Investigation of dynamic range requirement for MRI signal transmission by optical fiber link

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Introduction: Optical fiber links provide an electromagnetic interference free path for MRI signal transmission. However, the dynamic range of an optical link is still an issue. The k-space domain of MRI is peaked at the center and drops rapidly toward the periphery of k-space. This range in signal intensity is referred as the dynamic range (DR). MRI signal at higher field often has wider DR than at low field. The DR of a direct modulation optical link is analyzed, and tested on 0.3T and 1.5T MRI. Solutions for improving DR of an optical link at high field are presented.

Methods: The direct modulation optical link includes an optical transmitter and an optical receiver connected by an optical fiber. The link noise floor (N) determines the minimum detectable RF signal. Non-linearities in the laser and amplifiers tend to limit the maximum RF signal. The 1dB compression point is used to specify the DR when signal tone is transmitted. However, for links transmitting signals with different frequencies, the 3rd order imtermodulation free dynamic range (IMF3) and the 3rd order intercept point (IP3) are used to specify the DR. The 3rd order intermodulation (IM) terms should be controlled below the noise floor. The dynamic range of the optical link is measured on bench test using an HP 8595E spectrum analyzer. The noise floor of the spectrum analyzer is about -76dBm with the receiver bandwidth of 10KHz.

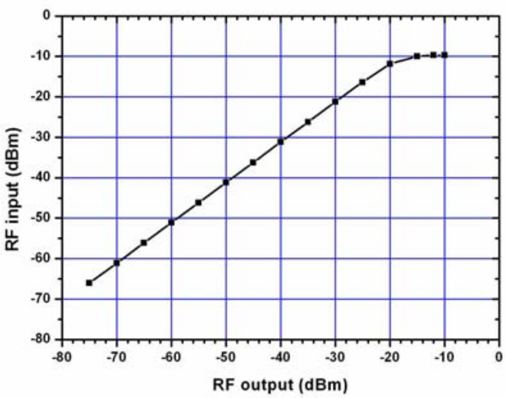

Fig.1 The linear region of the optical link

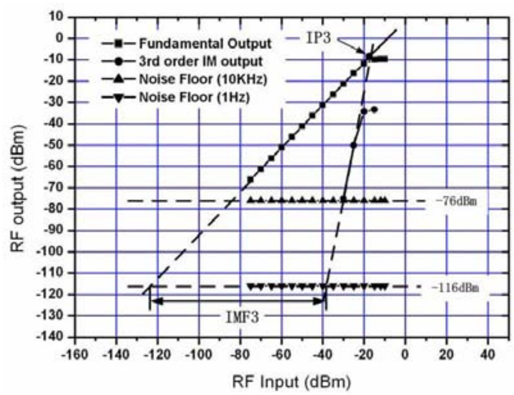

Fig. 2 IMF3 and IP3 of the optical link

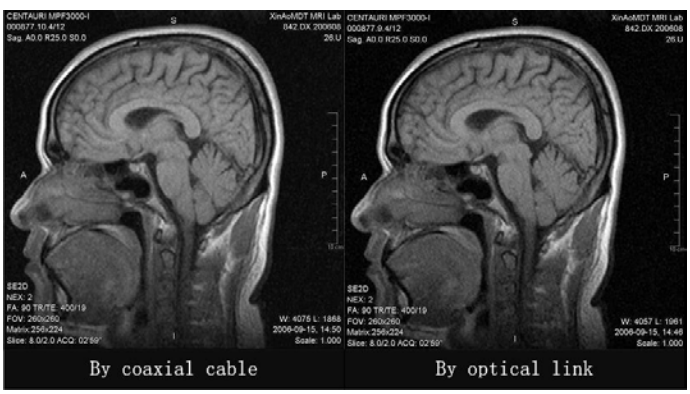

Fig.3 Head images by coaxial cable and optical link on 0.3T MRI

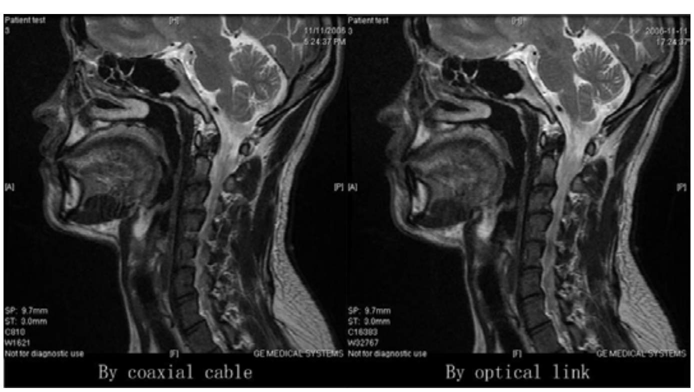

Fig.4 Head/Neck images by coaxial cable and optical link on 1.5T MRI

Results and Discussion: The linear region of the optical link in Fig. 1 is about 56dBm, from -76dBm to -20dBm. The 1dB compression point appears at -18dBm input power. IP3 and IMF3 of the optical link are shown in Fig.2. IMF3 can be calculated by IP3, noise figure (NF), gain (G), bandwidth (BW) and noise floor (N) by Eq. (1):

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

The optical link was tested on a XinAoMDT 0.3T vertical MRI for head imaging as shown in Fig. 3, compared to the image by coaxial cable. The default preamp for the head coil was used in front of the optical transmitter. A 2D spin echo sequence with TE/TR:400/19ms, NEX:2, and Matrix: 256*224 was used. There is no visible distortion found in Fig. 3, which indicates the link DR satisfies the requirement for 0.3T MRI. The MRI signal at 1.5T has much wider DR than at 0.3T. The signal intensity could be as high as -4dBm detected by an oscilloscope, which means the DR of 125dB over the receiver bandwidth of 31KHz. The link DR was optimized by the use of a low noise preamp and a variable attenuator successfully. The comparison of the images at GE Signa1.5T MRI is shown in Fig. 4. Spin echo with TE/TR:2500/84.9ms, NEX:2, and Matrix: 320*224 was used for imaging. The image quality by the optical link is also comparable with that by the coaxial cable.

Balance should be made between the noise figure and DR performances [1]. According to Friis's fomula shown in Eq. (2):

$$nf_{total} = nf_1 + (nf_2 - 1)/g_1 + (nf_3 - 1)/g_1 g_2 + \ldots\ldots \qquad (2),$$

the high preamp gain benefits the total link noise figure, so as to keep the high SNR during transmission. However, with respect to DR, if the preamp gain is too large, the amplified signal may exceed the linear range of the optical link and cause distortion. On the other hand, the too small preamp gain may limit the minimum signal intensity that the optical link could detect. Therefore, the combination of low noise preamp and attenuators is an effective method to keep balance between the noise figure and DR. Their gains and noise figures could be specifically optimized to meet the critical requirement on DR for high field MRI applications.

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References: [1] J. Yuan, P. Qu *et al*, 14th ISMRM, 2031 (2006);