Hardware Companions to the GNURadio Companion: A comparative study of Software Radio Hardwares

Mithu Sugathan[1], Premanand V[2], Senthil Murugan[3], K P Soman[4,]
Centre for Excellence in Compuatational Engineering and Networking,
Amrita Vishwa Vidyapeetham
Coimbatore, Tamil Nadu, India

***Abstract*— Software Defined Radio or SDR is basically a radio functionality implemented in software. Going into the subtleties of an SDR, we can find that there is a hardware component to serve the purpose of an RF front end, without which a radio is non-functional. GNURadio Companion serves as the software end to which the hardware is attached. There have been advances in the hardware end over the years and this paper serves to compare the different hardware counterparts of the GNURadio companion. We have taken hardwares extending from the high cost series of Universal Software Radio Peripherals (USRPs) to medium cost FUNcube Dongle (FCD) to the extremely low cost RTL-SDR dongle.**

Keywords- Software radio, USRP, FCD, RTL-SDR, GNURadio Companion

I. INTRODUCTION

Software Defined Radios provides a more flexible and reconfigurable environment by providing both hardware and software alternatives. In a typical radio, a signal is captured at the RF-front end, modulated by hardware counterparts that involve both analog and digital circuitry. In a software radio, except for the RF front end reception, all other processes are done in software [1].

The ability of a software radio to morph into practically anything from a traditional FM radio to a GPS receiver has brought it much attention. This reconfigurability and ability to change on the fly has made the software radio an excellent tool in the educational scenario [2]. Labs and other facilities at schools and colleges aim to provide inexpensive tools to students where they can experiment and learn things in an interesting way, with minimal amount of components and resource sharing. The basic architecture of a software defined radio system is given in Figure 1.

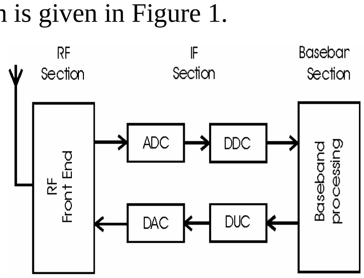

Figure 1. SDR Architecture

GNURadio is the software part which does the entire signal processing which was earlier done in hardware. It is like a building block package with libraries written for each signal processing block and a means of adhesive to bind these blocks together. The blocks ranges from simple signal sources to FFT blocks to filters and literally anything that is found in a communications textbook. Programming the radio is like building a graph with the blocks acting as vertices and edges representing data flow between the blocks. The blocks have input or output blocks or both and mostly differs in the type of input stream, namely integer, float and complex. The signal processing blocks are written in C++ and the graph programming is done through Python. The most promising and attractive feature that makes the GNURadio popular is the fact that it is a free and open source development platform. The GNURadio Companion is the GUI version of GNURadio that aids in experimental study. Figure 2 shows the total system showing where we place the software part.

Various hardwares have given ardent software players an opportunity to experiment and learn things in an easy way. Studying communication theory has been proved effective and intuitive with the help of this improved hardware. Yet, there has been a constraint in terms of hardware unit costs. The high cost of USRP series have limited lab facilities for students in at least few cases, but the development of FCD and DVB-T dongle based on RTL-SDR have changed the situation.

We have analyzed each of these hardwares and compared them with each other in terms of sampling rates, ADC rates, components, costs, functionalities, frequency range, functions etc. The next section deals with each of these hardwares in detail.

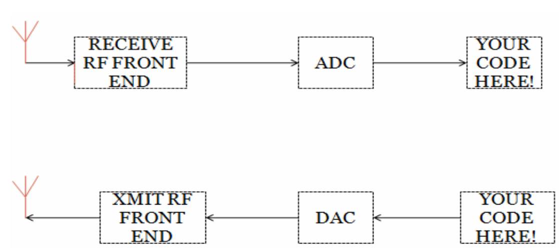

Figure 2. Placing the Software

II. THEORY

A. Universal Software Radio Peripheral (USRP)

Universal Software Radio Peripheral (USRP) is a hardware platform for use with software radio. It is designed and offered for purchase from Ettus Research and its parent enterprise, National Instruments [3]. USRPs provide experiment support to students, labs, researchers, ardent SDR players and universities. It extends as an RF front end by connecting to a host computer through a high speed USB or Gigabit Ethernet connection. The USRP 1 series uses a USB connection and USRP 2 utilises the Ethernet link.

The USRP series have similar architecture and differs in the selection of daughter boards. It is basically a motherboard with slots for a maximum of four daughter boards. These daughter boards serve as the RF front ends. They come in different types in terms of operating frequencies. The motherboard has functionalities of a clock, FPGA, data converters (ADCs and DACs), power etc.

The Analog to Digital Converter (ADC) inputs analog signal and converts it into digital form at the rate of 64 million samples per second (Msps). The DAC or Digital to Analog Converter makes these digital data efficient for transmission by converting it into analog form at the rate of 128 Msps. The FPGA deals with the signal processing part and mainly sample rate conversions. Since the USB supports a maximum speed of 480 million bits per second (Mbps), the FPGA has to reduce and increase data rates in both receive and transmit paths respectively, to match speed constraints of the USB.

The different USRP series products are: USRP Networked series, USRP Embedded series and the USRP bus series. The USRP bus series is commonly known as USRP 1. It comes around a solid price of 40,000 Indian Rupees. The USRP 2 series are no longer available and are being replaced by better counterparts like the networked and embedded series. They come around one lakh INR, excluding the daughter boards.

The daughter boards are actually the frequency dependant components in a USRP. USRPs allow a maximum of four daughter boards. Two slots are allotted for transmitter side and two for receiver path. The slots provided for each of the transmitter and receiver sides are labeled as TXA and TXB, RXA and RXB, referred to as side A and side B.

Each side has access to 2 of the 4 ADCs and DACs, ADC input for receiver and DAC output for transmitter. The commonly available daughter boards are the basic ones, LFTX/LFRX, TVRX, DBSRX, WBX boards etc, each differing in the operating frequency ranges. Figure 3 and Figure 4 shows the USRP 1 and USRP 2. Figure 5 shows daughter boards.

Figure 3. USRP 1

Figure 4. USRP 2

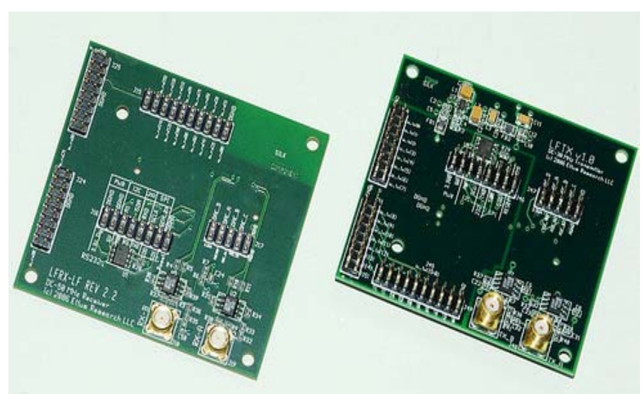

Figure 5. Daughter boards

FPGAs are key players in a USRP system. They are the heart of any signal processing involved in a system. The flow of control with USRP involved is as shown in Figure 6.

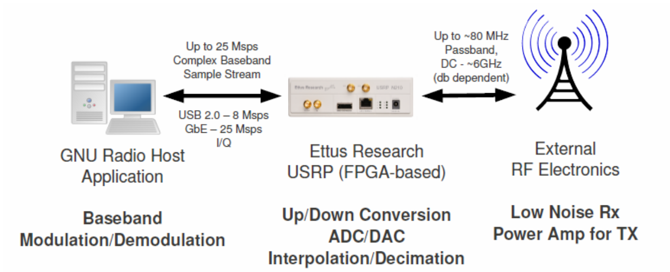

Figure 6. Control flow in systems with USRP

The GNU Radio Host application holds modules provided in GNU radio project to communicate between two end systems. The PC communicates with USRPs through USB interfaces (for USRP 1) and Gigabit Ethernet connection (for USRP 2). A maximum of 32 MB/sec is supported through the USB. The input samples are in 16 bit IQ form as signed integers. 16 bit each of I and Q data results in 8 M complex samples per second across the USB. In case of Ethernet connection, it is 25 M samples per second. The FPGA includes digital down Converters (DDC) implemented with Cascaded Integrator Comb (CIC) filters (for receivers). Digital up converters (DUCs) on the transmit side are actually contained in the AD9862 CODEC chips, not in the FPGA. Interpolators are the only transmit signal processing block in the FPGA.

The FPGA in USRP 1 is ALTERA EP1C12 and the one in USRP 2 is Xilinx Spartan 32000. The ADC samples in USRP 1 are 12 bit at 64 MS/s and in USRP 2 at 14- bit, 100 MS/s. The DAC samples in USRP 1 are 14 bit, 128 MS/s and USRP 2 at 16- bit, 400 MS/s. Resolution of ADC and DAC increases with increase in number of bits. Higher the sampling rate, more the bandwidth handling capabilities. USRP 1 can digitize a band as wide as 32 MHz, whereas the USRP 2 can handle a bandwidth of 64 MHz.

B. The FUNcube Dongle

The USRP series of SDR devices seemed to be a fairly large component in terms of size and shape. So, there evolved some new SDR devices that were smaller in size but with almost the same functionalities as that of the USRP. With a goal to educate, excite and support the student community and institutions in diverse fields of Radio, Space sciences and electronics, the AMSAT-UK came up with a novel idea of a satellite named FUNcube, which is a single CubeSat satellite project. To receive data from the FUNcube, a receiver had to be designed, which was affordable and easily available for students. The low cost FUNcube Dongle (FCD) was thus developed to serve as an inexpensive solution to connect a host PC with an antenna feed [4].

A satellite project contains a ground segment to receive and process the telemetric data and FCD can be considered as the ground segment in the FUNcube project. The host PC has to be enabled with appropriate software to handle and display the received telemetric data. The FCD satisfies every criterion to be rightly called an SDR. Similar to the USRP 1 series, the FCD is a USB interface device and works with different operating systems including Windows 7, Vista, XP, Linux and MacOS. A satellite project contains a ground segment to receive and process the telemetric data and FCD can be considered as the ground segment in the FUNcube project. The FCD satisfies every criterion to be rightly called an SDR.

The FCD is targeted for use in frequency band from 64 to 1700 MHz. Limitations within the tuner chip hampers the performance of the FCD from 1100 to 1270 MHz. There are two versions of the FCD, namely the Base and Pro versions targeted for different applications and frequencies. The Base version is intended for educational purposes and for data reception from the FUNcube and other satellites. The main difference between the Base and Pro version is that the Pro version is not frequency limited, whereas the Base version is intended for particular frequency range.FCD works with all modulation schemes and has a bandwidth capability of 80 kHz. It provides I/Q data through the USB interface for audio and control. The price of the FCD comes around INR 10,000. Figure 7 shows the FCD hardware. Figure 8 shows the FUNcube satellite project with the FCD hardware.

C. RTL-SDR Dongle

The most disappointing fact about SDR devices is the extremely high cost of the devices. Research and studies were conducted to bring down the cost and size of these devices. It was once thought impossible and has turned into reality with the discovery of the Realtek RTL2832U dongle based on the DVB-T Dongle. So, it can be rightly called the Black Swan of the radio world. Antti Palosaari discovered the possibility of using DVB-T receiver as an SDR device which is turned out to be a low cost device and it comes around 1200 INR. It is better known as the 20$ revolution in the radio world [5].

The operating frequency range falls between 64 to 1700 MHz. The frequency range depends on the tuner adopted. Elonics E4000 tuner chip provides the highest range of 64 to 1700 MHz.

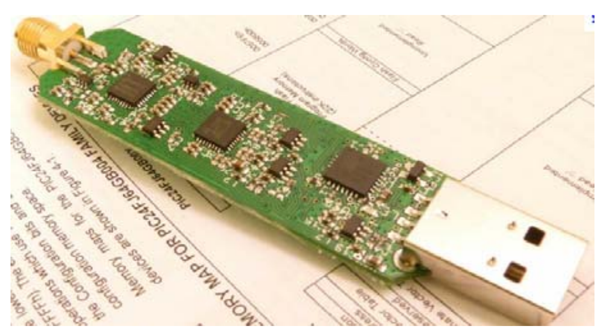

Figure 7. FCD Hardware

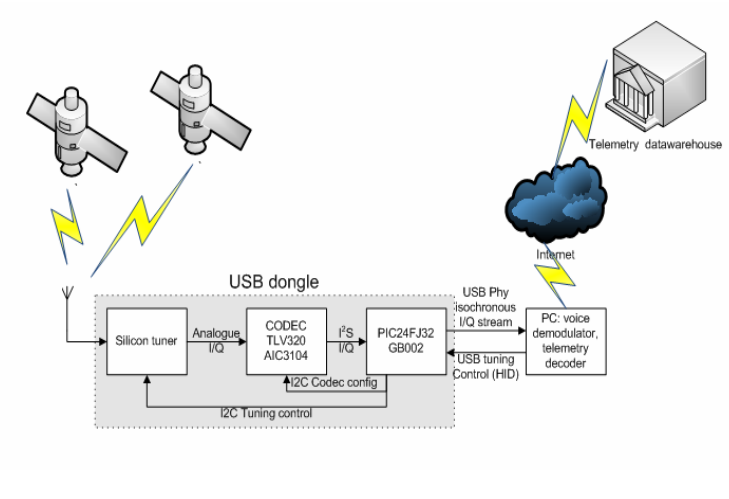

Figure 8. FUNcube satellite project

This small device provides immediate demodulation, decoding and decryption of received data. It serves the purpose of a receiver alone. There is no transmitting mode for the RTL-SDR and FCD. The RTL SDR provides 8 bit I/Q output samples and has a sample rate of 2.8 Msps. It can demodulate data in 2 MHz bandwidth range. Other tuners do not provide good coverage as the Elonics E4000 tuner chip.

The RTL SDR is not spectacular as the USRP, but the low cost feature makes it an attractive option for sdr enthusiasts and hobbyists. Figure 9 shows the RTL-SDR hardware. Elonics E4000 tuner chip block diagram is given in Figure 10.

III. RESULTS

With so many low cost receivers entering the market, the electromagnetic spectrum seems to be opened to the public. The signals between 64 to 1700 MHz include public service like police, fire, air traffic control, military, maritime, certain satellite based services including navigation, to name a few. People can receive these signals if appropriate softwares are installed. Certain signals are encrypted by strong codes and cannot be decoded. There will not be any serious problems as interference can be easily detected in highly encrypted spectrum ranges. Table 1 gives comparison of the USRP, FCD and RTL-SDR in terms of frequency range, bandwidth, cost, sampling rate etc. Users can choose the device based on the frequency range they want to capture.

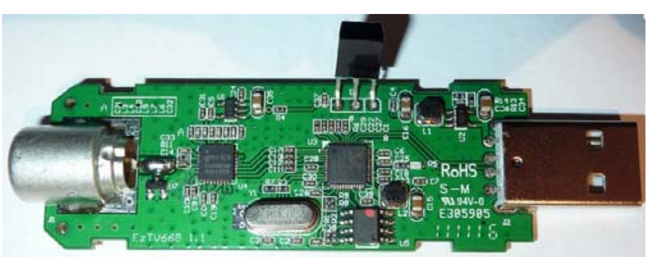

Figure 9. RTL-SDR hardware

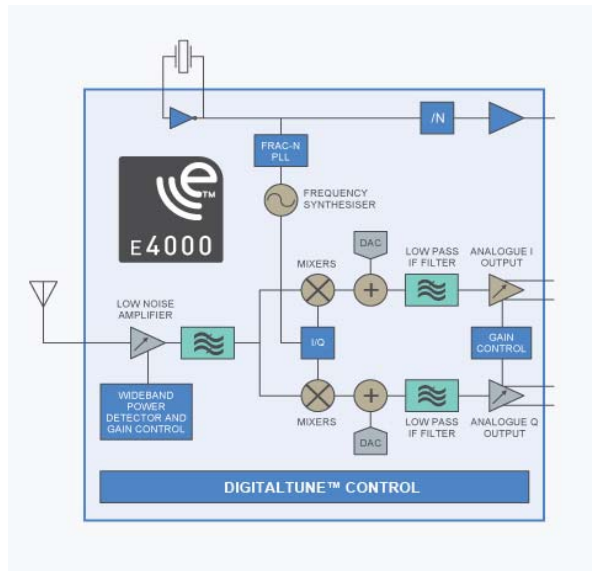

Figure 10. Elonics E4000 tuner chip block

IV. CONCLUSION

In this paper, we have tried to compare the hardwares associated with the software radio in terms of frequency, bandwidth, sampling rates and cost. We have found that most of the experiments can be performed using low cost devices, if frequency is not a main constraint.

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APPENDIX

TABLE 1

Device	Frequency	PC Interface	Bandwidth	Cost (in INR)	Sampling rate
USRP 1	Dependant on daughter boards	USB	8 MHz	40,000 (USRP1)	64 Msps (ADC rate) 128 Msps (DAC rate)
USRP 2	Dependant on daughter boards	Gigabit Ethernet	25 MHz	>1,00,000	100Msps (ADC rate) 400Msps (DAC rate)
FCD	**Base** 64-1700 MHz **Pro** Unrestricted frequency	USB	96 KHz	10,000	96 ksps
RTL-SDR	64-1700 MHz	USB	3.2 MHz	1200	2.8 Msps