On the operation of Bluetooth devices inside the MR Faraday cage

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Introduction Bluetooth technology provides an attractive means of communicating with devices confined within the Faraday cage of the MR magnet. Operating at 2.4GHz, the operation frequency is well outside the passband of the MR signal. Unfortunately, the Faraday cage significantly attenuates a Bluetooth signal such that communication becomes unreliable. To circumvent this, a USB Bluetooth transceiver can be placed within the waveguide enabling broadcasting of the Bluetooth signal inside the Faraday shield. Compromising the waveguide using this RF antenna however could introduce spurious RF noise that falls within the passband of the MR system and contaminate the images with additional noise. The purpose of this study was to quantify the communication reliability of Bluetooth devices compared with image noise contamination by compromising the waveguide.

Methods All experiments were performed on a GE 1.5T HDX scanner using the quadrature transmit receive head coil (GE Medical Systems USA). Both MR transmitter and receiver gains were kept constant throughout the experiment. A single, axial slice was acquired using a fast spoiled gradient echo sequence with imaging parameters TR/TE/θ=10/1.8/30, a +/- 250kHz read bandwidth, and 512 readout points. 512 phase encodes were also acquired, however with the phase encoding gradients disabled. This yielded 512 repeated averages of the noise signal.

As the noise signal, a 63.8MHz sinusoidal wave was created using a signal generator and amplified using a wide band 25 Watt RF amplifier (Amplifier Research, USA). This antenna was placed 2 meters away from the waveguide, in a vertical orientation. A Bluetooth transceiver attached to an USB extension cable was incrementally inserted into the waveguide. An MR image was acquired at each insertion depth and the magnitude of the introduced 63.8MHz noise wave were captured with the 512 repeated phase encodes. The noise data were normalized to noise achieved at 0% insertion depth. Additionally, for each insertion depth, the reliability of the Bluetooth connection was evaluated by placing a connected device positioned on the opposite edge of the room inside the Faraday shield however out of a line of sight. Using the Linux 'hcitool' receiver signal strength indicator (RSSI) values were recorded. The returned RSSI value was normalized to the RSSI value achieved when a Bluetooth compatible device was placed immediately next to the transceiver.

Results Figure 1 shows an image of the Bluetooth transceiver and USB antenna, while figure 2 shows the measured introduced RF noise as a function of antenna distance within the waveguide. The insertion of the antenna resulted in an increase in noise amplitude however no frequency response was observed. The introduced sinusoidal noise peak is detectable even through the RF shield without any antenna insertion. This single peak shows little increment as the antenna is inserted; however increases dramatically as the tip of the antenna is inserted into the room. Figure 3 shows the normalized RSSI of the Bluetooth devices.

Discussion By insertion of a Bluetooth transceiver even up to 80% of the length of the waveguide, no more introduced noise is detected by the MR system than without the transceiver in place. However, Bluetooth communication efficiency is drastically improved when the antenna is inserted even half way through the waveguide. Within this limit as a threshold, Bluetooth transceivers can be introduced into the MR room without compromising image quality. This opens the door to a wide array of both controller devices, such as keyboards and mice, as well as Bluetooth headsets for communication between operators inside and outside the room.

Figure 1: Bluetooth transceiver and devices
A simple USB extension cable is used to extend the communication range of the a class 2 Bluetooth transceiver (Kingston Technology, USA). Additionally pictured is a Bluetooth enabled mouse (Microsoft, USA) that was used to test communication strength.

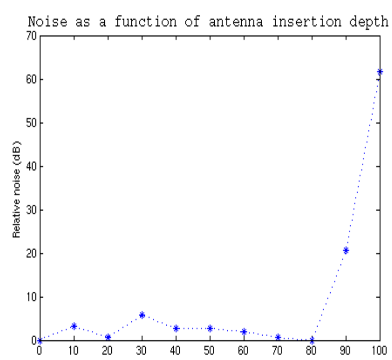

Figure 2: Normalized noise detected through RF cage as a function of antenna penetration
Detected noise inside the MR system is negligible up to an insertion depth of approximately 80% the length of the waveguide. After this point, the waveguide is compromised enough that spurious noise can start entering the MR image.

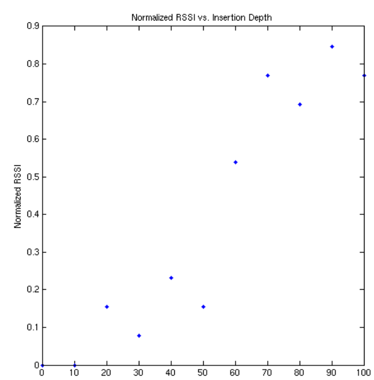

Figure 3: SNR of Bluetooth as a function of antenna penetration depth
Bluetooth communication reliability increases when the antenna has past the halfway point of the waveguide, reaching approximately 85% the level of the RSSI achieved with no obstructions.