Superconductor Analog-to-Digital Converter for High-resolution Magnetic Resonance Imaging

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Abstract — Magnetic resonance imaging (MRI) requires a sensitive radio receiver to detect the weak resonant magnetic field from nuclear spins, usually hydrogen in biological tissues. In a typical static magnetic field of 1.5 T, a transient RF magnetic field at 63 MHz must be measured to fT amplitudes. This must be amplified and then digitized with an analog-to-digital converter (ADC) with a high dynamic range (typically 16 bits), in order to obtain high image resolution. As the magnetic field is increased in order to obtain even finer resolution, the required dynamic range is expected to increase further. A superconductor ADC (oversampling at 20 GHz) has previously been demonstrated to exhibit very high dynamic range (up to 24 bits) as part of a receiver for broadband digital-RF communication. Here we present preliminary results on a similar ADC applied to a 4 T commercial small-animal MRI system, substituted for the built-in 16-bit ADC. The superconductor ADC was mounted on a 4K cryocooler in a magnetically shielded container outside the MRI room, and functioned well despite the presence nearby of a large static field and a high power RF transmitter. Images were obtained either using direct digitization of the 170 MHz signals, or alternatively using a low-noise analog mixer and digitization of a 1 MHz intermediate frequency signal. While the results demonstrated the superior dynamic range of the superconductor ADC, further improvement was limited by the thermal noise from the room-temperature pickup coil. Current work is investigating the use of a cryocooled coil (which may be superconducting) and a cold low-noise preamplifier in order to take full advantage of the large dynamic range of the superconductor ADC. This should permit improved spatial resolution, allowing one to "zoom in" to a region of interest.

Keywords (Index Terms) — Analog-digital conversion, Cryogenic electronics, Dynamic Range, Magnetic Resonance Imaging, Radio receivers, Superconducting integrated circuits