

Radio Astronomy with RASDR2 and RASDRviewer¹

D. Fields², P. Oxley, B. Vacaliuc³, C. Lyster, S. Kurtz⁴, Z. Tamosevicius⁵ and S. Berl
Tamke-Allan Observatory⁶
Roane State Community College
276 Patton Lane
Harriman, TN 37748

ABSTRACT

The RASDR design team is releasing a software-defined receiver (SDR) for radio astronomy called RASDR2⁷. The receiver consists of two high-density circuit boards -- a wide-band femtocell⁸ chip on the front end analog interface MyriadRF board⁹ linked to a DigiRed digitization and function control board -- coupled to a computer via either a USB2 or USB3 interface. RASDRViewer software runs in a Windows environment and performs receiver control, FFT analysis, spectrum averaging, power monitoring and other functions. Depending on the specific application, RASDR2 is used with an antenna, filter, preamplifier, optional upconversion or system control devices, and external frequency/time reference signals. The team has three RASDR2 units in operation and is working to make units available to SARA members.

This presentation covers RASDR2 application to solve some common experimental challenges encountered by members of the community of amateur radio astronomers. Results of operation in several RF spectral bands will be shown and discussed. These results include monitoring HI emissions from distant clouds, interfacing to the NRAO 40' radio telescope to record spectral data; interfacing to the NRAO 20m radio telescope to record and extract information from data taken at different observing sessions; monitoring a 10MHz section of the commercial FM band with a wire antenna; and monitoring a section of the crowded HF short wave band with a wire antenna. The use of upconverters is discussed. Software analysis was done with RASDRwindows, Excel, and Python. [NRAO 40' and 20m results are omitted from this version of the paper but were discussed in the presentation. They will be documented separately.]

Details of RASDR2 software, firmware and basic hardware are discussed in other conference presentations.

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² fieldsde@aol.com

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⁴ UNAM, Morelia Campus, Mexico

⁵ Lime Microsystems, Ltd.

⁶ www.roanestate.edu/TAO

⁷ RASDR – Radio Astronomy Software Defined Radio; <http://rasdr.org>

⁸ Lime Microsystems Field Programmable RF (FPRF) Transceiver IC;
<https://github.com/myriadrf/LMS6002D-docs>

⁹ Component 1434-1001-ND available from Digi-Key, Inc.

Introduction: The RASDR Project

The SARA development of an SDR that is optimized for Radio Astronomy, RASDR and which is applicable to a wide variety of SARA projects, includes a front end digital package (RASDR2) and a software-driven desktop computer back end[1][2]. The front end uses a computer chip containing the entire RF digital receiver chain, designated LMS6002d [3][4]. The back end computer controls the front end hardware and permits the user to control receiver functions, display signals and perform analysis functions (averaging, computation of spectrograms, determination of power time-spectrum, and generating output files).

Signal processing permits dealing with low S/N data, and presents data as spectral plots and data files, and metadata. Current RASDRviewer software [5] for the Windows OS, performs parameter optimizations, user control, spectra output, power characterization and output data formatting via a Graphical User Interface (GUI).

This design evolution is based on the need to have widest possible data pipeline speed for radio astronomy applications, and to make this available to SARA members[6]. The software is described at this conference in a second sister paper. [7]. The following sections describe initial tests to evaluate the radio spectrum environment. In all cases, a USB2 connection was made to a 5-y old PC laptop running WinXP.

Operation of RASDR2 in Various Radio Astronomy Bands

The FCC spectral designations from 3kHz to 30 GHz [8] are shown in Table 1:

| Band Number | Symbol | Frequency Range | Wavelength Range |
|-------------|----------------------------|-----------------|------------------|
| 4 | <u>VLF</u> | 3 to 30 kHz | 10 to 100 km |
| 5 | <u>LF</u> | 30 to 300 kHz | 1 to 10 km |
| 6 | <u>MF</u> | 300 to 3000 kHz | 100 to 1000 m |
| 7 | <u>HF</u> | 3 to 30 MHz | 10 to 100 m |
| 8 | <u>VHF</u> | 30 to 300 MHz | 1 to 10 m |
| 9 | <u>UHF</u> | 300 to 3000 MHz | 10 to 100 cm |
| 10 | <u>SHF</u> | 3 to 30 GHz | 1 to 10 cm |

Table 1. FCC band plan from 3kHz to 30GHz.

Development of these bands for radio astronomy research is shown in the following table. It is taken from various sources and contains comments by the author. The Jovian kilometric band is not often considered, but it has been observed by Voyager and other space probes, and may be a valid radio astronomy band from earth under certain circumstances.[9][10]

RASDR2 operates in bands 9-10 (up to 4 GHz), but with additional components the coverage may be considerably extended, as will be discussed.

| | | | |
|-------------------------|------------------------------|---------|------------------|
| Ionospheric Monitoring | | ULF-VLF | 0.00030 to 0.003 |
| Jovian VLF [10,11] | Jovian kilometric | VLF | .015 to .025 |
| Jovian and Solar | RASDR upconverter F<400MHz | HF | 10 to 35 |
| Solar / Solar Wind | | VHF | 70 |
| Pulsar | 1 second for pulse shape | VHF | 70 |
| | 0.05 Seconds bin width | VHF | 150 |
| | Clock Discipline 0.1 Second | UHF | 322 |
| | | UHF | 406 |
| Continuum, VLBI, Solar | Consider Dicke Switching | UHF | 608 |
| 21 cm Hydrogen | Galactic doppler +/- 1.4 MHz | L-Band | 1420 |
| | Extra Galactic +/- 5 MHz | | |
| Solar Continuum | | L-Band | 1420 |
| OH spectral | galactic doppler +/- 1.6 MHz | L-Band | 1665/1667 |
| OH spectral, SETI | | L-Band | 1702 |
| Continuum, Solar | | S-Band | 2655 |
| | | S-Band | 2690 |
| | Calibration to NOAA obs | S-Band | 2800 |
| Continuum, Solar | | S-Band | 3260 |
| | | S-Band | 3332 |
| | | S-Band | 3345 |
| | LNB required for RASDR | C-Band | 4800 |
| | operation above 3800 MHz | C-Band | 4990 |
| | | C-Band | 5000 |
| | | C-Band | 6650 |
| | | X-Band | 10600 |
| Methanol / Doppler | Doppler +/- 12 MHz LNB Req | C-Band | 6670 |
| | | KU-Band | 12178 |
| Methanol Maser Activity | Narrow Band LNB Required | KU-Band | 14500 |

Table 2 Candidate radio astronomy research bands. Bands shown in and above HF are designated. The band shown as VLF is proposed for monitoring [11]

Hydrogen HI Spectroscopy. L-band (1420 MHz)

Using RASDR2 for observing an HI hydrogen cloud signal requires a suitable antenna, a high-gain preamp (LNA) and signal averaging to extract the HI signal from the RF noise.

One may ask how much sensitivity is needed. A popular special-purpose spectrometer that works well for observing HI emissions from distant hydrogen clouds is SpectraCyber II[12], which was invented and constructed by RASDR team member Carl Lyster.

As a point of reference, the SpectraCyber bin width is about 5 KHz. If we desire to cover 10 MHz of HI spectrum then we probably require about 2000 frequency bins or about 2048 samples/FFT. One may choose the a higher number of samples/FFT observe more detail, although more averaging would be required.. One of the significant advantages of RASDR2 is that it has a high bandwidth.

RASDR2 control data consist of only a few values and they are discussed by Paul Oxley in a related paper.[7] Based on the preceding discussion, an initial data screen for HI spectroscopy is shown in Figure 1, with non-default values shown in red.

Center Freq (Hz): 0 Span(Hz) 10000000 Add n

Start capturing samples Bw (MHz): 10 30

Stop capturing samples RF Freq 1.420 20

☒ Ave Ovr Frames: 64 VGA1 25.17 10

Samps/Frame: 2048 VGA2 Gain(dB): 30 10

Samp Rate (S/S): 10000000 LNA Gain Mode: -6 dB APPLY

Chip - ver: 2 rev: 2 mask: 1

Figure 1 Initial choices of RASDR2 control parameters for comparison with typical SpectraCyber results. See text for choice of values shown in red.

The first tests with these settings provided a noisy graphical output. The LNA gain used in this series of tests was 15dB and skies were cloudy. In general, one expects to average over many samples. Initial runs with 99 and 999 samples produced the output shown in Figure 2. It is clear that more samples must be included in the averaging process, which will require a small software change from the current program. Note that the noise spurs (that appeared only after averaging) are about 9 dB above the floor and they are present in both tests.

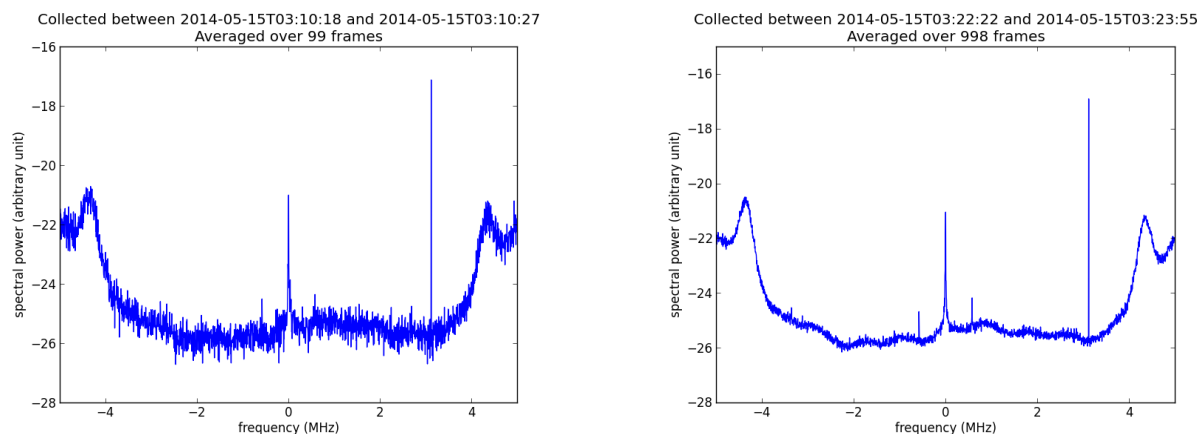


Figure 2 The importance of spectral averaging is shown with processing of 99 frames (left) and 999 frames (right). Control settings were as shown in Figure 1. USB2 connectivity was used to an IBM laptop running WinXP, and using a USB2 interface.

A second necessity is to remove the background noise and normalize for system response. Figure 2 shows the result of subtracting the two files shown Figure 1 to removing the common baseline variation and the 9 dB spurs, but leaving only random noise component. This component is not present in the 999 FFT average.

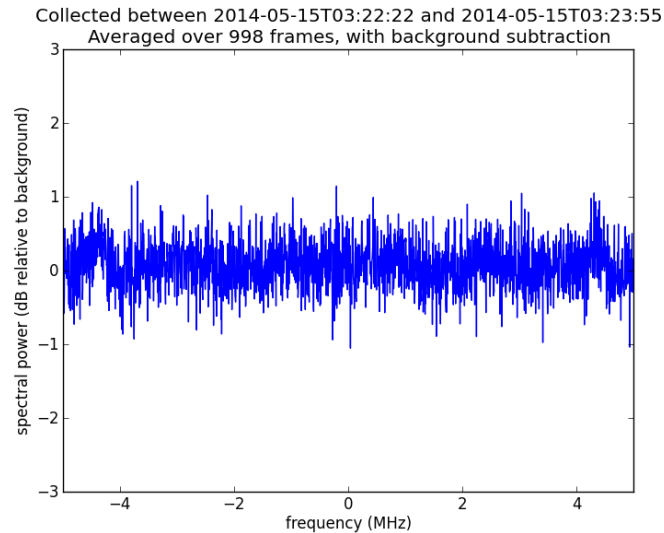


Figure 3 This figure is the difference file using the 99 file average and the 999 file average shown in Figure 2. The 2dB noise component from Figure 2 (left) is all that remains. The common feature is removed, and the same method can be used to remove system response from the HI spectra measurement.

Radio Astronomy in the VHF band (80-190 MHz)

It is highly desirable to extend RASDR2 coverage to lower-frequency RF bands. Such an extension makes it far more useful to SARA members.

This section will consider extension of operation to the VHF band, specifically 80-190 MHz. This band is useful for solar monitoring and for meteor detection and it also contains an AM aircraft band, amateur radio activity, commercial FM band that are interesting for performance verification, and the output Intermediate Frequency (IF) band for the 40' Green Bank Radio Telescope.[13] Application to the Green Bank 40' radio telescope is planned for the 2014 SARA conference.

To add functionality below the intrinsic RASDR2 band, an upconverter was designed and constructed.

The basic LM6002d covers a wide frequency range from 300-4000MHz but RASDR2 has been used initially above 400Mhz. The VHF upconverter extends reception to an input frequency band between 100-200 MHz. Filters were included to reject incoming signals that upon mixing would have been upconverted to below 400MHz, to avoid the third harmonic of the local oscillator (LO) that was used for mixing, and to remove the LO fundamental frequency component.

Our VHF upconverter uses the third harmonic of a 100MHz oscillator[14][15]. The 3rd harmonic (300MHz) is mixed with the input signal. The following basic components are also required, and there are about 25 additional components:

| | |
|------------------------------------|---------------------------------|
| Crystal oscillator | Raltron CO19025-100.000MHz [15] |
| Low Pass Filter | LFCN-225 [16] |
| Mixer, | IAM81000 [17] |
| Output Bandpass filter combination | PHP-400[18] |
| | LFCN-225 [16] |

Figure 4 shows the functional diagram of the VHF upconverter constructed for RASDR2 tests.

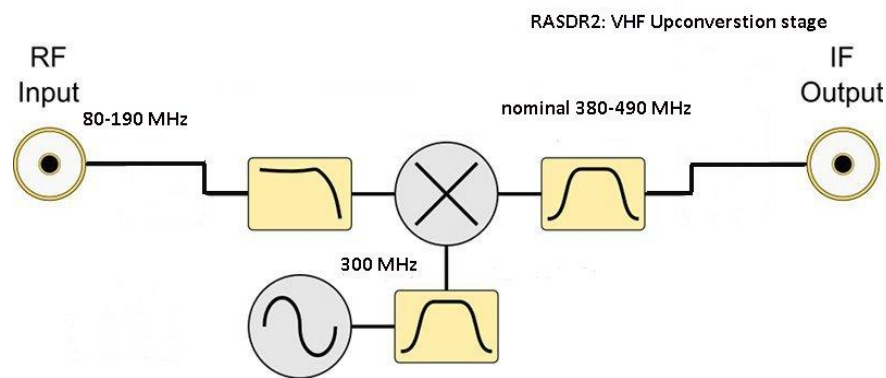


Figure 4. Block functions of the VHF converter show conversion of 80-190MHz VHF signals into the RASDR2 input band acceptance range.

Several filters are shown, the input low pass filter to avoid VHF components in the input from reaching the mixer; the 300 MHz bandpass filter to clean up the third harmonic of the oscillator, and the output bandpass filter (two filters are used in our unit) to select just the frequency components desired from the mixer stage.

Figure 5 shows the completed VHF converter stage that upconverts inputs from 80-190 MHz to 380-490 MHz:

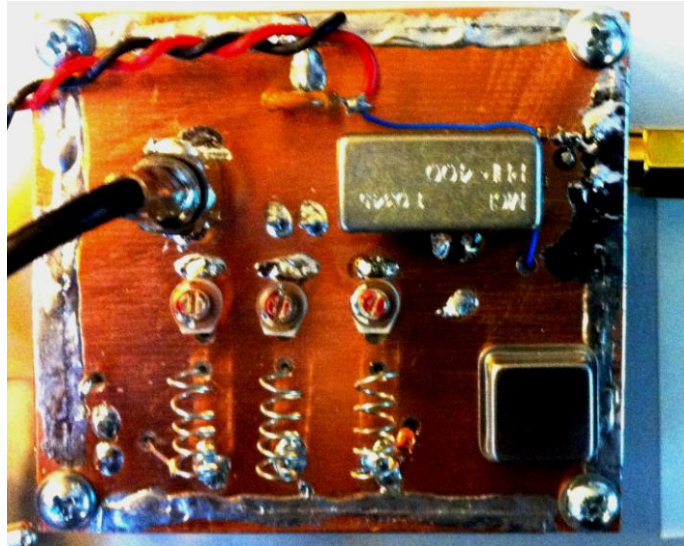


Figure 5 Completed VHF converter used with RASDR2. Input is via the coax cable while the output is via the SMA connector shown on the upper right.

The circuit shown has a mixer with about 10dB gain resulting in no overall signal loss for the unit. The noise floor is about -120 dBm.

The unit is intended for several applications, including meteor detection, spectroscopy with the NRAO 40' antenna, and solar monitoring. A convenient test signal is the commercial FM band, using a random wire antenna about one wavelength long. A random length of hookup wire was connected to the input of the upconverter

Figure 7 shows a 10 MHz section of the band taken directly from the RASDR2 GUI video output, using a 2m piece of hookup wire for an antenna, and the upconverter of Figure 5.

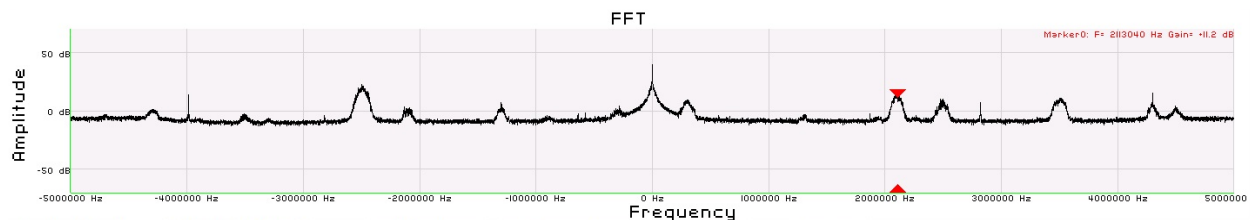


Figure 6 Commercial FM band. The antenna was a random wire about 2m long, connected to the VHF upconverter, then to RASDR2. The red marker was added on the RASDR2 display to denote a local FM station broadcasting at 102.113 MHz.

Selecting RASDR2 internal filters to narrow the band to 2.5 MHz width, demonstrates a practice that is useful to reject interfering signals outside the region of interest and avoiding any intermodulation. The result of setting the bandwidth to 2.5 MHz is shown in Figure 7.

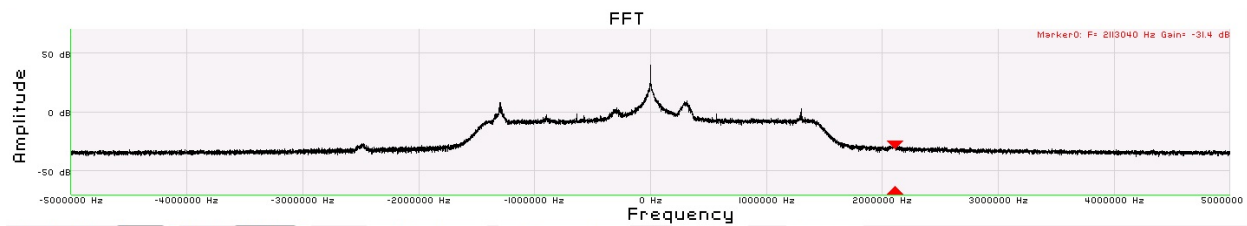


Figure 7 RASDR2 internal narrow-banding was chosen to select a region of interest. In practice, narrow banding is useful to reject unwanted outlying signals (noise).

RASDR2 output is more information-rich than suggested here. Figure 8 shows the complete primary-window display of a 10MHz-wide band centered at 90 MHz, with the RASDR2 marker function used to denote a couple of interesting local FM stations. Additional windows provide “Tools” and “Define Output”. As data were taken, the writer was listening to 91.9 MHz (red triangle marker) on the stereo.



Figure 8 The complete RASDR2 video output with VHF input shows the input signal stream as digitized (I and Q values); the I vsQ plot (a circle if there is a single coherent source, the FFT spectral display with markers if selected, digitization and internal gain settings, and a power vs. time plot on the lower right shows the result of moving the antenna.

Radio access to signals collected by the NRAO 40' telescope are restricted to using the local IF feed. This VHF upconverter was designed with this challenge in mind. Study of HI using RASDR2 at NRAO, might be done by dialing in the 40' telescope local oscillator to 1315 MHz and measuring the signal at the output IF feed (1420 -1315 MHz), which would be at 105 MHz. This could be upconverted to 405MHz and examined with RASDR2. That is a future project and we are looking forward to performing this measurement at the 2014 SARA conference.

RASDR Spectroscopy in HF band (2-80 MHz)

RASDR2 operation has been described as applied from 400MHz to 4GHz, and with the VHF upconverter, to the input range from 80-190 MHz. To demonstrate functionality in the HF band from about 2-66 MHz, we used an upconverter obtained from Nooelec[19] that upconverts this HF input band to a 102-166 MHz output band. Thus the output is compatible with input of the VHF converter described earlier.

The Nooelec upconverter functionality is shown in Figure 9. The device shown has a measured internal loss of about -10 dB of signal. The noise floor is about -80 dBm. This device was used with a 100 MHz crystal oscillator, but one can also obtain it with a 125 MHz oscillator. If this component selection is made, then the output will be shifted by 125 MHz, and avoid the commercial and aircraft bands.

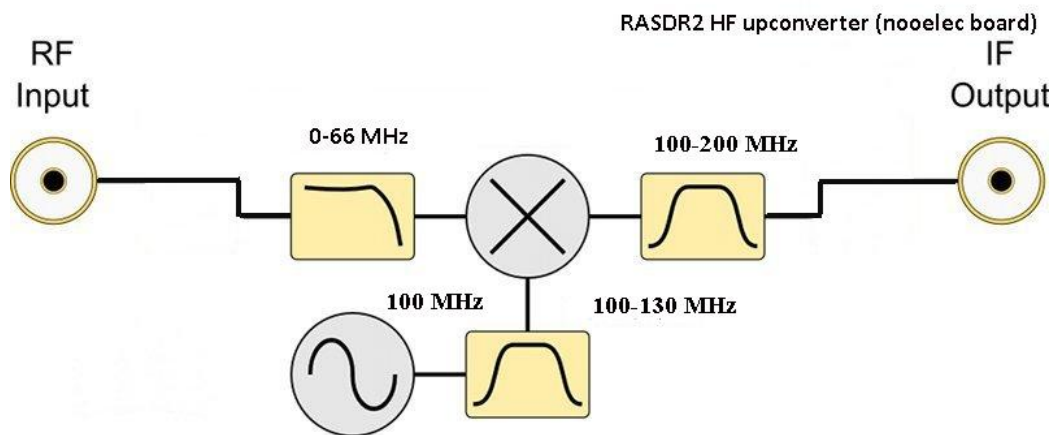


Figure 9 Functionality of the Nooelec upconverter is as shown. The RF input is nominally specified 0-65 MHz and the measured performance covers in the range 2-66 MHz. Filter functions are as described with reference to Figure 4.

For testing purposes, the HF upconverter was mounted as shown in Figure 10, where it is the PC board on the lower left. The VHF converter discussed earlier is shown on the upper right.

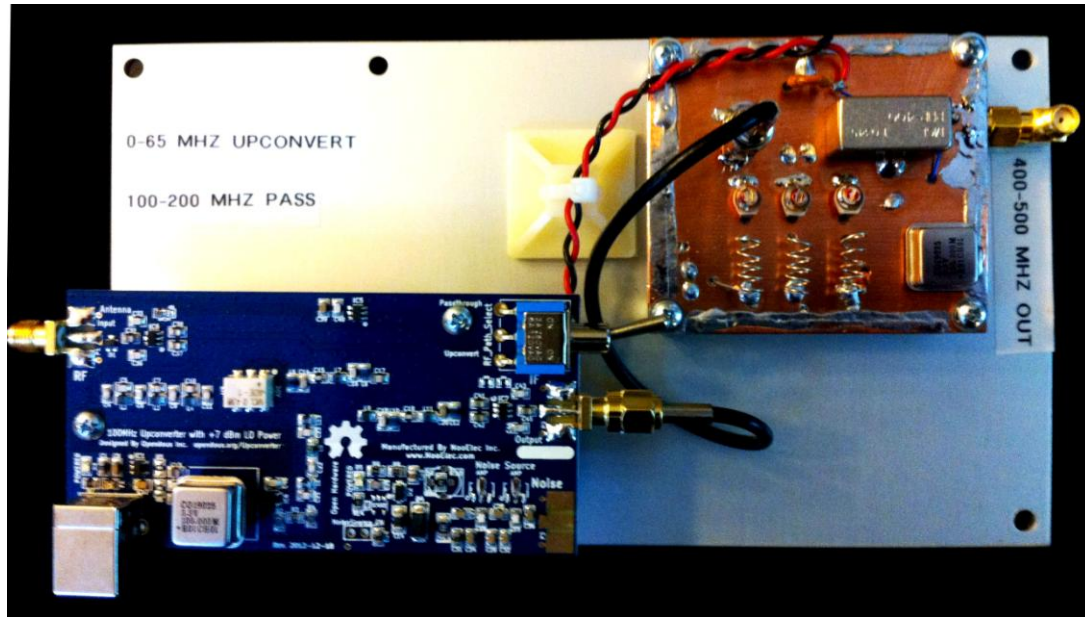


Figure 10 Two upconversion stages are shown here, which provide for conversion of the 2-66MHz portion of the HF band to the 402-466 MHz band prior to processing with RASDR2. The Nooelec converter is on the lower left while the VHF converter described earlier appears at the upper right.

Results were as might be expected using an antenna very short (2m) compared to the frequency. Figure 12 shows a 5.5 MHz section of the HF band centered on 15 MHz. The plot contains signals, spurs, and noise. The lesson from this figure is that one must use a respectable antenna and preamplifier, possibly a preselection filter, and background subtraction for a noisy band.

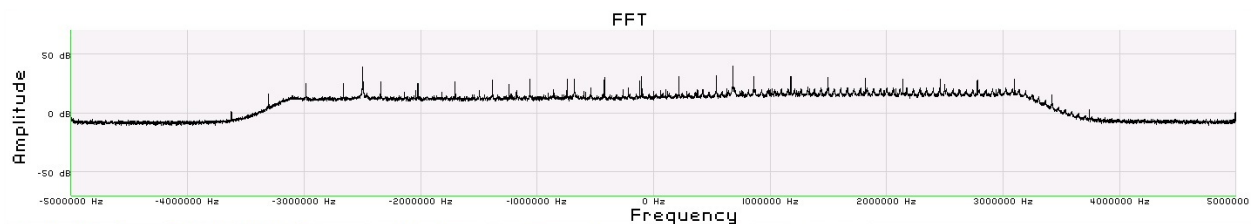


Figure 11 Noisy 5.5 MHz section of the HF band centered on 15 MHz. This measurement was made with an electrically short antenna and no preamplifier. It shows various sources of noise including some from the Nooelec upconverter. This experiment suggests the importance of a decent antenna, more preamplification and background subtraction.

Summary

Several initial applications and extensions of the RASDR2 device have been discussed. The unit is showing considerable potential, provided the user is willing to precondition the input and use software processing at the output.

Citations

- [1] RASDRgroup, "RASDR – Radio Astronomy Software Defined Radio," 2014. [Online]. Available: <http://rasdr.org>.
- [2] P. Oxley, B. Vacaliuc, D. Fields, C. Lyster, S. Kurtz and Z. Tamosevicius, "RASDR update," *Radio Astronomy -- Journal of the Society of Amateur Radio Astronomers*, no. January-February, p. 72ff, 2014.
- [3] LimeMicrosystems, "Field Programmable RF (FPRF) Transceiver IC," Lime Microsystems, 2014. [Online]. Available: <https://github.com/myriadrf/LMS6002D-docs>.
- [4] Myriadrf, "Home page of Myriadrf," [Online]. Available: <http://myriadrf.org/>. [Accessed 20 May 2013].
- [5] Myriad, *Personal Communications to RASDR team*, March-June, 2013.
- [6] B. Vacaliuc, D. Fields, P. Oxley, S. Kurtz, C. Lyster, R. Vadoklis and Z. Tamosevicius, "Production Manufacturing Plan for RASDR2 Appliance," in *Proceedings of the 2014 SARA Conference*, Green Bank, WV, 2014.
- [7] P. Oxley, D. Fields and S. Kurtz, "RASDR2 Control and Analysis Software," in *Proceedings of the 2014 SARA Conference*, Green Bank, WV, 2014.
- [8] Wikipedia, "Radio_spectrum," 2014. [Online]. Available: http://en.wikipedia.org/wiki/Radio_spectrum. [Accessed 11 May 2014].
- [9] D. Fields and N. Tesla, "Detection of Jupiter Radio Emissions below the Plasma Cutoff Frequency: Implications for SID Monitoring," in *Proceedings of the Annual Meeting of the Society of Amateur Radio Astronomers*, Green Bank, WV., 2011.
- [10] J. Avellone, "Detection of Jovian VLF Noise," *Radio Astronomy -- Journal of the Society of Amateur Radio Astronomers*, no. March - April, p. 48ff, 2014.
- [11] D. Fields, R. Kennedy and K. Roy, "Interplanetary Radio Transmission through Serial Ionospheric and Material Barriers," in *Proceedings of the Seventh IAA Symposium on Realistic Near-Term Advanced Scientific Space Missions : Missions to the outer solar system and beyond. International Academy of Astronautics*, Aosta, Italy, 2011.
- [12] J. Bernard, "SpectraCyber I/II™ 1420 MHz Hydrogen Line Spectrometer Installation and Operation Manual No. SC1/2-2006," Carl Lyster through Radio Astronomy Supplies, [Online]. Available: http://www.ncra.tifr.res.in/rpl/facilities/4m-srt/SCI_IIManual.pdf.
- [13] NRAO, "NATIONAL RADIO ASTRONOMY OBSERVATORY 40-FOOT RADIO TELESCOPE OPERATOR'S MANUAL," 2014. [Online]. Available: <http://www.gb.nrao.edu/epo/manual.pdf>.
- [14] Ebay, "Raltron CO19025-100.000MHz," 2014. [Online]. Available: www.ebay.com.
- [15] "Through hole clock oscillators – 3 state HCMOS compatible," Raltron, 2014. [Online]. Available: http://www.raltron.com/products/pdfsspecs/clock_co15-co19.pdf.
- [16] "LFCN-225," Mitron, 2014. [Online]. Available: <http://www.mitron.cn/cxchanpin/Filters-n/LFCN-225.pdf>.
- [17] Hewlett-Packard, "Silicon Bipolar MMIC 5_ GHz," 2014. [Online]. Available: <http://www.qsl.net/n9zia/omnitracs/IAM81008.pdf>.
- [18] Minicircuits, "Plugin High Pass Filter," [Online]. Available: <http://www.minicircuits.com/pdfs/PHP-100+.pdf>.
- [19] Nooelec, "Ham It Up v1.2 - RF Upconverter For Software Defined Radio," Nooelec, 2014. [Online]. Available: <http://www.noelec.com/store/ham-it-up-v1-0-rf-upconverter-for-software-defined-radio.html>.