The RTL-SDR USB Dongle: A Versatile Tool in the RF Lab

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Target Audience: RF engineers, MRI physicists, service technicians and engineers

Fig. 1: DVB-T stick with ferrite cores, and input attenuator.

Purpose. A few years ago, enthusiasts discovered that some low-cost USB DVB-T sticks can operate as frontend for multipurpose Software Defined Radio (SDR) receivers. This approach provides an enormous flexibility and a very active community is developing a growing number of open source software. Meanwhile, this solution is used in academic education [1] and research [2]. Here, we show that MRI researchers might also benefit from such a device.

Material and Methods. The USB dongles used for this study were NESDR Mini (*NooElec, Oscoda, MI*). The main receiver components are the tuner chip R820T (*Rafael Micro, Hsinchu, Taiwan*) and the 2ch. ADC and USB interface RTL2832U (*Realtek, Hsinchu, Taiwan*). The input connector type is MCX. Bypassing any decoder, real/in phase (I) and imaginary/quadrature (Q) raw data streams (8-bit unsigned integer format, 2 bytes per sample) are provided (Fig. 2). A sample rate of 2.4 Msps is recommended, the input frequency range is typically from 24 to more than 1800 MHz. Depending on gain setting, the minimum noise figure for the tuner chip is advertised as 3.5 dB [1], the maximum undistorted input level is around −10 dBm. External attenuators are required when scanner Tx pulses are being captured. During overload condition, the ADC simply clips the data to full-scale values. Input impedance (Fig. 3) has been measured (*VNA ZVT 8,Rhode&Schwarz, Munich, Germany*). It is finally good practice to place ferrite cores on both the USB and the input cable to avoid electromagnetic interference problems.

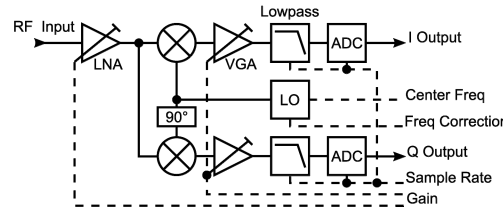

Fig. 2: Block diagram of the RTL-SDR-dongle.

On a Windows-computer, the freeware SDR# [3] is a good starting point to gain initial experience with the RTL-SDR dongle. The installation script also downloads a tool named Zadig, which is required for installing the alternative device driver. To capture the complex data samples and control the stick from a command line or script-file (e.g., MatLab/Octave, Python) another software layer is required. The Osmocom site [4] provides zipped pre-built Windows binaries as well as source code for Linux and related OS via a git repository. Recording raw data with the program rtl_sdr.exe, as suggested in [1], was not satisfying because of occasional data losses. However, there is a TCP server included in the Osmocom package, and a TCP client was written in C. Buffering the data in allocated (physical) memory before writing them to disk prevented data losses. An input level indicator was added as a helpful feature considering the low resolution ADC. The command interface of our TCP-client is text-file based.

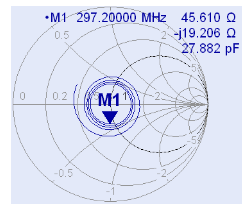

Fig. 3: Input impedance; freq. range is 30 to 300 MHz.

There are a few hardware limitations, which have to be overcome in practice, such as frequency and gain drifts after cold start-up [2]. At least 10 min. warm-up time must be scheduled. A remaining frequency offset can be minimized by applying the rtlsdr_set_freq_correction command. Even if the lowest possible gain setting is selected and automatic gain control is disabled, an uncertainty may appear. Probably depending on RF input level during start-up one of two (approx. 20% difference) sensitivity levels will be chosen. Repeated calibration by means of a reference generator is strongly recommended.

Especially at low gain settings, quantization white noise dominates and hides some spurious signals. An external amplifier might thus be needed for improved results. Noise power might be lowered by reducing bandwidth (e.g., narrow Bessel band-passes). Alternatively, an additional mixer stage was implemented through post processing (Fig. 4). The subsequent low-pass was implemented as 12-point moving average (MA) filter (Figs. 5, 6); 26 filter passes approximated a Gaussian filter response [5] well. To maintain sufficient sum frequency suppression, the dongle center frequency should be tuned to not less than 80 kHz away from the signal frequency.

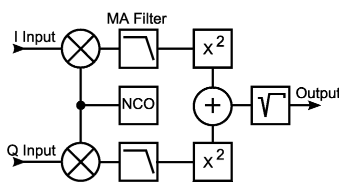

Fig. 4: Post processing (PP): Mixer, filter, and amplitude demodulation.

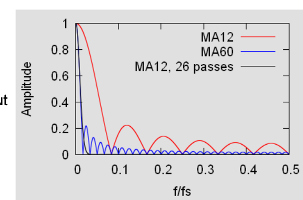

Fig. 5: PP (as in Fig. 4) filter frequency response.

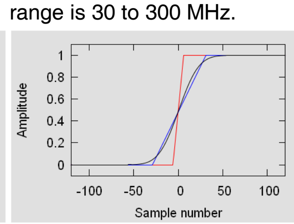

Fig. 6: PP filter step response, colors as in Fig. 5.

Results and Discussion. With the current implementation, a simple but versatile tool with excellent price/performance ratio is obtained. Among the range of potential applications in MRI are amplitude demodulation to restore the RF-pulse envelope and spectral analysis. Recording transmitted RF pulses can help to identify errors during sequence development or to malfunctioning scanner hardware. As an example, the RF pulses of a twice-refocused spin-echo sequence recorded from a 3T clinical scanner (*VERIO, Siemens, Erlangen, Germany*) are shown in Fig. 7. An RTL-SDR dongle-based FFT-spectrum analyzer can detect RF noise sources which may cause image artifacts. This is of growing interest given the increasing number of electronic devices operated in the magnet room or even inside the bore (e.g. stimulation devices, video cameras for motion tracking, devices for physiologic monitoring or eye tracking). Unwanted RF sources near the Larmor frequency and insufficient shielding may be easily identified.

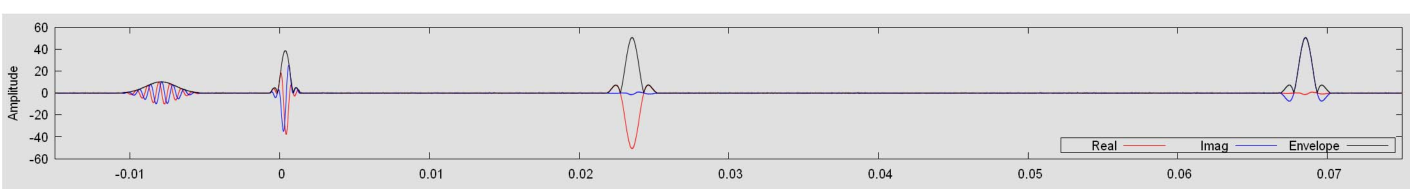

Fig. 7: Twice-refocused spin-echo sequence ($90°_y$-$180°_x$-$180°_x$) with preceding Gaussian water-suppression pulse.

Conclusion. Due to its flexibility and low cost, an RTL-SDR dongle might be an attractive diagnostic device for MRI labs.

References. [1] M.A. Wickert. *http://www.eas.uccs.edu/wickert/ece4670/lecture_notes/Lab6.pdf* [2] M. Higginson-Rollins et al. *Am. Astron. Soc. Meeting Abstracts 223* (2014) [3] *http://sdrsharp.com/#download* [4] *http://sdr.osmocom.org/trac/wiki/rtl-sdr* [5] P. Kovesi. *Proc. DICTA, Sydney* (2010).