An Open Source Mobile NMR Relaxometry Platform

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Target Audience: This work is relevant to those interested in low field NMR, portable NMR, and NMR relaxometry.

Purpose: In recent years a great deal of effort has been put into developing small, low cost MRI and NMR magnets and coil arrays. Such efforts are aimed at a wide variety of applications, such as depth profiling, material and fluid characterization, biosensors, and quality control[1,2,3]. While the focus of such research is on the development of the magnets and coils, a hardware platform for conducting NMR experiments is also required. Unfortunately, such research is often forced to make use of repurposed equipment with costly, excessive features, or undesired limitations. Previously, we attempted to address this issue by presenting a low cost NMR system based on the Arduino platform[4]. Here we present the next generation of the system. The new system implements a fully packaged and functional NMR relaxometry platform that is capable of operating as a standalone unit for portable or mobile applications. The platform has improved versatility and performance with regards to experimental design and sequence execution. The design of the platform is open source[5].

Methods: *System control*: A AT32UC3C1512 MCU from Atmel was used as the main processor that allowed for more sophisticated and configurable pulse sequences, and faster handling of sequence events compared to the previous generation. *RF signal chain*: With the exception of the transmit power amplifier (TPA), the RF chain was broadband (5-80 MHz). An AD9958 dual channel DDS was used to generate the RF prototype signals for the TPA and the downconverter local oscillators. The TPA was implemented as a Current Mode Class D topology whose amplitude was modulated using a high bandwidth digitally-controlled supply voltage. The TPA was the only part of the RF chain which needed to be tuned to a specific frequency. The RF receive amplifier has a nominal NF of 2.3dB, and its gain can be digitally varied between 43 and 89 dB. This version of the system used a zero-IF downconversion architecture, with the orthogonal LOs being provided by the two channels of the DDS. The baseband outputs were fed to anti-aliasing filters with f_c=180 kHz and G=23.5 dB. The quadrature baseband signals were sampled by a 14 bit simultaneous sampling ADC. Fig 1 shows a block diagram of the full system. *Interface*: While operating in standalone mode, the platform stores experiment parameters and all sampled data on a micro SD memory card. The platform also features a touch LCD module, which provides a user interface when not connected to a PC host. In order to define experiments and analyze sampled data, the platform must be connected via USB to a host PC running MATLAB. *Packaging*: The NMR magnet and coil are not integrated into the platform itself, and must be connected to an external NMR probe via a 50 Ω coaxial cable. The platform hardware is packaged into a shielded enclosure, and includes a rechargeable 14.4V battery pack that can provide power for over 6 hours of continuous use. The combination of a standalone user interface, nonvolatile memory, and an integrated battery pack makes it possible to operate the platform as a standalone system. A photograph of the platform is shown in fig 2. *NMR Experiment*: We used the platform with a 8.35 MHz custom surface magnet and surface coil[6] to measure the overall magnetization and T_2 of epoxy adhesive as it sets and cures. The experiment used a simple phase-cycled CPMG sequence with TE=60 µs and 300 echoes, with TR=0.5 s.

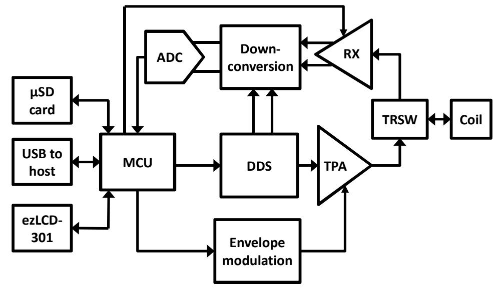

Figure 1: Block diagram of the NMR system

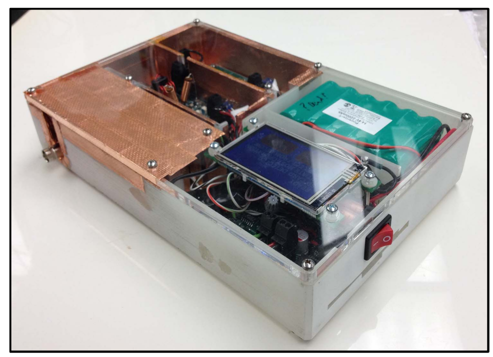

Figure 2: Photograph of the platform

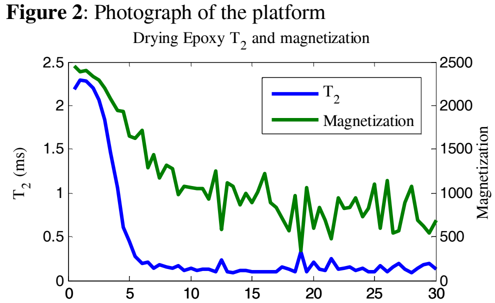

Figure 3: Plot of T_2 and overall magnetization for a sample of epoxy over time.

Results: Fig 3 shows the results of the example experiment described above. Groups of 60 raw sequences are averaged together to provide one overall measurement every 30 seconds. The transition from the setting phase to the curing phase can clearly be seen by the sharp drop in T_2, which occurs as a result of rapid crosslinking in the polymer chains.

Discussion: The robust packaging of the hardware, along with the versatile firmware, provides good performance and relatively easy operation. In other experiments, we have shown that the platform is capable of performing relaxometry experiments similar to those found throughout literature and industry[6]. The current version of the platform was intended only for use in relaxometry applications in highly inhomogeneous static fields, and therefore did not include a gradient system. Another limitation of the platform was its narrowband TPA, which must be manually re-tuned when changing operating frequency by more than approximately 1%.

Conclusion: Our results demonstrate a working NMR relaxometry platform that can perform various relaxometry experiments with a variety of magnets and frequencies. The platform is fully packaged and can operate in a standalone mode, making portable and mobile applications feasible. The platform dimensions are 23.8x15.7x4.9 cm, and weighs 1.3 kg. It is constructed almost entirely from off the shelf components, and the materials are estimated to cost less than $750 USD. All aspects of the design are open source, and are available online[5].

References: [1] "Advances of unilateral mobile NMR in nondestructive materials testing," *Magn Reson Imaging*, vol. 23, no. 2, pp. 197–201, Feb. 2005. [2] Bruker Optics, "Solid Fat Content (TD-NMR)," 2012. [Online]. [3] Goga N O "Non-destructive characterization of materials by single-sided NMR," Dissertation, Rheinisch-Westfälische Technische Hochschule Aachen, 2007. [4] Twieg M "An Open Source Low-Cost NMR System," ISMRM 2012, Montreal, Canada, 2012. [5] Twieg M [Online]. Available: http://ccir.case.edu/Research/mri/lowcostmr/V2intropage. [6] Twieg M "Open Source NMR Relaxometry Platform," Thesis, Case Western Reserve University, Cleveland, OH, 2013.