Noise Figure and Dynamic Range Optimization in Optical Links for MRI Applications

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Introduction:

Electromagnetic interactions (EMI) between coil elements present a great challenge in MR array with large coil numbers. Coil interconnects by glass fibers [1] can solve the problem absolutely due to the natural immunity of optical fibers to EMI. However, applications in MRI impose some special critical requirements for optical fiber links. Noise figure (NF) and dynamic range (DR) are two major issues. Although fibers have very low loss of 0.3dB/km, it shows little advantage in the short distance application like MRI (usually less than tens of meters). MRI signal often has very high DR, which also needs optical links have high DR to avoid signal distortion.

Methods:

Fig. 1 is an illustration of k-space amplitude in log scale from a human head MR image acquired at 3T by spin echo sequence, with the pixel size of 1mm. In this figure, the MR signal amplitude has the dynamic range of 43dB. It requires the optical link has at least 86dB dynamic range in power. In order to maintain the SNR in transmission, MRI application requires the transmission link with NF lower than 1dB.

The NF of an optical link is mostly determined by the modulation component and the laser source. The minimum value of an optical link NF is 3dB and the typical value is 10~40dB for both direct modulation (DM) and external modulation (EM) link with the optical components up to date, which cannot meet the critical requirement of the NF below 1dB in MRI. Therefore a low noise preamp is necessary for an optical link to reduce the system NF. The effect of a preamp on the combined system NF is shown in Fig. 2. It is seen that the system NF approaches to the preamp NF of 1dB when the preamp gain is large enough.

3rd order intermodulation-free (IMF3) DR is used for evaluate the DR of an optical link. IMF3 is related to the 3rd intercept point (IP3), NF, gain, bandwidth (BW) and thermal noise floor (-174dBm) by Eq. (1):

$$IMF3 = (2/3)\cdot[IP3 - (G + NF + 10\log BW - 174)] \qquad (1).$$

Since a preamp is necessary, we have to consider the IMF3 of the combined system of the preamp and the optical link. A DM optical link was built. It has the link gain of -18dB, NF of 29dB and $IP3_{,link}$ of 15dBm. Its DR performance with the combination of a preamp was evaluated by Eq. (1). IP3 of the combination system is expressed by Eq. (2):

$$1/10^{IP3,sys} = 1/(10^{IP3,pre}\cdot 10^{G,link}) + 1/10^{IP3,link} \qquad (2).$$

The IMF3 DR of the cascade system for 1Hz bandwidth *vs.* preamp gain is plotted in Fig. 3. If the IP3 of the preamp is large enough, the original DR of the optical link remains when the preamp gain is less than the absolute value of the optical link gain (-18dB). However, the cascade system DR decreases significantly when the preamp gain is larger than 20dB regardless of the preamp IP3. Referring to Fig. 2 and Fig. 3, a preamp with NF of 1dB is optimized at IP3 of 40dBm and gain of 40dB, to achieve the tradeoff between DR of 110dB and NF of 1dB for the DM optical link. For a MRI application with typical bandwidth of 100KHz, the corresponding DR of the cascade is 77dB, lower than the requirement of 86dB shown in Fig. 1.

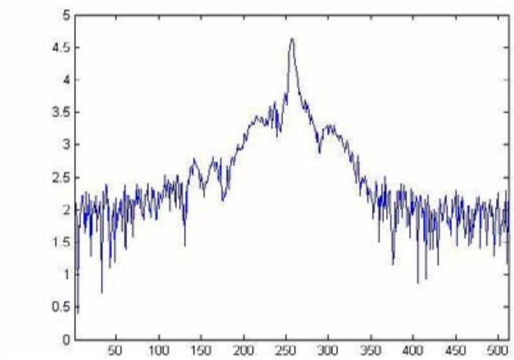

Fig.1 Amplitude of K-space data (log sclae) at 3T. Vertical axis is normalized to arbitrary value.

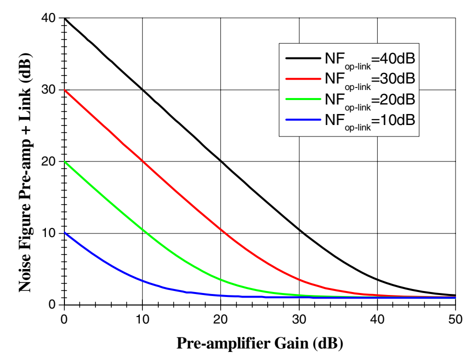

Fig. 2 NF of the combined system vs. preamp gain

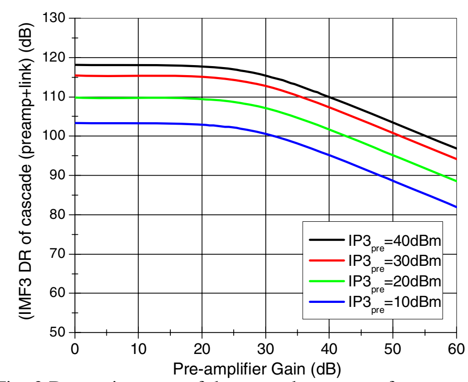

Fig. 3 Dynamic range of the cascade system of preamp and optical link

Discussion:

The low gain and high NF of an optical link are mainly caused by the inefficiency of electrical-to-optical (E/O) conversion in modulator and optical-to-electrical (O/E) conversion in photo detectors. Fortunately, the link NF could be compensated by a low noise preamp with high gain. However, the preamp also produces intermodulation distortions and reduces the system DR. The present optical link should be feasible in MRI applications below 3T. For higher field imaging, DR of an optical link is still a big issue. To increase DR by high power laser in EM optical link seems not practical so far for MR array interconnect due to the large size and high cost of the high power laser. Pre-distortion and other linearization methods can be used for improving the dynamic range of optical links, but increase the complexity at the coil.

Conclusion:

An optical link is promising for the MR array interconnect. The high NF of an optical link can be reduced significantly by the use of a low noise preamp. But a tradeoff must be made between NF and DR of the cascade system. DR of the current optical link should be further improved to meet the critical requirement in high field MRI applications.

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References:

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