A Simple Model of an Analog Fiber Optic Link for MRI

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Introduction The aim of this paper is to introduce and demonstrate a simple, yet effective, mathematical model of a directly modulated analog fiber-optic (FO) link for transmission of radio-frequency (RF) signals in magnetic resonance imaging (MRI.) Cable shield currents remain a serious safety and image quality concern in applications of RF coils for medical MR imaging. Furthermore, the cable management is becoming an increasingly important issue in coils with 16 and larger number of channels, due to the size, weight, and the rigidity of the conventional coaxial cables. RF signal transmission via an analog optical fiber link has long been recognized as a possible solution [1]. The experiments [2], although very encouraging, also confirm the adverse effects of the shot noise, which is due to the quantum nature of photon and electron processes, and the relative intensity noise (RIN) and non-linearity, which are due to the practical limitations of electro-optical devices. These effects had made it impossible in the past to simultaneously satisfy all the requirements of an ultra-high performance RF front-end such as typically implemented in a MRI scanner [3].

Approach A detailed theory of analog FO links, primarily motivated by the developments in the communications industry, is well established [4,5]. At this early stage of FO implementation in MRI, however, we felt that a simpler, yet accurate, mathematical model would be desirable, in order to answer several questions. First, what device parameters affect the analog link performance the most? Second, what performance tradeoffs are inherent in a FO link implementation? Third, what is the minimum set of device parameters required for the design?

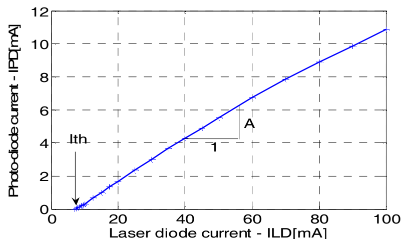

Fig. 1 Static transfer characteristics.

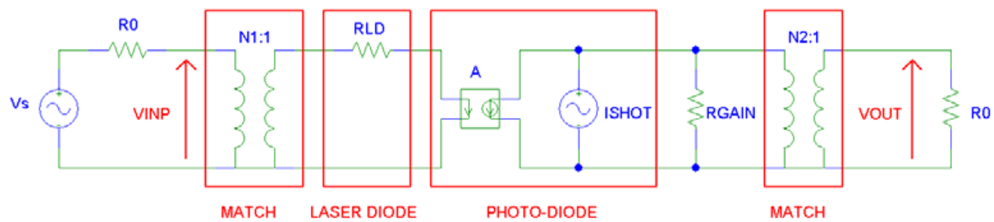

Fig. 2 Small-signal circuit model of a directly modulated MRI fiber-optics link.

The high performance laser diodes, identified through a collaborative effort with a major fiber-optics company, have such high bandwidth and come so close to the ideal shot noise performance at the frequencies of interest to MRI that a very accurate model can be deduced relying solely on the static characteristic shown in Fig. 1, a theoretical expression for the shot noise, and a simple small-signal equivalent circuit shown in Fig. 2.

Results The FO link shown in Fig. 3 has confirmed both the theoretical predictions for gain, noise figure, and the gain compression point and the value of the simple model for the optimal selection of laser and photo diodes. The shoulder images in Fig 4 were acquired with a single channel coil, while the SNR profile shown in Fig. 5 was acquired with a high-performance 12 channel head coil which had one of the channels enabled for either coaxial of fiber-optic signal transfer.

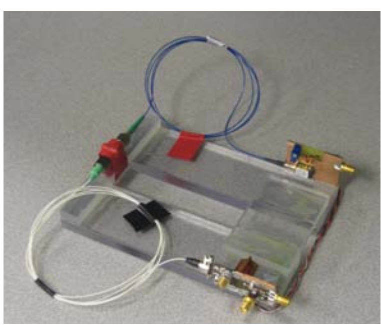

Fig. 3 MRI fiber-optic link prototype.

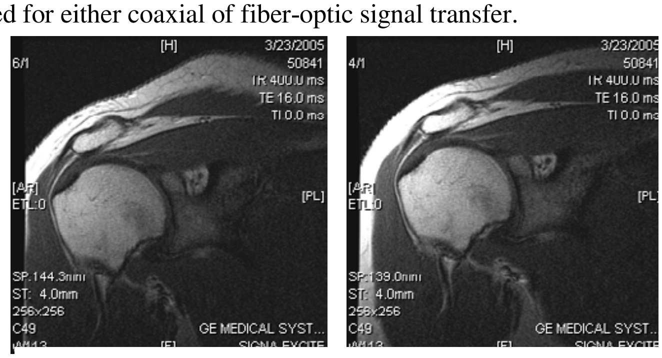

Fig. 4 1.5T shoulder scan with a single channel coil (coax left, FO right.)

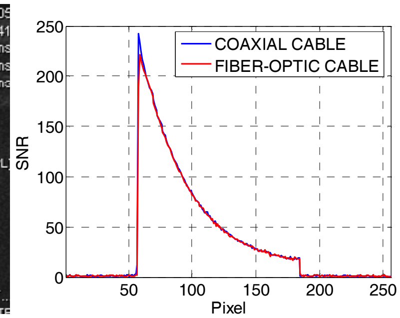

Fig. 5 12 channel SNR comparison.

Conclusion Thru a collaborative effort between major players in the MRI coil industry, the fiber-optics industry, and academia we have demonstrated an analog fiber-optic link fully compatible with the high-performance requirements of a MRI system front end. Furthermore, we have identified a simple model that accurately describes all the important link parameters and the associated tradeoffs.

References [1] O. M. Mueller, et al., US Patent #5,545,999 (1996); [2] G. P. Koste, et al., Proc. ISMRM 13-411 (2005); [3] J. Bollenbeck et al., Proc. ISMRM 13-860 (2005); [4] Charles H. Cox III, Analog Optical Links: Theory and Practice, Cambridge University Press (2004); [5] William S. C. Chang, RF Photonic Technology in Optical Fiber Links, Cambridge University Press (2002).