An Integrated mm-wave Transceiver for Wireless MRI

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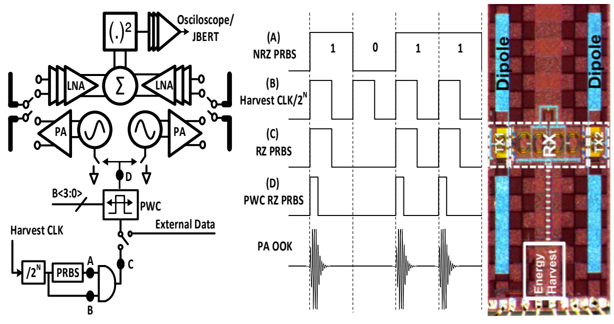
Introduction: Since its inception, MRI has always relied on a wired connection between the receiver coil array and the external processing circuitry to generate accurate images. With the ever increasing size of receiver coils arrays the complexity of the cabling for this connection has also increased as baluns are required for each channel and cables must be routed to minimize coil interactions. This in turn has led to an increased focus towards the development of wireless MRI systems [1]-[6] to minimize or remove these cables. All these efforts use frequencies (up to 3GHz) and protocols (802.11b, MIMO, etc.) that are intended for long range (10-100m) data communication. This results in a sub-optimal solution for wireless MRI receiver coil arrays, which demand a short range <1m, high data rate wireless system with minimal power consumption. Here we report our progress towards a wireless transceiver that has been designed specifically for wireless MRI receiver arrays. The transceiver operates in mm-wave frequencies with RF carrier at 60GHz. The transmitter (TX) power scales from 260µW to 11.9mW supporting data rate from 38Mbps to 2.45Gbps at a distance of 10cm using on-off keying (OOK) modulation. The transceiver occupies an area of 1.62mm^2 in TSMC 40nm CMOS process.



(a) **(b)**

Figure 1: (a) Transceiver architecture and the TX timing diagram, (b) Die photo (0.9x1.8mm^2)

Methods: The MRI transceiver architecture and TX timing diagram is shown in Fig 1(a). The transmitter baseband generates a return-to-zero (RZ) bit stream from a non-return-to-zero (NRZ) input data which is then fed to the transmitter radio frequency (RF) front-end. The transmitter consists of two identical TX elements. Each TX element consists of a voltage controlled oscillator (VCO), a power amplifier (PA), and an on-chip dipole antenna. The VCO drives a class F^{-1} PA with a simulated drain efficiency of 29%. The VCO and the PA are turned on and off by the pulse width controller (PWC) modified RZ bit stream to generate impulse radio ultra wide-band (IR-UWB) waveforms at the PA outputs.

The receiver (RX) frontend consists of a 3-stage transformer coupled low noise amplifier (LNA). The last stage sums the received signals from the two dipole antennas, resulting in an improved sensitivity. A passive AC-coupled self-mixer is used to extract the OOK modulation envelope. The RX baseband is a 3-stage DC-coupled inverter chain followed by a common-source amplifier with programmable resistive load. The last stage drives an external 50Ω load and is biased in class C. To make it truly wireless, the transceiver also includes RF energy harvesting circuit operating at 2.5GHz. It comprises of four stages of cascaded CMOS rectifiers with its output connected to an on-chip 3nF capacitor for energy storage thus eliminating any wires for the power supply.

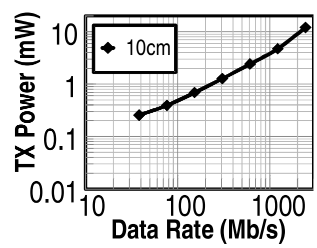


Figure 3: Measured TX power vs data rate

Results and Discussion: The proposed transceiver was fabricated using TSMC 40nm CMOS process and is shown in Fig. 1(b). The transmitter power consumption varies from 260µW to 11.9mW as the data rate is increased from 38Mbps to 2.45Gbps as shown in Fig. 3. The RX including the baseband (BB) drivers consumes 74mW.

The proposed transceiver addresses multiple challenges associated with wireless MRI systems:

a. *High Data Rate:* As compared to analog transmission, the digital transmission offers better noise immunity, stability and flexibility. The proposed transceiver can easily support high data rates generated by commercially available ADCs designed to meet MRI system's SNR requirement. For example, Texas Instruments ADS5263 processes data from four receiver coils to produce 1.6Gbps of raw data.
b. *Clock Synchronization:* The energy harvesting circuit in the proposed transceiver also generates a clock on the transmitter side which is used to sample the NRZ data before transmission. Thus multiple transmitters in the MRI bore can be synced by using an external RF energy source thus solving the problem of clock synchronization between multiple channels.
c. *Scalability:* One of the major problems with wireless MRI is scalability. As the number of receiver coils increase, the probability of interference between multiple wireless channels also increases. The proposed architecture solves this problem in two ways. First, each transceiver can easily support data from four receiver coils thus reducing the number of wireless channels by a factor of four. Second, the design uses highly directional, linearly polarized, on-chip dipole antennas which can be placed orthogonal to each other along the MRI bore as shown in Fig. 4. This reduces the cross talk significantly.

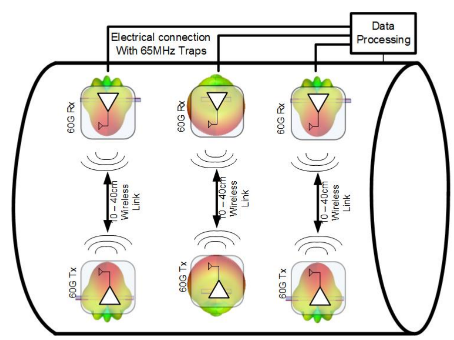


Figure 4: Side-view of MRI bore with orthogonal TX-RX links with their respective antenna patterns.

Conclusion: RF transceivers based on mm-wave frequencies offer a low power, scalable solution for short range, high data rate systems like wireless MRI. The next step is to test this transceiver inside an MRI bore and compare the image quality with state of the art MRI system.

References: [1] Y. Murakami, US Patent 5,384,536 Jan 1995 [2] E. Boskamp, US 2003/020619A1, Nov 2003 [3] G. Scott, ISMRM 2005 [4] M. J. Riffe, ISMRM, 2009 [5] J. Wei, JMR 2007[6] O. Heid, Proc. ISMRMed 2009.

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