Single Cable Transmission for Multi-Channel MRI Using Frequency Division Multiplexing

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Introduction: The rapid development of parallel imaging has inspired the use of large numbers of array elements, even up to 96 channels [1]. The interference caused by a number of coaxial cables seriously deteriorates the imaging quality. Therefore, the use of wireless transmission capable of AM and SSB modulation has been proposed to replace these cables recently [2]. However, this method requires precise time synchronization between transmitter and receiver clocks, which means expensive and complicated clock recovery circuits must be constructed. In addition, the transmitter and receiver power amplification circuit can not be omitted. Here we propose a method of "FDM (frequency division multiplexing)" to transmit multi-channel coil array signals by a single cable.

Theory and method: The MR signal can be treated as a frequency modulated radio signal with a bandwidth of some dozens of kHz on both sides. Here, we down converted each channel signal frequency to different lower frequencies, such as 200kHz, 400kHz etc. Then add them together and send to the processing unit.

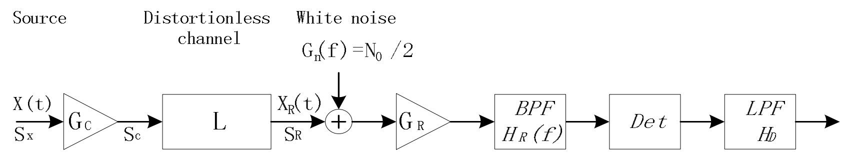

Fig.1 Signal transmission link

As in Fig. 1, when a lot of signals are transmitted through a cable, they must be bandpassed to differentiate each other. Firstly, we analyze one channel signal, and assume G_C and G_R are the gains of preamplifiers of transmitter and receiver, respectively. The bandwidth of BPF (band-pass filter) is B_T, and the pre-detection SNR is $\left(\frac{S}{N}\right)_R = \frac{S_R}{N_R} = \frac{S_R}{N_0 B_T}$. Assume the ideal LPF (low-pass filter) with bandwidth W and definitely $B_T \geq W$. So the $\left(\frac{S}{N}\right)_{D(SINGLE)} = \frac{W}{B_T}\left(\frac{S_R}{N_0 B_T}\right)$. However, in the traditional transmission link for coil array, one cable corresponds to one coil and there is not necessary to use bandpass filter to differentiate the signals. Therefore, the SNR, $\left(\frac{S}{N}\right)_{D(MULT)} = \frac{S_R}{N_0 W}$ and then, $\left(\frac{S}{N}\right)_{D(SINGLE)} \leq \left(\frac{S}{N}\right)_{D(MULT)}$. To get maximum SNR, the BPF should be built with the bandwidth close to that of LPF, which is also close to the bandwidth of signal. To minimize the costs and complexity of hardware, the fractional bandwidth should be within 1-10 percent.

In our system, the MR signals are mixed with the reference signals and their frequencies are very close to each other, about several hundreds of kHz apart. We use programmable DDS technique to get the synchronous reference signals accurately up to the resolution of 0.04Hz with a 180MHz system clock. The multiplier acts as a mixer and the mixed signal is sent to the filter to remove the up converting part. The signal of each channel is down converted to the lower frequency and each channel occupies the bandwidth of less than 200kHz.

Fig. 2 MRI two channel FDM PCB prototype

Results: A prototype of the two channel FDM PCB board is shown in Fig. 2. The two channel standard 64MHz sinusoidal signals are input to the board and the expected two different frequencies (200kHz and 400kHz) mixed signals are obtained as output to verify the FDM function. A high frequency, high Q bandpass filter is difficult to design and construct. However, after we down converted the signal frequency, the design is relatively easier. Finally, we can get the mixed signal with SNR above 95% of that obtained using the traditional method.

Discussion: This two channel FDM method can be extended to multi-channel coil arrays. This circuit could be directly integrated into the coil array, if the circuit is made more compact. After the FDM signal passed through the cable, the appropriate demodulation method should be applied, which has a critical requirement for a high quality bandpass filter. However, the signals from the different channels are set to different carrier frequencies by FDM method, so we can separate each channel by Fourier transform directly and the difficulties for the construction of a high Q bandpass filter are avoided.

Conclusions: By down converting MR signals from array channels to different lower carrier frequencies and transmitting these new modulated signals by single cable, this single cable FDM transmission method offers the possibility to eliminate numerous cables and electromagnetic interferences between channels. In the receiver end, bandpass filters with the bandwidth equal to that of the MR signal are used to separate different array channels. Above 95% of the original SNR value is maintained during single cable FDM transmission.

References:

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[2] G.Scott et al, Wireless Transponders for RF Coils: Systems Issues, Proc ISMRM 13, 330 (2005).

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