

# Remote Spectrum Analyzer based on Web Software Defined Radio for Use in Telecommunication Engineering Remote Laboratory

F. Yudi Limpraptono, Eko Nurcahyo

*Department of Electrical Engineering, National Institute of Technology Malang.  
fyudil@lecturer.itn.ac.id*

**Abstract**—Software defined radio (SDR) is a new paradigm in the design of wireless communication devices. Currently SDR technology is widely used in the field of telecommunications such as mobile phones and is very popularly used on amateur radio. SDR technology not only can be used for radio transceiver system, but SDR can also be used as a spectrum analyzer. The spectrum analyzer is an instrumentation that is needed by researchers in the field of telecommunications and amateur radio activists. The problem of researchers and amateur radio activists is how to use spectrum analyzers that can be accessed remotely, so that they can observe the spectrum of the radio frequency that produced by their communication devices remotely when they experiment with the radio transmitters or antenna. From this background, this research proposes the development of a remote spectrum analyzer system based on web software defined radio. The remote spectrum analyzer will be integrated with remote laboratories that can be accessed by the wider community either by researchers, amateur radio activists, and students at educational institutions, by accessing it through the internet network.

**Index Terms**—Web Software Defined Radio; Embedded System; Remote Laboratory.

## I. INTRODUCTION

SDR technology is currently used widely in the field of telecommunications such as satellite communications, mobile phones and is very popularly used on amateur radio [1]. Software defined radio is a new paradigm in the design of wireless communication devices. The concept of radio software was first initiated by Joseph Mitola in the early 90's [2]. Joseph Mitola illustrates that an ideal SDR is to contain only the physical component of an antenna and an ADC on the receiving end and vice versa on the transmitter side there is a DAC and a transmission antenna. And the next task will be handled by the processor that has been programmed [3].

SDR technology not only can be used for radio transceiver system, but SDR can also be used as instrumentation for radio frequency spectrum analyzer. The spectrum analyzer is an instrumentation that is needed by researchers in the field of telecommunications and amateur radio activists. The function of the spectrum analyzer is for the process of measuring and testing of telecommunication equipment either production testing at factory or maintenance and repair activities. This equipment is required for research and development activities in telecommunication laboratories. A spectrum analyzer is a type of measuring instrument with a very high price, so not all institutions can have it. The others problem of amateur radio researchers and activists is how to use spectrum analyzers that can be accessed remotely, so that they can

observe spectrum of the radio frequency that produced by their communication devices remotely when they experiment with the radio transmitters or antenna.

From this background, this research proposes the development of a remote spectrum analyzer system based on web software defined radio. The remote spectrum analyzers will be integrated with remote laboratories that have been developed and realized by authors since the 2011s. In 2015 authors have developed remote instrumentations system based on embedded web to support remote laboratory. The aim of the research is to create a prototype of remote instrumentation consisting of an oscilloscope and a frequency generator that has highly efficient specifications [4].

The authors are doing research with the aim of completing the remote lab project, by adding a remote spectrum analyzer. So that the remote spectrum analyzer can be accessed by the wider community either by researchers, amateur radio activists, and students at educational institutions, by accessing it through the internet network.

Implementation of embedded systems (Raspberry PI 3) on the remote spectrum analyzer systems is expected to contribute to the remote instrumentation engineering based on green technology that has the characteristics of efficient, energy efficient and low cost.

The structure of the paper is as follows, in Section II we review the concept of the software defined radio technology. Section III design of the web software defined radio, Section IV digital signal processing and Section V is the conclusion.

## II. SOFTWARE DEFINED RADIO TECHNOLOGY

Software Defined Radio has been available since the 1980s. Although the theoretical for building an SDR system has been around for a long time, its true potential has been opened slowly, in parallel with the increasing computational performance of computer [1].

The advantages of SDR is reconfigurable, which results in flexibility. The key part of an SDR system is the software, which can be modified and updated at any time [5]. Another key point of SDR is reliability. DSP algorithms work on discrete signals and except for some special cases, have fully predictable output, giving exactly the same result for the same input every time [1].

### A. Software Defined Radio Architecture

Most software defined radio receivers use to direct the quadrature down-conversion. This kind of architecture is a

form of “digital IF” or “digital baseband”, depending on which functions are implemented in DSP. Block diagram of an SDR receiver using direct quadrature down-conversion shown in Figure 1. The RF signal is mixed with a sine and cosine (thus an oscillator with complex output). The low-pass filters remove the out-of-band components, and the resulting complex signal is centered at DC, and can be sampled with two ADCs [1].

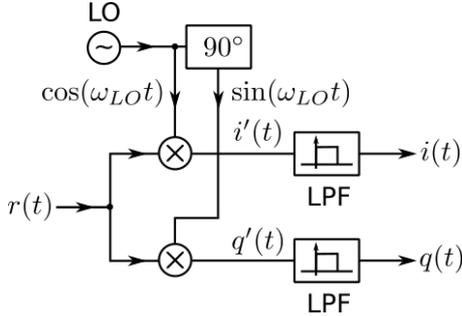


Figure 1: Block diagram of the SDR receiver using direct quadrature down-conversion

The frequency conversion operation is accomplished by a component known as a mixer. The purpose of a mixer is to output the product of two input: the RF signal  $r(t)$  and the local oscillator (LO) signal. In fact, there are two mixer chains, to yield both the in-phase (I) and quadrature (Q) components of the received signal. This is done by driving one mixer chain with a LO signal  $\cos(\omega_{LO}t)$  and the other with the LO signal shifted by  $90^\circ$ ,  $\sin(\omega_{LO}t)$ . The original message can be demodulated from the I and Q components, since complete amplitude and phase information of the modulated signal is present between these two components [6].

The theory is as follows. The two mixer chains should produce

$$i'(t) = r(t) \times \cos(\omega_{LO}t) \text{ and } q'(t) = r(t) \times \sin(\omega_{LO}t) \quad (1)$$

If  $r$  is a sinusoidal signal  $r(t) = \cos(\omega_{RF}t)$ , the mixing process yields sum and difference frequencies, from which the desired product can be filtered out. For example, if  $r(t) = \cos(\omega_{RF}t)$ , then from trigonometric identities,

$$i'(t) = \frac{1}{2}\cos[(\omega_{RF}) - (\omega_{LO})t] + \frac{1}{2}\cos[(\omega_{RF}) + (\omega_{LO})t] \quad (2)$$

which is the superposition of the sum frequency and the difference frequency. The difference frequency resulting from mixing the LO signal with the input signal, which is called the intermediate frequency (IF),

$$(\omega_{IF}) = (\omega_{RF}) - (\omega_{LO}) \quad (3)$$

The undesired component is filtered out using a low pass filter (LPF)

$$i(t) = \frac{1}{2}\cos(\omega_{IF}t) \quad (4)$$

Similarly,

$$q(t) = \frac{1}{2}\sin(\omega_{IF}t) \quad (5)$$

### B. Universal SDR Hardware and RTL-SDR

If an SDR receiver hardware can be tuned within a wide frequency range (from a few MHz to a few GHz), and contain an ADC that supports high sample rates (more than 1 Msps), it might be considered universal, as it can sample most of the signals transmitted by common RF communication devices.

DVB-T tuner USB dongles with RTL2832U chip can be used as a general purpose SDR hardware front-end. These devices can provide an 8-bit baseband I/Q signal via USB interface. Although their primary function is to demodulate DVB and send MPEG transport stream to the host, these devices also capable of receiving broadcast FM and DAB stations.

Architecture RTL-SDR device can be classified as a digital IF device that uses quadrature down-conversion. Block diagram of the architecture of an RTL-SDR shown in Figure 2. It consists of a tuner IC, and an RTL2832U chip, which contains two ADCs, a DVB demodulator and a USB interface. The tuner IC is responsible for down-conversion of the RF signal to baseband or IF, and it can be controlled via I<sup>2</sup>C [1].

RTL2832U chip serves to digitize the baseband or IF signal at a conversion rate of 28.8 Msps, and it contains a DDC in hardware to produce the baseband I/Q signal of a lower sample rate [7]. The ADC produces 8-bit real (in-phase denoted by I) and imaginary (quadrature denoted by Q) interleaved sample values, in an unsigned format. The RTL-SDR dongle uses a phased locked loop based synthesizer to produce the local oscillator required by the quadrature mixer. The actual output is interleaved, so one byte I, then one-byte Q with no header or metadata (timestamps) [8].

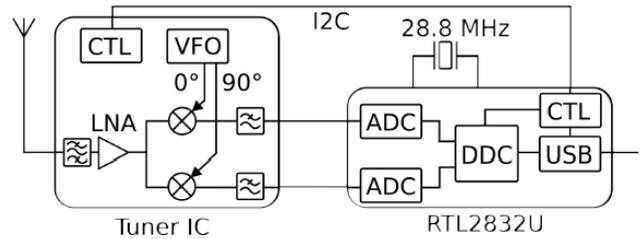


Figure 2: Architecture of an RTL-SDR

### III. DESIGN SYSTEM

According to research objective, this paper proposed the development of the remote spectrum analyzer system based on web software defined radio and it will be integrated with remote laboratories that have been realized and published in the manuscript titled ‘*Development of the Remote Instrumentation Systems based on Embedded Web to Support Remote Laboratory*’ [4]. Block diagram system is shown in Figure 3., consist of five major components: web server as remote lab gateway, internet and intranet network, webSDR server, RTL-SDR receiver and remote computer client.

The web server for the remote lab gateway is implemented with an embedded system using the Raspberry Pi 3. The embedded system has 1GB of RAM, various I/O ports and Ethernet port 10/100. The embedded system using the Raspbian embedded Linux operating system. The web server remote lab gateway contains several software applications such as Apache web server, a MySQL database server and a remote lab user management application based on PHP. The user management application functions to handle user

requests that will access the remote lab and manage all remote lab resources [9]. The hardware of the Web software defined radio shown in Figure 4.

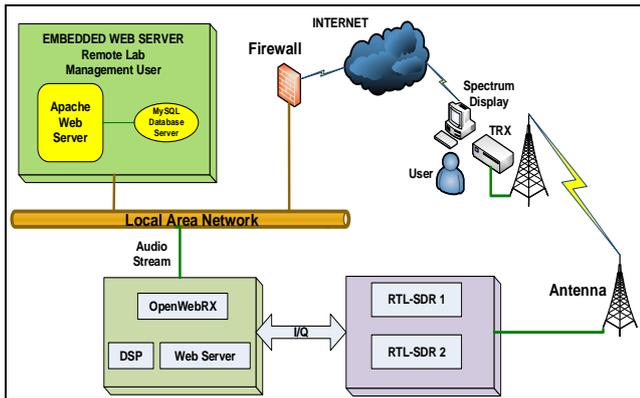


Figure 3: Block Diagram System



Figure 4: Hardware of the WebSDR

We use a webSDR server application that has been developed by A. Retzler with the titled 'OpenwebRX'. WebSDR server contains multiple classes, and imports some python modules that belong to the project [1].

The front-end contains the files required for running the web application in the browser. These files are contained under htdocs subdirectory of OpenWebRX, and the web server sends them to clients on request. The OpenWebRX.js file is written in JavaScript, and it is the heart of the Open WebRX front-end, as it provides all interactive behavior of the web page.

OpenWebRX was designed to work without the need of downloading additional JavaScript libraries. The only JavaScript file is openwebrx.js that does everything that we need in this particular application. When index.wrx is loaded, the function openwebrx\_init is called in openwebrx.js. It initializes UI elements, and opens the WebSocket to the server. After a handshake process, the server sent the parameters of the receiver and preconfigured setting of the waterfall diagram. The waterfall displays and the frequency scale is initialized accordingly.

#### IV. DIGITAL SIGNAL PROCESSING IN WEBSDR

For the baseband processing of the signal, we used an embedded system based on Raspberry Pi 3. Raspberry Pi is connected to RTL-SDR using USB connection. The demodulation process of the signals is done by the digital signal processing in OpenWebRX. How does it work, the input of the DSP is the data streaming I/Q coming from

receiver front-end RTL-SDR, after down-conversion and sampling process.

In this project we have implemented standalone DSP library called *libcsdr* that contains all necessary function for modulation. Diagram of the DSP chain for modulation shown in Figure 5.

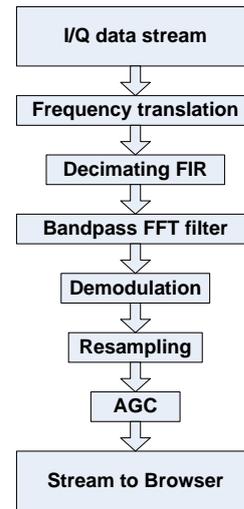


Figure 5: DSP Chain for Modulation

Sequences of the demodulation process can be explained as follows: the first step is channelization to select the signal to receive. In this step can be done frequency translation to shift its center to DC in the frequency domain, and it can decrease the sample rate with a decimating FIR filter. Next step we can apply a band-pass FFT filter. The passband of this filter can be selected on the web user interface. The demodulator performs conversion of complex signal to a real-valued audio signal. The automatic gain control to keep the signal level constant. And the end of the process output of the DSP chain is streamed to the web browser of the user.

The user interface of OpenWebRX is similar to other SDR software, it has the appropriate buttons for changing modulation, receiver frequency can be set by clicking on a signal shown on the waterfall display. Display of the spectrum analyzer shown in Figure 6.

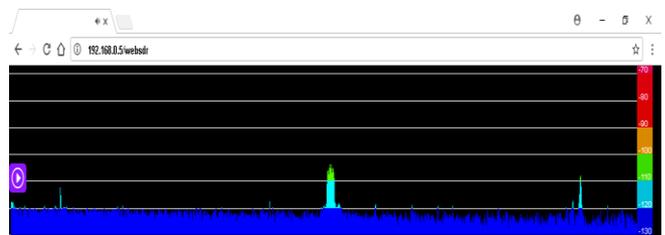


Figure 6. Spectrum Analyzer Display

#### V. CONCLUSION

This paper present the development remote spectrum analyzer based on web software defined radio for use in telecommunication engineering remote laboratory. A prototype of the remote spectrum analyzer is designed as efficiently as possible by applying embedded system hardware (Raspberry Pi 3) and receivers using low-cost universal SDR (RTL-SDR), while the application software uses 'OpenwebRX', which can be developed according to our

needs. At the time of writing, the research project is still ongoing and the results are expected to provide a remote spectrum analyzer and a remote radio receiver that can be used by researchers and amateur radio activists around the world.

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