An investigation on the channel spacing limits in SSB-based wireless MRI receiver arrays

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Introduction: Reducing the number of coaxial cables in large MRI receiver arrays mitigates the negative effects associated with cable interactions and cable loops. Multiple groups have proposed using frequency-multiplexing techniques like single sideband amplitude modulation (SSB) to transmit the array's many signals on a single cable or wirelessly [1-3]. In theory, the frequency spacing required for the encoded signals is only limited by the bandwidth of the MR signal. This would allow for a very dense transmission spectrum, which is necessary when transmitting all the signals from highly parallel detector arrays. Unfortunately, this dense spacing only works if the noise outside the MR signal bandwidth does not impact the other multiplexed signals. In this work, we investigate the practical limit of spacing in SSB-based arrays by constructing an eight channel wireless head array for 1.5T.

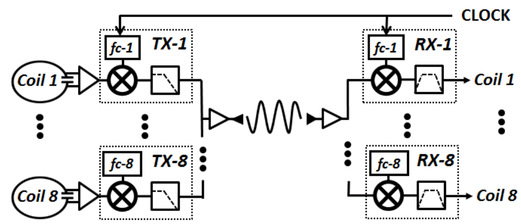

Figure 1: Simple diagram describing the SSB-based eight channel wireless head array.

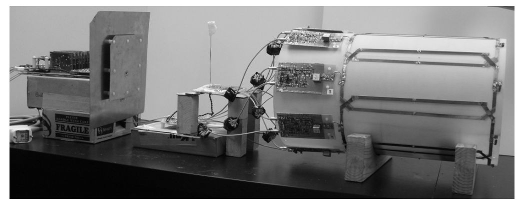

Figure 2: Picture of completed wireless head array

Methods & Materials: Array Construction: Eight rectangular (27x13cm) 63.6MHz coils were mounted on a 25cm diameter cylinder. As illustrated in figure 1, the output of each coil's preamplifier was fed to a local SSB transmitter module (*TX-n*). There, the MR signal was multiplied with a unique high frequency carrier (*fc-n*) and the lower sideband was selected with a 7^{th} order Chebyshev low-pass filter. The modulated MR signals were combined and transmitted with a single antenna. The cumulative wireless signal was received and split into receiver modules (*RX-n*). Each receiver module mixed the cumulative signal with a carrier that corresponded to a particular transmitter module and coil, which recovered the coil's original signal content. The recovered signals were then treated as if they were normal MR coil signals. To ensure synchronization between carriers, a 1ppm 5MHz clock was fed to all the modules. Important system parameters, including SSB dynamic range & -1dB gain compression point, were designed to preserve MR signal quality. Figure 2 shows the constructed wireless array.

Channel Spacing: Figure 3 depicts a measured noise profile from a single transmitter module. Despite aggressive sideband filtering, substantial off-band noise still existed from the preamplifier and carrier. Using this noise profile, a simulation was performed to determine the optimal spacing for eight SSB channels. The increase in signal noise floor was calculated for each possible combination of eight carrier frequencies. The transmission bandwidth of the antennas restricted the carriers to be between 905MHz and 980MHz. Due to limitations in the PLL+VCO combination used, carrier frequencies were also restricted to only multiples of 5MHz. The microcontrollers that handle carrier generation [4] were programmed to use the channel spacing combination that resulted in the smallest increase in signal noise floor.

SNR Performance: The noise figure for one channel was measured: (1) with only the preamplifier, (2) with only the single channel operating wirelessly, and (3) with all the wireless channels simultaneously operating. These noise figure measurements were repeated for each channel in the wireless array. The wireless array was then used to image a water phantom on a Siemens Espree 1.5T system. Images were collected both wirelessly and directly from the preamplifier outputs. Each wireless channel signal was collected individually and with all channels transmitting. The acquisition used was a GRE acquisition: TE/TR/FA=10ms/150ms/47˚, 225x225mm, 128x128, BW=100Hz/Px. Multiple slice thicknesses were used to vary the acquisition signal-to-noise ratio (SNR). For each acquisition, an additional 0˚ noise scan was also acquired to quantify SNR.

Results & Discussion: The optimal channel spacing was found to be a simple channel separation of 10MHz. Off-band noise from the preamplifier prevented smaller channels spacing, and the carrier noise prevented larger channel spacing. Figures 4 & 5 show that a single wireless channel preserved the MRI signal quality well. When all the wireless channels were transmitting, the noise interference from the other channels had a large impact on the MRI signal quality. This loss of signal quality would have likely been worse if the channel spacing had not been optimized. Through optimization, the wireless array was able to collect useful anatomical images, as shown in figure 6.

Conclusion: The spacing of channels in a SSB-based wireless array is not limited by the MRI signal bandwidth, but by the filtered noise profile of the outputs from the wireless system. This must be taken into consideration to avoid substantial SNR loss when implementing a wireless solution for receiver arrays. Our results show that the upper limit of wireless SSB transmission density is significantly lower than predicted by the MR signal bandwidth alone.

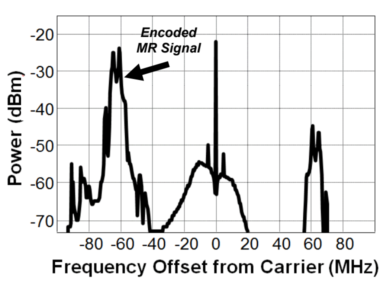

Figure 3: Measurement of output noise from a transmitter module. Noise is present from both the preamp & carrier.

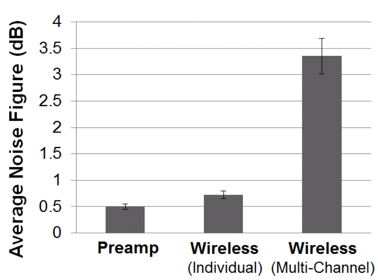

Figure 4: The average increase in noise figure when a single channel is transmitting vs. all eight channels transmitting together.

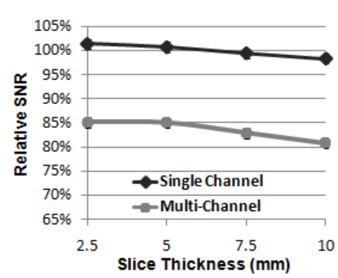

Figure 5: The average phantom SNR decrease in wireless transmission when compared to a wired counterpart.

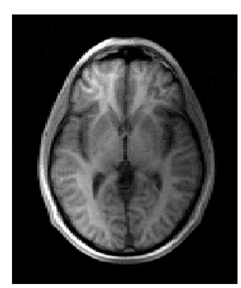

Figure 6: A GRE head image acquired wirelessly with the eight channel wireless array.

Acknowledgements: This research was supported by Siemens Medical Solutions and the Ohio Third Frontier Project Innovation Incentive Fellowship. Thanks to Hiroyuki Fujita from Quality Electrodynamics. **References:** **[1]** Scott G et al, Proc. ISMRM #330, 2005., **[2]** Wei J et al. Proc. ISMRM #220, 2006., **[3]** He et al. Rev Sci Instr. 78(1):15102, 2007 **[4]** Riffe M et al. Proc. 17th ISMRM. 2010; #2936.