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FM Receiver Based on Software Defined Radio

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Abstract Now wireless communications growing very fast, in their applied techniques and equipment. Hardware reduction became a main objective for less cost and less complexity wireless communication devices and systems. One of the most efficient solutions for the hardware complexity reduction in wireless communication systems is Software Defined Radio (SDR), it’s modulation and demodulation execute through software in a Field Programmable Gate Array (FPGA), stored in a USB Dongle used to reduce the hardware by using software, that’s enable the radio system to be multi-functions instead of one function as in the classic radio systems. This paper shows the software demodulation of FM broadcast (88 – 108 MHz) by using RTL2832 USB dongle which capture from monopole antenna to the RF Front-end (E4000chip) then to Digital Signal Processor (DSP) for demodulation and channel decoding through (RTL2832U) chip, As shown in the plotted received (demodulated through software) signals, Signals are so smooth (no ripples) which shows the high resolution of received signals. Furthermore the channel can be tune many channels simultaneously which cannot be done by the classical radio systems.

***Keywords**: SRD, Vision 101.3 FM, Receiver, DSP, RTL2832 USB dongle (RTL – SDR), Raspberry Pi, SDRsharp*

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1. Introduction

A radio is any kind of devices that wirelessly transmits or receives signals in the radio frequency (RF) part of the electromagnetic spectrum to facilitate the transfer of information. In today's world, radios exist in a multitude of items such as cell phones, computers, car door openers, vehicles, and televisions. A SDR is a radio communication system that performs radio signal modulation and demodulation in software [1]. SDR are characterized by their flexibility just by software replacement or modification it is possible to change completely its functionality. This allows upgrading or improving the performance of the equipment without any hardware modification. It can be easily modified to satisfy the needs of any particular application. The key difference between a radio that uses software and a software defined radio is that the first one uses software internally to implement a specific function, whereas in a SDR all of its functionality can be changed by means of software modification. This kind of technology is driven by the convergence of voice, video and data transmissions over mobile devices like cellular phones and smartphones [2]. Tayfun Nesimoglu in 2010 made a receiver design but he noted that a receiver should transform a low-power RF input signal into a complex baseband signal. But he found the parameters don’t give a clear identification for the receiver’s performance, so he used SDR to cover all parameters needed so the receiver could be manufactured as an integrated circuit (IC) [3]. Lima and Menezes in 3, June 2007 made another technique based on Software defined radio called Smart Antennas. Which used the joint frequency and direction of arrival, which was an improvement to the direction of arrival [3]? Kenington in 2, 2002 made a Transmitter linearization by using software defined radio systems, in particular for the base station because of its advantages in terms of efficiency and cost [3].The reason of using SDR is to Move as much of the processing in the radio from fixed hardware to software (because every specific function need its own hardware), with the intention of making the function of the radio more configurable.

2. SDR Design

2.1. The General Block Diagram

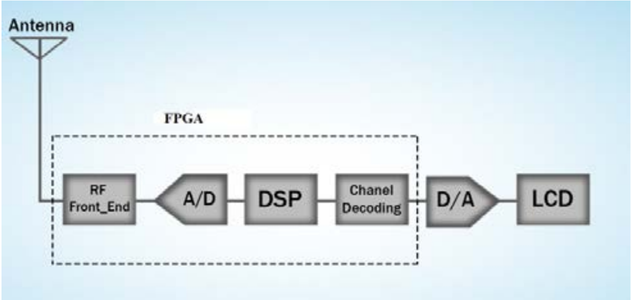

Figure 1. SDR schematic drawing

Tools in use:

- RTL2832 USB dongle (RTL – SDR).
- Raspberry Pi 3.

SDRsharp software program with laptop RTL2832 USB dongle (RTL – SDR) contains two main sections:

The first section is RF Front-End section. It's to catch the radio signal within the required bandwidth range of FM broadcasting and its down convert the frequency from that range to suitable range of demodulation. The second section is DSP in which the signal is demodulated.

The RTL2832 is an IC produced by Realtek Corporation to demodulate DVB-T (digital TV) signals and send them to a host computer over the USB bus. It has an additional mode designed to allow reception of consumer FM radio, and this is achieved by capturing I/Q samples and forwarding them to the host computer for demodulation and playback. This feature was discovered by a Linux kernel developer while writing a Linux driver for devices using this chip, and the discovery was quickly put to use by implementing drivers for SDR programs such as HDSDR, turning these devices into cheap SDR receivers. As the devices have a wide tuning range (typically continuous from 64MHz to 1.7GHz) they are very flexible. As so many devices have been produced based around this chip, it is difficult to reliably tell which devices are suitable for use with SDR

Figure 2. RTL2832 USB dongle with extensions

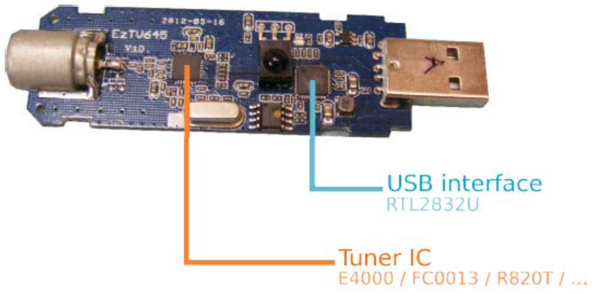

Figure 3. RTL2832 USB dongle internal design

RTL-SDR device can be classified as a 'digital IF' device that uses quadrature down conversion. It consists of a tuner IC, and an RTL2832U chip, which contains two ADCs, a DVB demodulator and an USB interface. The tuner IC is responsible for down conversion of the RF signal to baseband or IF (depending on part), and it can be controlled via I2C. The table below summarizes the different tuning limits for different types [4].

Tuner IC	**Tuning range**
Elonics E4000	52-2200 MHz (gap between 1100-1250 MHz)
R820T/R828D	24-1766 MHz
FC0013	22-1100 MHz
FC0012	22-948.6 MHz
FC2580	146-308 MHz,438-924 MHz

Summary of tuning range depending on tuner IC.

2.2. Antenna

The short antenna supplied with DVB-T dongles provides poor reception and should be replaced with a good VHF-UHF antenna mounted outdoors if possible. Low-loss RG-6/U coax is readily available at reasonable price. Adapters can be purchased to adapt the "F" connector used on RG-6/U to the PAL connector used on the dongle. Alternatively the supplied cable can be cut near the end and used to make an adapter patch cable. Details for making inexpensive wideband VHF/UHF antennas such as the disc one can be found online, old TV or scanner antennas, "rabbit ears", etc. can also be used.

2.3. RF Front_End

This stage is to catch the radio signal within the required bandwidth range of FM broadcasting stations i.e. from 88MHz to 108MHz and providing it to the next stage. In this stage, some amount of amplification is also done to offer next stage better processing capability. This stage includes antenna and other impedance matching circuitry as well. This stage also down convert the high frequency to a frequency that can be processed by our DSP Hardware. In this case, we call it IF stages, where the frequency of received radio signal is down converted from 88-108MHz to 360KHz. The conversion requires two IF stages, also called as double conversion. The stage FR Front-End has two tasks, the first is to tune to the desired FM channel for processing, and the other task is to down convert any incoming frequency between 88 MHz to 108 MHz to 10.7MHz.

This RF Front _End constructs of:

1. RF filters its represent a class of electronic filter, used to combine or separate multiple frequency bands [8].
2. Low-Noise Amplifier (LNA) use to supply a power gain of 100 (20 decibel - dB) while decreasing the signal-to-noise ratio by a factor of two (a 3 dB noise figure). Although it's concerned with weak signals that are just above the noise floor, it's also consider the presence of larger signals causing intermodulation distortion. Consequently, low-noise amplifiers often do not have high gains [5].
3. Mixer which use to converts RF power at one frequency into power at another frequency to make signal processing easier and also inexpensive. A fundamental reason for frequency conversion is to allow amplification of the received signal at a frequency other than the RF, or the audio, frequency. A receiver may require as much as 140 decibels (dB) of gain. It might not be possible to put more than 40 dB of gain into the RF section without risking instability and potential oscillations [6].
4. Local oscillator (LO) is an electronic oscillator used with a mixer to change the frequency of a signal. This frequency conversion process, also called heterodyning, produces the sum and difference frequencies from the frequency of the local oscillator and frequency of the input signal. Processing a signal at a fixed frequency gives a radio receiver improved performance [7].

5. IF filter use to passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency [9].

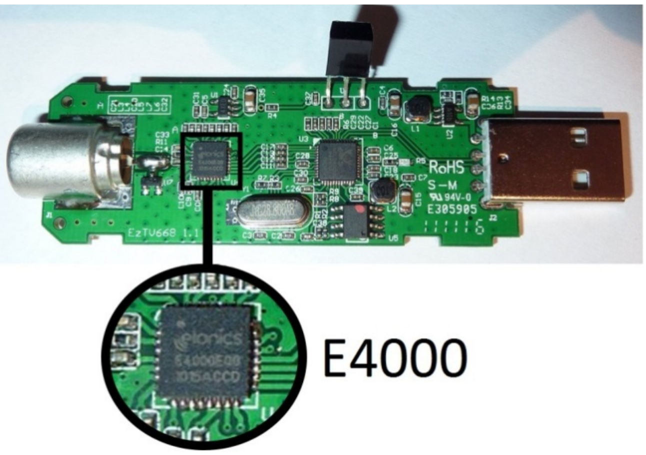

Figure 4. E4000 Elonic chip

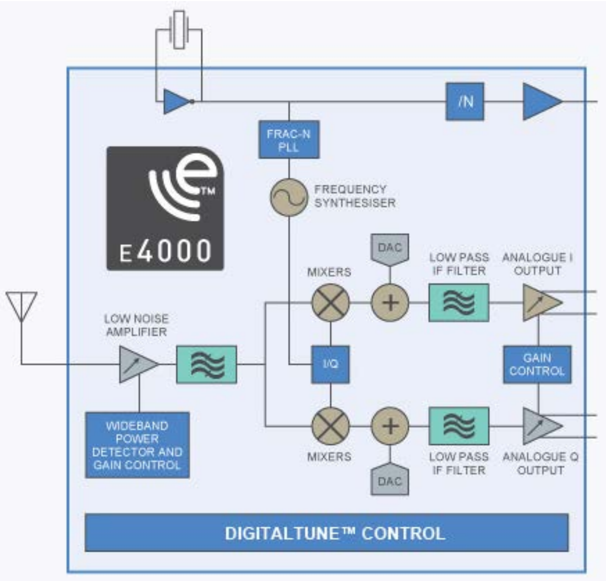

Figure 5. E4000 Block diagram

Both of the tasks above require a main block (E4000 Elonic) which responsible to tune to the station by changing its oscillation frequency which is commanded by DSP voltage feedback. The second IF stage is simply the conversion from 10.7 MHz to 360 KHz.

At the heart of the E4000 is Elonics innovative DigitalTune™ architecture, which allows the user to adjust the performance of the tuner for optimum linearity or noise figure according to the signal conditions. It enables manufacturers to significantly improve reception quality, whilst supporting multiple broadcast standards. It contains a single input LNA with RF filter, whose center frequency can be programmed over the complete frequency range from 64MHz to 1700MHz. This greatly simplifies antenna management especially for applications that require support for more than one broadcast standard.

2.4. RTL2832U

This chip contains an Analog to digital converter (A/D) and contains DSP in which the signal is demodulated, together with all other operation needed to accomplish this, like filtering, decimation, amplification, etc. It also contains channel decoding which recovers data information from this bit stream generated. In this stage a forward error correction mechanism is implemented, with convolutional or block codes, together with an interleave to reduce the probability of burst errors.

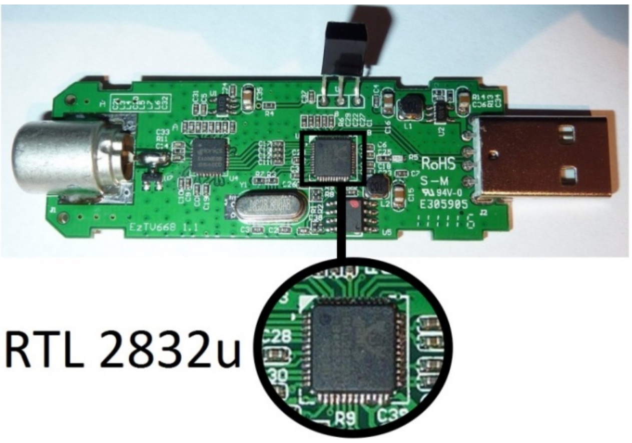

Figure 6. RTL2832U chip

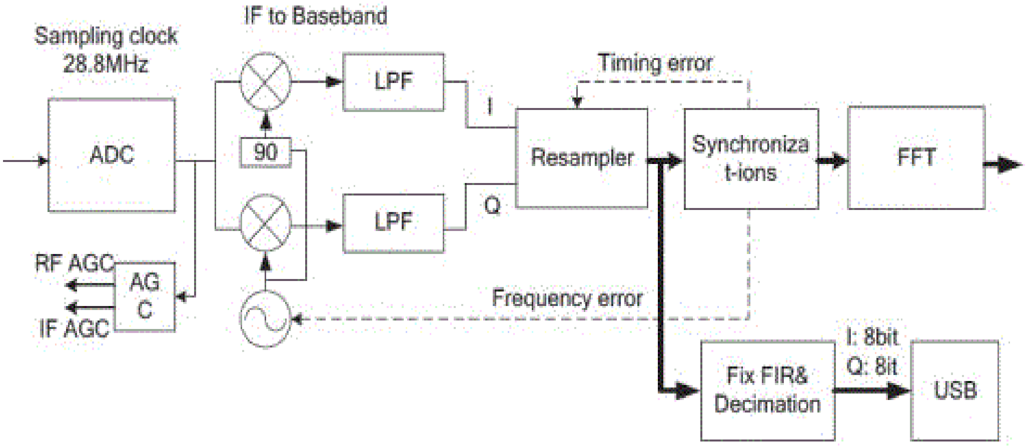

Figure 7. RTL2832U block diagram

In demodulation this chip uses IQ demodulation technique which samples the signal at a high enough rate to capture all of the sideband information on both sides of the carrier.

The I and Q components are not the same signal; they are samples of the same signal that are taken 90 degrees out of phase, and they contain different information. It's a subtle, but important distinction.

Separating I and Q in this way allows you to measure the relative phase of the components of the signal. This is important not only for FM (and PM) demodulation, but also for any other situation in which you need to distinguish the contents of the upper and lower sidebands of the carrier (e.g., SSB).

The IQ-demodulation consists of 3 main steps:

1. Down-mixing
2. Low-pass filtering
3. Decimation

The multiplication with the square root of two is included to preserve the energy in the signal (explained in section 3.4.) [10].

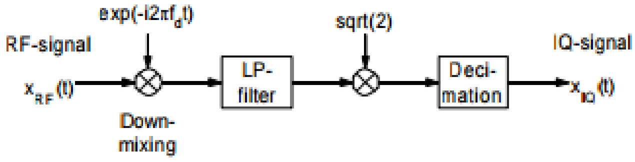

Figure 8. IQ demodulation

1. **Down-mixing:**

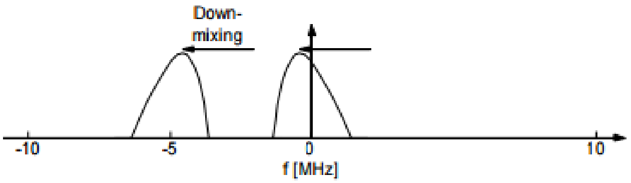

Figure 9. Down mixing

The real valued RF-signal is multiplied ("mixed") with a complex sinusoid signal:

$$X_{IQ}(t) = X_{RF}(t).\exp\left(-i2\pi f_{Demod}.t\right)$$

Where t is the time along the beam. The relationship between time and distance r is: t=2*r/c. c is the velocity of sound in human tissue (1540 m/s). The resulting signal xIQ(t) is complex.

Looking at the signal before and after the mixing explains the name "down-mixing". The frequency spectrum is actually moved down (to the left) in the frequency plane. After the down mixing, the resulting signal is complex, and the frequency spectrum is no longer symmetric about zero.

Because of the relationship between complex exponential functions and sine and cosine functions [10],

$$\exp(-i\omega t) = \cos(-\omega t) + i\sin(-\omega t) = \cos(\omega t) - i\sin(\omega t).$$

2. Low-pass filtering:

After down mixing, the complex signal is low-pass filtered to remove the negative frequency spectrum and noise outside the desired bandwidth:

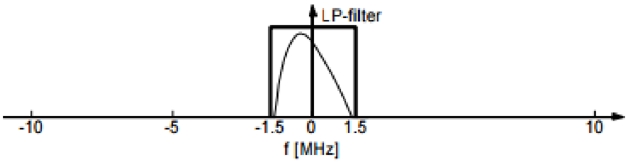

Figure 10. Low-pass filter

The low-pass filter on the complex signal can be thought of as a filter applied to the real and imaginary part separately. With careful choice of low-pass filter, the remaining signal becomes weak for frequencies outside the pass-band for both components. In our example, we chose a low-pass filter with rectangular frequency response and cut-off frequency 1.5 MHz The rectangular frequency response is approximated by using a FIR filter with Hamming weighted sinc coefficients.

The filter removes the frequencies stemming from the negative spectrum of the real RF signal, and the filter removes approximately half of the energy in the signal. In order to preserve the energy in the signal, the complex signal should be multiplied by the square root of 2[10].

3. Decimation:

The Nyquist theorem then states that the sampling frequency can be reduced to twice the cutoff frequency of the filter without loss of information. Because we have a complex signal, the bandwidth of the signal equals the complex sampling rate (the complex signal doesn't have an ambiguity between positive and negative frequencies).

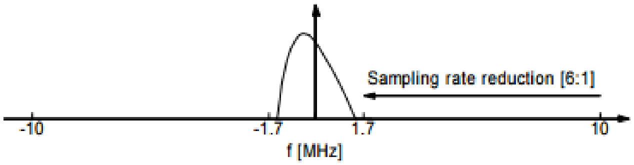

Figure 11. Decimation

This means that we can reduce the sampling frequency from 20 MHz to 3.33 MHz 3.33 is the smallest integer fraction of 20 which is larger than twice the filter cut-off frequency. The sampling rate is reduced by a factor 6. In practice, the desired decimation is obtained by keeping every 6th sample and throwing away the rest.

The IQ demodulation preserves the information content in the Band-pass signal, and the original RF-signal can be reconstructed from the IQ-signal.

The next chapter explains how to reconstruct the RF-signal from the IQ-signal.

The IQ data is written to EchoPAC files with 16 bit signed integer representation of the I and Q components, giving a total of 32 bits for representation of each sample [10].

2.5. Raspberry Pi 3

The Raspberry Pi is a credit-card-sized single-board computer developed in the UK by the Raspberry Pi Foundation to promote teaching of basic computer science in schools. Hardware includes a Broadcom BCM2835 System on a Chip (SoC): ARM1176JZF-S 700 MHz processor VideoCore IV GPU, 512MB RAM.

The RPi is an open project. Schematics and software source code are freely available Performance is something like a 300MHz Pentium II -- or PC computing circa 1997-1998 Linux is the preferred operating environment, many different distributions are available.

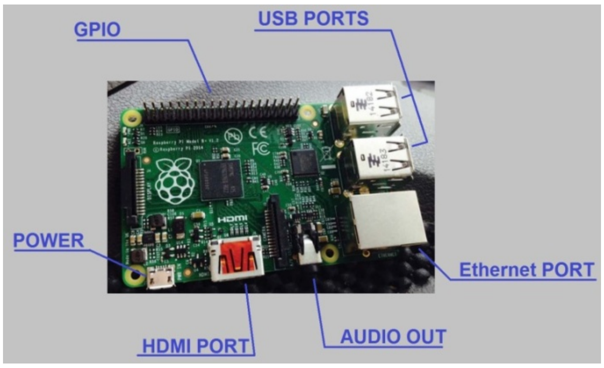

Figure 12. Raspberry PI3 component

1. USB PORT:

The Raspberry Pi 2 has four USB ports allowing you connect it to keyboards, mice, WiFi dongles, and USB sticks containing all your files. Since the ports don't provide much power, if you want to add a USB hub to the Pi you'll need to fid one that comes with an external power supply.

2. GPIO header:

This comprises the general purpose input/output (GPIO) pins. They're a set of connections that have various functions, but their main one is to allow you to connect to the Raspberry Pi with an electronic circuit. You can then program the Pi to control the circuit and do some amazing things with it.

3. Ethernet port:

The traditional way to connect to the internet is via a wire called an Ethernet cable. You'll fid a few similar ports like this at the rear of your router at home that will let you connect the Raspberry Pi directly into it. This method is easier to set up than WiFi and may provide faster internet, but you're then limited by the length of the cable.

4. Audio out:

This looks like a headphone socket because that's exactly what it is. A 3.5mm jack to be precise, this allows you to connect the Pi to computer speakers, or you could even plug in your favorite headphones and have a Raspberry jam.

5. Power:

This is the kind of small charging port you might fid in your smartphone. This micro-USB port means you can power the Pi with the right kind of mobile phone charger or directly from your PC – however, it's best to use the offal Raspberry Pi power supply to make sure the Pi is getting enough power.

6. HDMI port:

This is an HDMI port, the kind you'll fid on the back of most modern TVs and computer monitors. Use a standard HDMI cable to connect your Raspberry Pi to your chosen screen, to see (and hear) whatever it's doing. You'll definitely need to plug it in to set up the Pi.

7. MicroSD card slot:

A little SD card is used as the Raspberry Pi's hard drive. This is where the operating system will live once you've put it on there. Most computers won't be able to directly connect to a microSD card, but you can get an adaptor that plugs into normal SD card slots[11].

2.6. SDRSharp

SDRSharp is an easy-to-use yet small and fast Software Defined Radio application for. SDRSharp is written in C, a modern, general-purpose, object-oriented programming language developed by Microsoft.

SDRSharp is intended as a Digital Signal Processing application for use with a wide range of RF hardware, including:

- SoftRock .
- FiFiSDR.
- FUNcube Dongle.
- SDR-4.
- LazyDog's LD-1.
- SDR-IQ.
- SDR-14.
- RTL2832U / RTLSDR.
- Any sound card based SDR front end.
- Any ExtIO based SDR front end.

The SDRSharp human interface is intuitive and flexible to use. "Run" and "Stop" buttons are found the very top of the screen, along with the ability to select live data from a connected IQ stream or playback of stored files.

The balance of the SDRSharp screen consists of three functional areas:

- Expandable control panels along the left-hand side.
- Tuning controls and spectrum display at the top- right.
- Waterfall display at bottom-right.
- Controls for spectrum Zoom and waterfall Contrast along the rightmost edge.

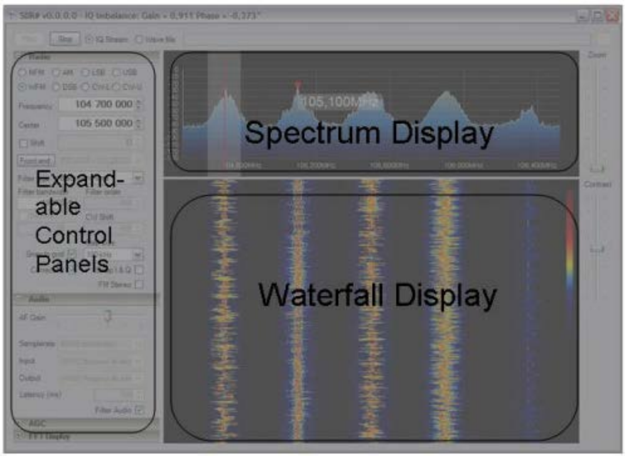

Figure 13. SDRsharp layout

SDRsharp comes with four standard control panels:

- Radio
- Audio
- AGC
- FFT Display

Each panel can be minimized by clicking on the "-" sign, or expanded by clicking on the "+" sign.

RADIO:

The Radio panel includes information needed to configure, control, and tune the Software Defined Radio. Here is a brief description of functions that are available:

1. MODE

Selections include Narrow FM (NFM), AM, Lower Sideband (LSB), Upper Sideband (USB), Wide FM (WFM), Double Sideband (DSB), and CW with lower or upper-side offset (CW-L and CW-U) NFM is used for all FM modes except FM broadcast, which is WFM.

2. FREQUENCY

This box shows the frequency that is actually being received. Direct entry is possible, but must be within range of the center frequency that is presently set. Click the mouse anywhere in the spectrum display to tune to that frequency.

3. CENTER

This box shows the center frequency that the RF front-end is tuned to. The combination of FREQUENCY and CENTER displays can be used to tune SDRsharp. Once the CENTER frequency is set, any signal within the spectrum display can be tuned, based on the sample rate of the RF front end. See “Spectrum Display” for information on tuning using the mouse, otherwise center frequency (in Hz) can be entered directly.

4. FRONT END

Various RF hardware options can be selected by clicking the down-arrow just to the right of the FRONT END button. Available devices can be selected via the pull-down menu, and applicable defaults will be displayed. The FRONT END button brings up a menu containing any configuration options that are available for the selected device.

5. FILTER TYPE, FILTER BANDWIDTH, FILTER

ORDER These three options allow customization of the window function, bandwidth, and order of the DSP filter used by SDRsharp. Default options are chosen for nominal operation in each model, but can be changed as desired, and the specified bandwidth will be shown as a highlighted area on the spectrum display. Filter settings will return to the default values when SDRsharp is restarted.

6. SQUELCH

Clicking the box enables the Squelch function, which mutes the audio output until the received signal exceeds the threshold value that is determined by the value in the box below. Lower values “loosen” the squelch or decrease the signal level needed for audio to be heard. Higher values require stronger signals before audio is heard. Squelch is available in AM and NFM modes only.

7. CW SHIFT

This value determines the offset between transmit and receive frequencies in the CW modes for devices having transmit capability.

8. SNAP TO GRID, STEP SIZE

These functions help to simplify tuning for channelized operation, and to customize the tuning response of SDRsharp for all modes. A wide range of step size options can be selected from the pull-down menu to accommodate various needs. For example, 12.5 kHz steps are used in aircraft communications, whereas single sideband requires tuning in increments of 100 Hz or less. The Snap-to-Grid option forces the tuned frequency to the nearest step size increment.

9. CORRECT IQ

SDRsharp has an original algorithm that compensates gain and phase imbalances between the IQ channels. Without this compensation strong signals are mirrored with respect to the center of the spectrum, as can be seen in the spectrum display of other SDR programs. This unique feature of SDRsharp should be left on unless there is a reason to disable it.

10. Swap I and Q

Most RF front ends will present I and Q signals in the proper way, but if not, click this box to swap them without changing hardware connections.

11. FM Stereo

When selected, stereo output is available in WFM mode (for broadcast FM listening).

12. Mark Peaks

Clicking this box toggles a visual indicator of peaks in the spectrum display as an aid for tuning.

One of the problems is that the Raspberry PI 3 hang in that’s why the work done by the Laptop.

One of the often overlooked features of the RTL drivers for the RTL2832U SDR sticks is the TCP server. The TCP server allows you to send data from the RTL2832U stick across your home network to a remote PC running a program to process the data back into SDR information such as SDR Sharp. While the Raspberry Pi is not quite powerful enough to run current programs to decode and process the SDR data from the RTL2832U stick, it can do a very good job of running the rtl_tcp server. This means that you can plug the RTL2832U stick directly into the Raspberry Pi and wind up with a very small and portable SDR radio server. You can either plug the Raspberry Pi directly to your router or use Wifi for more flexibility in placement.

3. Receieved Signals Analysis

Figure 14 shows that SDR can receive many channels simultaneously which cannot be done by the classical radio systems.

Figure 15, Figure 16, Figure 17 show the demodulation stages of the received signal.

Figure 17 shows very clear received signal without ripples.

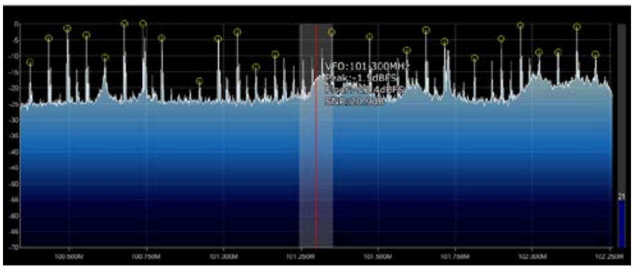

Figure 14. Simultaneous channels received

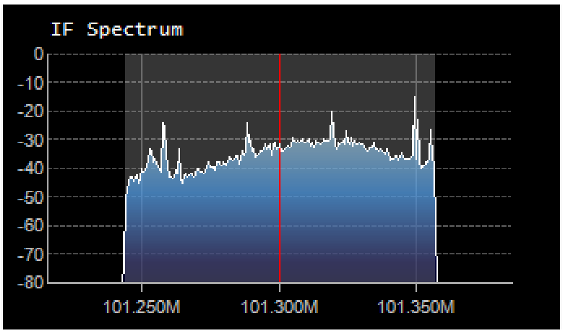

Figure 15. The IF spectrum of Vision 101.3 FM

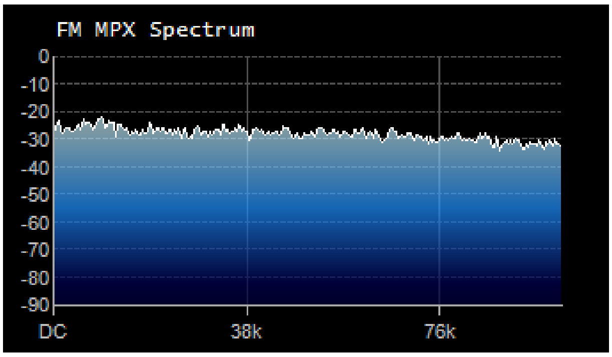

Figure 16. Vision FM spectrum

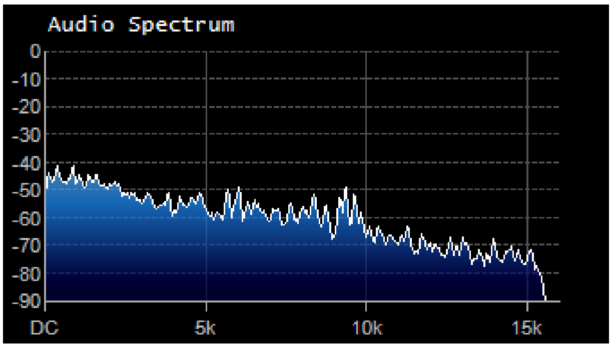

Figure 17. The information spectrum

4. Conclusion

The work shows that how software takes a normal IF (10.7 MHz) and obtained the demodulated data from FM broadcast by using FPGA (RTL2832 USB dongle (RTL – SDR) and then it has been analyzed using SDRsharp program on laptop and Raspberry Pi 3 without needing to modify new hardware.

5. Future Study

The RTL was used as a receiver only, since it can both receive and transmit, so it's an open area for researchers to work on the RTL as transmitter.

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