig. 2 and Fig. 3, respectively. In the optical transmitter, the input RF signal is first amplified by a low noise preamplifier made by ourselves. A second stage amplifier could be provided for additional RF power amplification if needed. To avoid too much RF power input, a RF protection circuit is included. A 1 mW 1330 nm Fabry–Perot (F–P) laser diode (LD) is used in the optical transmitter to convert the RF signal into optical output. The automatic power control (APC) circuit is used to eliminate the laser output variation due to the temperature shift. In the optical receiver, the input optical signal is first converted back into electrical RF signal by a photo diode (PD), then pre-amplified and low-pass filtered. Variable attenuators are used in the receiver to adjust the power of the output RF signal depending on the requirement for power gain, noise figure and dynamic range. The photodiode used in the optical receiver has the linearity from r from −112 to 2 dBm. The optical transmitter and receiver are connected by a single mode optical fiber using FC/APC connectors.

2.2. Link performance evaluation

The overall link performances are evaluated by the power gain, frequency response, SNR and dynamic range in this paper for MRI applications. These four parameters are measured in a bench test using an HP 8595E spectrum analyzer. Two HP 8647A signal generators are used as the RF signal sources in the bench test.

The intrinsic power gain g_i of an ideal optical link without power loss in the fiber, can be written by Eq. (1) [8]:

$$g_i = s_l^2 r_d^2, \tag{1}$$

where s_l is the slope efficiency of the LD, and r_d is the responsivity of the PD. The slope efficiency and responsivity are 0.15 W/A and 0.85 A/W, respectively, thus the intrinsic power gain should be about −18 dB. This power attenuation of −18 dB is determined by the low power conversion efficiency of the LD and PD between electrical and

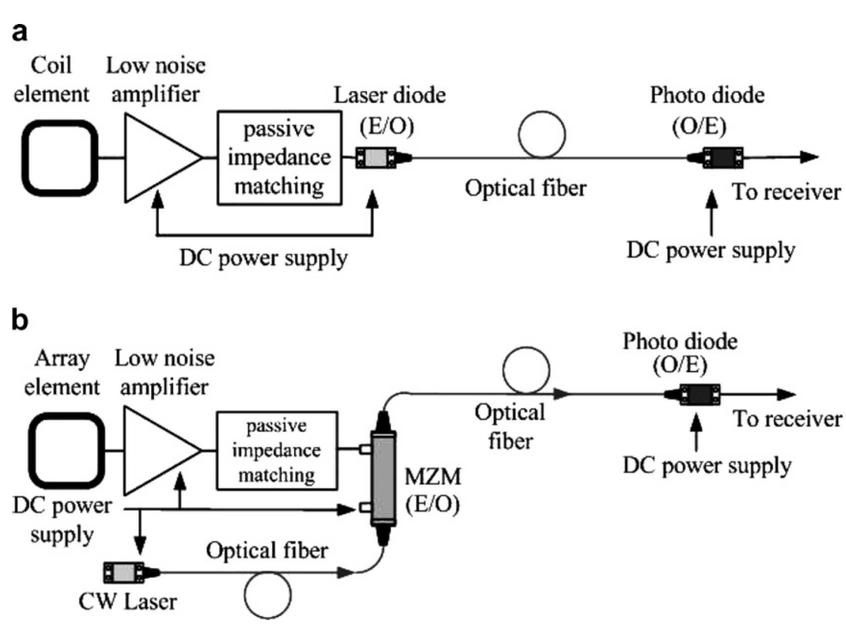

Fig. 1. Optical link structures of (a) a direct modulated link by an LD, and (b) an external modulated link by a Mach–Zehnder modulator (MZM).