An Ultra-low Cost Software-Defined Radio based NMR spectrometer

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In recent years, software-defined radio (SDR) systems, targeted mainly at data communications applications, have been appearing in the marketplace. As these systems have become more capable and lower cost, application of such hardware for NMR has become increasingly attractive. A number of groups have described SDR-based NMR systems, some examples can be found in [1-3].

A new inexpensive SDR system known as LimeSDR recently became available at a remarkably low cost (US$299) through a crowd-sourced funding model[4]. The system consists of a single board that is connected to a host computer via USB 3. It incorporates both transmit and receive systems, and is tunable from < 1 MHz to > 3 GHz.

This contribution describes our work to develop a complete high-performance multi-channel NMR spectrometer built using LimeSDR boards. The LimeSDR contains three main components: an LMS7002m SDR device, an FPGA that manages data communicates with the SDR, and a USB3 interface chip. The entire system is "open source" in that all of the software, firmware, and hardware source is available and free to be modified.

The core of the system, the LMS7002m SDR chip, contains what is essentially an analog NMR transmitter & receiver system. On-chip offset, phase, and channel balance calibration facilities are combined with a sophisticated digital transceive signal processor (TSP) resulting in a system that provides many of the advantages of fully digital rf. Residual artifacts of the analog system can be digitally shifted far outside the spectral window by the on-chip numerical oscillator and digital mixers. The chip has the capability of both analog and digital filtering of transmit and receive signals, as well as variable gain on both paths.

A number of general-purpose input/output lines on the FPGA should allow for the control of external devices (eg transmitter blanking and receive gating), although modifications to the FPGA "gateware" will be necessary to make this a reality. At present, the SDR board is synchronized to a more traditional pulse programmer (eg SpinCore Technologies PulseBlaster) to allow control of these other devices.

The SDR boards have been integrated into an existing home-built NMR spectrometer software system that provides a friendly graphical user interface for acquisition, parameter variation, and routine data processing. The software also allows for extremely simple and flexible pulse programming (examples shown in Fig. 1), that exposes the full power of the underlying hardware. Multiple transmitters and multiple receivers are supported. Sequence complexity and length are limited only by the resources of the host computer.

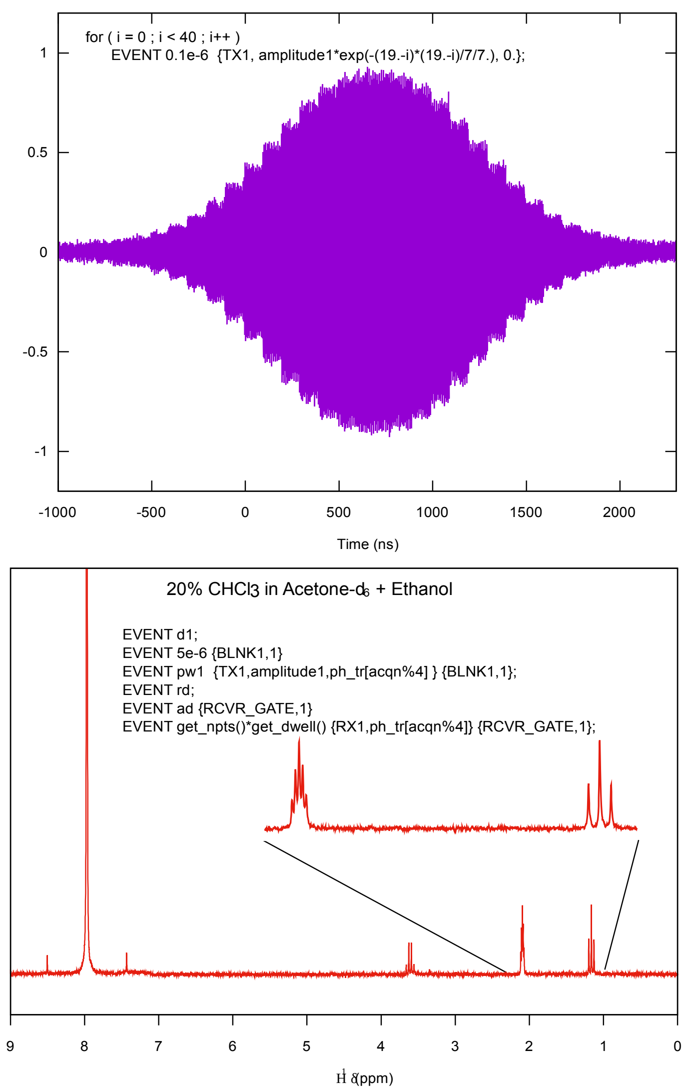

Figure 1. (a) Oscilloscope capture of the rf output (at 200 MHz here) of a LimeSDR board transmitter. The text indicates the two lines of pulse program code necessary to generate the (intentionally coarse) Gaussian pulse. Note that the amplitude steps each last just 100 ns, but could actually be shorter! (b) A ^{1}H NMR spectrum of a chloroform/acetone-d_6/ethanol sample collected in a single scan processed with 0.2 Hz exponential line broadening and Fourier transformation. The body of the pulse program used is shown.

References

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[3] C. J. Hasselwander, Z. Cao and W. A. Grissom. JMR **270** (2016) 47-55.
[4] http://www.crowdsupply.com/lime-micro/limesdr