

RASDRWin Companion Software for RASDR

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Abstract: An update of the RASDR project will be presented. The paper demonstrates Windows control of the RASDR system. User-provided data specifies center frequency, bandwidth, and some initial values used to choose optimal operational range of the Lime femtocell ship. Additional settings govern decimation, signal processing, external reference frequency and output options. The system uses USB2 to provide a high speed interface to the RASDR hardware.

RASDRWin is a Windows based platform that provides the control and data analysis for the RASDR system. It is written in C to allow portability across Windows, Linux and Mac-OS. The portability is maintained in part by avoiding graphical user interfaces that are specific to each platform. The use of C also provides the high speed processing necessary for data analysis at the RASDR rates (30.72 M Samples per Second Maximum).

The control portion of RASDRWin provides the user the capability of configuring and optimizing the LIME chip on the RASDR boards. This includes the DC calibration of the Chip stages, minimizing second order intermodulation and optimal gain, bandwidth and sample rate selection to meet the user's needs.

A portion of the code also provides user control of the capability to lock the sample clock and local oscillators to a standard reference such as a GPS receiver.

The analysis capabilities include an interface to Spectrum Labs software, a single snapshot interface to MS-Excel for display and Fast Fourier Transform (FFT) calculation, and a capability to produce multiple spectral line spreadsheets that are decimated to the user's desired sample rate and integrated over a user specified period. The decimation rates can be any power of 2 fraction of the inherent sample rate on the board being controlled. The integration period is user variable from 1 second to 3600¹ seconds. The raw sample data can also be directed to a binary file for post collection processing. This capability also manages the amount of user's disk space being consumed to avoid over filling a disk.

¹ Operation with an integration time above 60 seconds is not recommended.

Introduction: The Radio Astronomy Software Defined Receiver (RASDR) project has been documented in multiple previous papers² and presentations.³ It is a project to provide the SARA member and other interested parties with the capability of utilizing the Lime Micro Systems LMS6002D chip in the front end hardware for a Wideband High Speed Receiver. Other components include an interface board that contains a Complex Programmable Logic Device (CPLD) and USB2 interface... A team of volunteer SARA members⁴ are performing the tasks necessary for the project. The project has been broken into multiple phases each of which expands the capability of RASDR.

Recently, Nuand⁵ introduced the Blade RF board that provides the LMS6002D chip with a FPGA, USB3 interface and a low jitter clock generator. It was offered through a Kickstarter project where interested backers commit startup funding. The RASDR team committed to obtain a beta test board and an early production board. The beta test board has been received.



Figure 1 Nuand BladeRF Board

Figure 1 shows the Nuand Blade RF (Beta) board as received April 2013. The board contains a Lime Microsystems LMS6002D chip, an Altera FPGA and Cypress FX3 (USB3) chip.

² See SARA 2012 Proceedings and Periodic SARA Journal Status reports.

³ D. E. Fields, P. Oxley, B. Vacaliuc, P. Shuch, S. Hogle, K. Roy and R. Kennedy, "Algorithm Defined Receivers for Interstellar Travel and SETI," Tennessee Valley Interstellar Workshop, 3-6 February 2013. [Online]. Available: <http://www.youtube.com/watch?v=fLvwq1OhEUc>. [Accessed 9 May 2013]

⁴ David Fields, Bogdan Vaculiac, Stan Kurtz, Jeff Kruth and the author.

⁵ <http://nuand.com>

Lime Microsystems through their Myriad open source subsidiary also has developed a MyriadRF board that contains the LMS6002D chip. The original offering included a “DEO Nano” demonstration FPGA board and a DEO Interface board that provided a FX2 interface. Recently, the RASDR team was approached by Lime Microsystems to collaborate on a layout more suitable for Radio Astronomy. The new layout uses the MyriadRF board that is sandwiched with a “DigiRed” board that contains two FX3 (USB3) chips. DigiRed does not require a FPGA since it makes use of a unique scheme to control the handshaking via GPIO pins on the FX3 chip. Thus a lower cost is likely. Lime has promised two prototype boards for RASDR team testing.

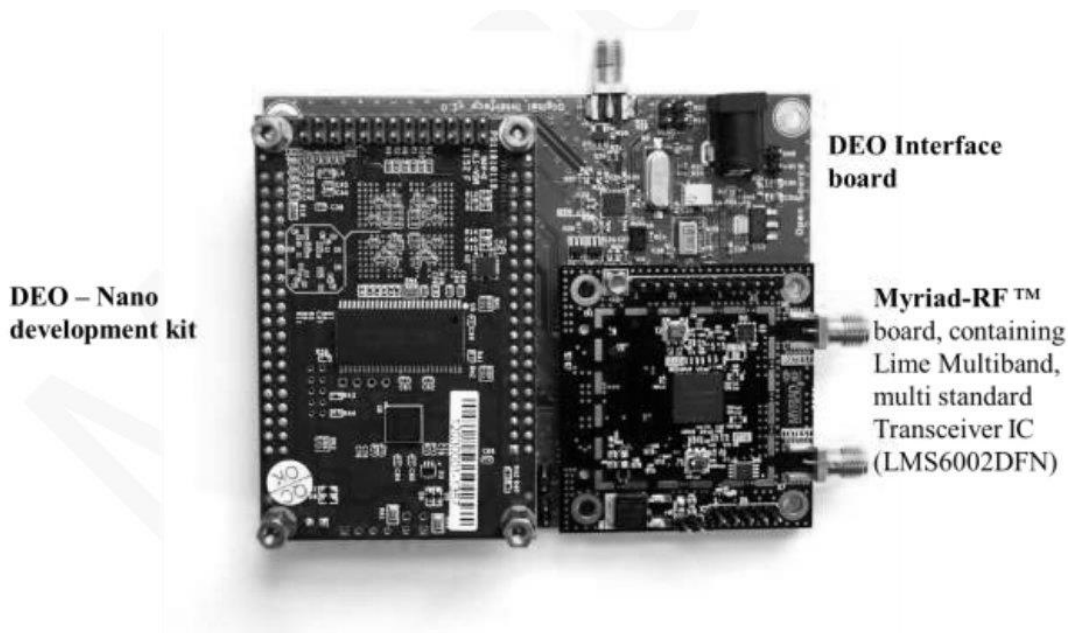


Figure 2 Lime Microsystems Demo Board

Figure 2 shows the Lime Microsystems / Myriad demonstration board. The Myriad-RF board shown in the lower right portion of the picture will be used in RASDR Phase 2. The DEO – Nano and DEO Interface boards will be replaced by a DigiRed board which will provide dual Cypress FX3 interfaces using USB3.

The RASDR team adopted either the BladeRF board or Myriad RF/DigiRed boards as the basic component of the RASDR Phase 2 implementation. Phases other than the breadboard (Phase 0) and the BladeRF or MyriadRF/DigiRed (Phase 2) have been placed on hold. Table 1 describes the remaining phases.

RASDR Phase	Max Sample Rate (MS/S)	Max Bandwidth (MHz)	Hardware	Software
0	7.68	7	Lime Evaluation Board, Lattice CPLD/FX2 Board and Minicircuits LF Modules	RASDRWin or :Linux
2	28.8 (USB3) 7.68 (USB2)	28 (USB3) 7 (USB2)	Nuand Blade RF containing FPGA and FX3 Chip. with RASDR LF Expansion Board	RASDRWin2 , Linux or MAC
2	30.72 (USB3) 7.68 (USB2)	28 (USB3) 7 (USB2)	MyriadRF board plus DigiRed dual FX3 chip board. With RASDR LF Expansion Board	RASDRWin2, Linux or MAC

Table 1 RASDR Phases

Both the BladeRF and MyriadRF/DigiRed boards will be on display at the conference.

This paper describes the associated software (RASDRWin) as written for the Phase 0 breadboard. Where appropriate the modifications necessary to accommodate Phase 2 are included.

Software Description: The RASDRWin is written in the C language. This provides the necessary high speed processing. The use of C also provides the necessary bit manipulation for both the decoding of the collected data and the setting of single bit portions of the registers on the Lime Chip. The code extensively uses the multi-threading capability of the Windows Operating system to provide optimization of the user's PC capabilities. If the user's PC has multiple CPU Cores, the processing load is shared between the cores. If the user's PC is a single core type, the single processor is optimized by time-sharing between the various threads. In either case since the PC processing speed is many times faster than the data collection rate, either type of PC should be adequate when the PC clock rate is in the GHz range and it is equipped with adequate (2 GB or larger) available RAM. In those cases where older slow processors are used it likely will be necessary to reduce the sample rate.

The software further provides the user with the ability to optimize the amount of disk space utilized on their PC for RASDRWin output files. For the large file size outputs, the user is given a calculation of the amount of disk space and corresponding recording time that is available on their selected disk drive directory. A further check is made to insure that the user has the necessary permission to write to the selected directory.

System Initialization and Program Flow: When the user executes RASDRWin, the program first checks to see that all of the necessary port interfaces are present and tested. This includes one USB port for the Lime chip and two for the Lattice Board. If the ports are not present, the user is given instructions on how to remedy the situation. For the BladeRF Phase 2 board, the number of USB interfaces will be reduced to a single USB3 interface. For the DigiRed solution, only the receive USB3 interface will be necessary.

The program then performs initialization of the calibration parameters on the Lime chip. This process utilizes the automatic calibration process as documented by Lime. The objective of the automatic calibration is to minimize the false DC component in the output data.

The next initialization process performs a search for the best second order inter-modulation contribution from the mixers. This step further minimizes the DC component in the output as well as minimizing other second order products.

The final initialization process is to find the best front end DC offset values for both the In Phase (I) and Quadrature (Q) streams.

When the first data collection is initiated, the program first initializes the High Speed USB2 interface for bulk data transfer. Since a data collection is initiated on each of the preceding initialization steps, this high speed initialization is transparent to the user. During initialization, the program uses the mean value of multiple sample data points to establish the DC offset of the data.

User Defined Parameters: To the extent possible, the user is guided in the selection of the parameters necessary for a given data collection session. The user only needs to know the desired center frequency for the session. From the center frequency, the system selects the appropriate input port and offers the user choices on bandwidth and sample rates that maintain the Nyquist criteria from the sampling theorem. If the user wants to override the criteria, one bandwidth step beyond the Nyquist Limit is available. This avoids the creation of data with unreal spectral lines from aliasing.

Other parameters are also user selectable that allow the program to operate in the user's environment. Table 2 describes the user parameters.

Parameter	Source	Notes
Lime Com Port #	User Input	From Device Manager with USB cable connected
Lattice Com Port #	User Input	From Device Manager with USB cable connected
Output Type	User Selection	Valid Types Offered
Output Decimation	User Input	Power of 2 Divider
Output Integration Period	User Input	Seconds 3600 Max, 60 recommended Max
Output File or Directory	User Input	Permission and Capacity Verified
Measurement Center Frequency	User Input	MHz
Measurement Sample Rate	User Selection	M Samples / Second
Measurement Bandwidth	User Selection	MHz To Meet Nyquist Criteria or Override
System Gain	User Input or Automatic to Dark Sky	dB or automatic
External Reference Frequency	Optional User Input or 10 MHz Default	MHz

Table 2 User Parameters

Once the user parameters are entered, the user can choose to save the configuration for future use. The next time that the system is initialized, all of the parameters are the same as the previous session. The user can choose to use the previous configuration or modify any of the parameters.

Gain Setting: The gain of the system can be set by the user in either a manual or automatic manner. For the manual setting, the user is given a range of dB values for the selected configuration. The automatic gain setting is performed by pointing the antenna at dark sky. The program finds the necessary gain to bring the dark sky collected data to the lower portion of the dynamic range. The gain value is set to prevent clipping from the lowest ADC step which would introduce intermodulation products in the output.

Chart 1 below is an I vs Q plot with the gain set too high. In this case, the ADC is operating near the 2048 maximum step which created the square shape and 1.5dB compression. The sample values are limited to +/- 2048. The intermodulation products produced the random data points within the square.

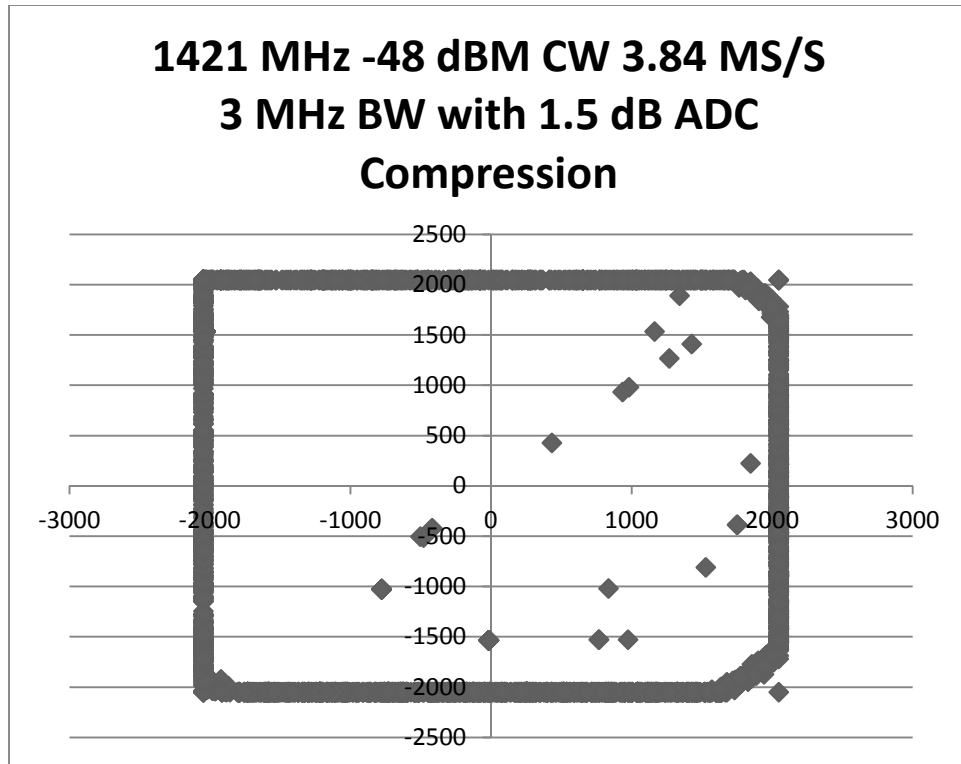


Chart 1

Level Calibration (future): A feature will be added in the future to allow the system to be calibrated to a known value. This might include a user provided calibration source, trees, or the use of an echosorb material at a known temperature. When this feature is introduced, an additional gain setting option will be included to use the calibration value of the known source.

External Frequency Reference: The Lime Evaluation board used in the breadboard layout has a Temperature Compensated Voltage Controlled Crystal Oscillator (TCVCXO) to provide the data collection clock and locking of the Phase Locked Loop (PLL) local oscillators.

If the user desires to have a higher stability, the Lime Evaluation board has an additional PLL that can be used to lock the system to an external reference such as a GPS receiver or higher stability source. Both the BladeRF and Digi-Red boards have similar capability. The program provides the user with the ability to select the frequency of the external reference frequency. In most cases, this will be 10 MHz that is the default. If a signal is present on the reference input, the system will lock to this reference. If not, the TCVCXO will operate without a reference input.

External Time Reference: Phase 2 of RASDR will introduce a capability of inserting a 1 Pulse per Second (PPS) signal into the data stream. If the user supplies a 1 PPS signal from a GPS receiver, the accuracy of time stamping can be in the microsecond to nanosecond range depending on the GPS selected.

Data Collection: The user initiates data collection by the use of either the single frame or continuous data collection options. The single frame option collects 1024 data samples that are placed in the user selected output medium and waits for further user interaction.

The continuous data collection option allows the user to set the number of frames to collect. The number can be any value up to the maximum value presented to the user. The maximum value protects the user selected disk directory from being overfilled. A one G Byte reservation prevents the PC from becoming unstable from lack of disk space for necessary tasks such as paging.

Data Analysis: The program provides a limited capability to do data analysis. This includes the calculation of the mean value of a sample stream, total RMS power in a frame, decimation of the sample rate and integration over a user selected time period.

The output data can be further analyzed with the tools connected to the output port. This can include FFTs (Excel, Bulk Source Data and Spectrum Labs outputs), further integration, further decimation or pulsar folding analysis (Bulk Source Data output). The Spectrum Labs output can also perform digital filtering.

The MS-Excel Output: The MS-Excel output provides two files both of which are in the .csv file extension format for direct importing into Excel.

The first is a 4096 (Maximum) sample stream of the first set of data collected. The In Phase and Quadrature values are in columns with a third column containing a complex representation of these values. An FFT can be performed on the third column using the optional (free) FFT analysis feature ⁶ of Excel.

The second .csv output contains a list of the total power in each frame.

The following charts display the Excel Plotting Capability.

Chart 2 is a time domain plot of the In Phase (I) verses Quadrature (Q) data with a 1421MHz CW signal applied. As you can see from the chart, the signal produces a circular pattern since the I & Q signals are sine and cosine representations of the signal. The spreading of the signal outside the basic circle is noise. If the calibration steps are ideal, the center of the circle should be at the origin. This type of plot is very useful in testing the system.

Chart 3 is a frequency domain plot of the same data as chart 2. It was produced by the Excel FFT analysis tool. The residual DC value is in the center of the chart at 1420 MHz which corresponds to zero frequency at baseband. The noise in the system produced the small lines along the baseline.

⁶ The FFT is in the Excel Analysis Toolkit see <http://technet.microsoft.com/en-us/magazine/ff969363.aspx>

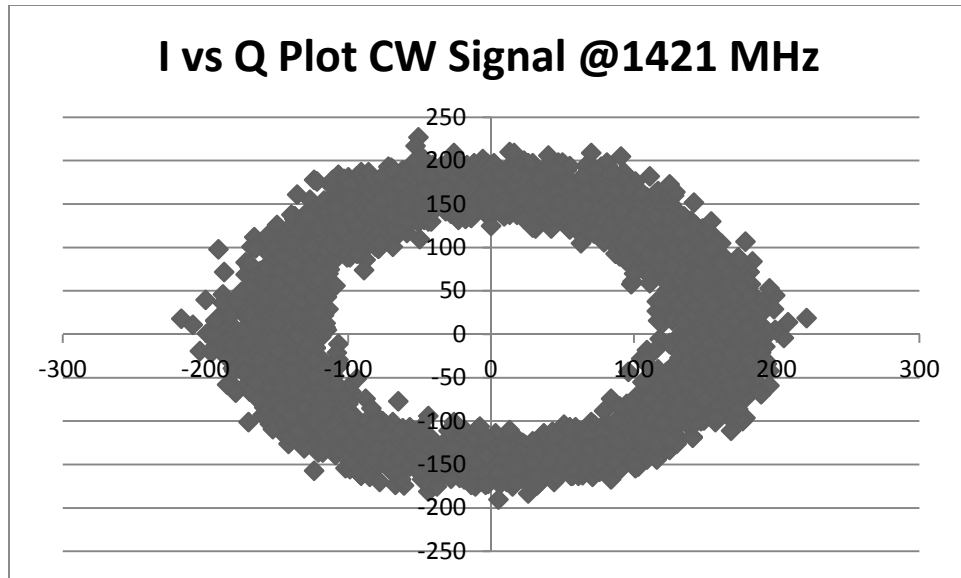


Chart 2

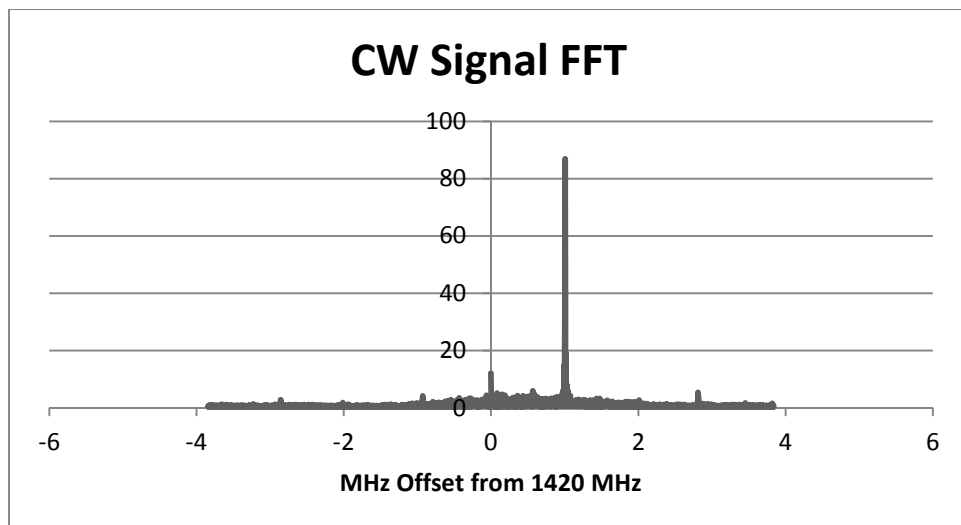


Chart 3

Output to Spectrum Labs Software: This output streams the data to a named pipe on the PC which can be fed into the Spectrum Labs Software. The user can choose to do decimation of the data in either the CPLD or the output interface to bring the high sample rate down to one that can be handled by the Spectrum Labs Software.

Binary Source Data Output: When this output is active, a binary file is written which contains the source sample data. The data is recorded in 16 bit signed integer format with the Quadrature sample value immediately following each In Phase 16 bit signed integer format value. Since this option will rapidly fill a disk, the user is given the amount of time that can be recorded with the amount of available storage reserving 1 GB of space for other uses of the disk.

The author plans to add an external high capacity removable disk drive to his system once the USB3 interface is available with the future Blade RF and Digi-Red boards. This would allow the user to move the data to another computer for analysis. Without the USB3 interface, the Binary Source Data recording must be limited to a high speed drive (either solid state or rotating disk) on the system via the PCI or SATA interfaces.

Spectral Line Data Output: The Spectral Line output can provide one or more 4096 .csv formatted output files. The data format and Excel plotting capability is the same as shown in Charts 1 & 2 above. The user is given the option of decimation rates in either the CPLD or output interface. Decimation can be performed in both at the same time. To obtain the maximum sensitivity, the user should operate the CPLD at the maximum sample rate (7.68 MS/S for the breadboard layout, 28.8 MS/S for BladeRF, 30.72 for the Digi-Red) and decimate further if desired in the output interface. The CPLD decimation method uses the dropped sample method of data rate reduction. The output interface uses a sample averaging over N consecutive samples to obtain the output value. Thus the sensitivity of the system is improved by $20 \log N$ (dB) with the output interface method.

A further option is provided to integrate the 4096 sample records over a specified period that can vary from 1 second to 3600 seconds. One record is written to disk after the end of each sequential integration period. Each of the 4096 samples in the frame are averaged over the sample period. Since this is on a synchronous data stream without any lost samples, the sensitivity of the system is improved by $20 \log M$ where M is the number of samples integrated in the selected overall integration period.

It should be noted that the user should carefully select the integration period to avoid integration of data that is outside the capability of the data collection. The use of the higher integration periods must be limited to those situations where the object observed can be held within the beam width of the antenna and the changes in Doppler shift from the earth's rotation can be tolerated. Integration periods in excess of 60 seconds are not recommended. Antenna tracking is recommended for most situations.

Alternatively, one might want to set the integration period to a relatively small value and perform analysis of the Doppler shift on an object's spectral line(s) by using multiple FFTs on the data.

Conclusion: The capability to perform the data collection and control of the Lime chip has been demonstrated to work in the Windows environment. The user is presented with a very powerful tool that allows flexibility within the limits of sound science. The results to be obtained are only limited by the user's capability to design a given experiment.

Continuing Work: The software will be modified to operate with the Blade RF and the MyriadRF/DigiRed boards. The software will provide capabilities up to 28.8 or 30.72 MS/S with a full 28 MHz maximum bandwidth. The time stamping will be included in the data stream. Porting of the software to Linux and MAC-OS will be completed.