Low cost prototype simulation of spectrum analyzer base on GNU radio and RTL-SDR

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Abstract—this paper describes the prototype spectrum analyzer simulation using Software Defined Radio technology. The use of this technology continues to grow very rapidly, this is what drives researchers to develop this system. SDR is a radio communication system where the modulation system contained in the hardware is replaced by implementing software on a computer or embedded system. The SDR system commonly used is GNU Radio. The use of SDR is very cheap (around $ 20), and is small in size so that it offers cost effectiveness and portability requirements added by GNU radio software that is open source. In this experiment, there were several parameters measured including power and signal to noise ratio (SNR) measured using GNU Radio and compared with measurements using the Spectrum Analyzer GSP-730 which was applied to prototype simulations using 60 MHz to 80 MHz frequency inputs from generator frequency. From the experimental results show the average GNU radio power is -15.28 dBm and the average spectrum analyzer power is -15.2 dBm, so the accuracy level of the power measurement on GNU Radio reaches 99.47%, while the average SNR spectrum analyzer is 54.2 and GNU radio SNR 54.32 so the accuracy of SNR measurement in GNU Radio reaches 99.78%.

1. Introduction
Spectrum analyzer is a multipurpose measuring instrument in measuring signals in the frequency domain. An analyzer that can be used to measure signals on a transmitter that requires measurement parameters such as frequency, power, gain, and noise[1]. Spectrum analyzer are also used to investigate the distribution of energy along the frequency spectrum of known electrical signals, from this investigation obtained very valuable information about the width of the frequency field (bandwidth), the effect of various types of modulation, the generation of false signals and so on all its benefits in RF frequency (radio frequency) planning and testing[2]. Spectrum analyzer have a special function to measure a number of signals in a limited frequency spectrum [3]. The many uses of spectrum analyzer do not be surprised if the price of spectrum analyzers is not cheap. Whereas GNU Radio is software that can be used free of charge, and is used to create a Software Defined Radio (SDR), without the need for hardware[4]. GNU Radio uses the C++ or Python programming language in its implementation. The advantage of GNU Radio is open source software, and it doesn't cost much in terms of its operations. Researchers aim to measure the power of a frequency using GNU Radio then compare it to a spectrum analyzer[5].

Every individual or institution that uses on a frequency wave must use a spectrum analyzer and it will cost more to buy a spectrum analyzer. This prototype wants to simulate a spectrum analyzer using SDR and GNU Radio so as to reduce prices in the use of spectrum analyzers. The simulation carried
out is measuring the power & Signal to noise ratio at frequencies 80, 75, 70, 65, 60 MHz, the difference in power units between the spectrum analyzer (dBm) and GNURadio (dB) requires that this simulation convert units into the same units in this case the simulation is done on dBm units, to change the dB units on GNU Radio using the principle of 30 dBm = 1000 mW = 1W[6] so it can be concluded to convert dB to dBm by subtracting 30 dB. GNU Radio is not only useful in research but also useful in the world of education, according to the research [7] it has been suggested that alternative methods for developing practical sessions on the Theory of Communication Theory have been widely presented. Many universities apply learning using an equation-based environment such as Matlab, or only focus on the signal processing capabilities offered by DSP but the incorporation of hardware-software systems in GNU Radio and HackRF allows learning to be more effective. SDR is the best solution for next generation technology, SDR is one of the solutions for researchers to test techniques in real time, SDR proves technological advancements especially in telecommunications and electronics[8].

2. Technical Description
This section will explain technically the concept material that will be used such as: Signal to Noise Ratio and Fourier analysis.

2.1. Signal to noise ratio
In several studies to find the direction of multiposition of radio sources with unknown parameters, continuous wave measurements can be determined by knowing the signal-to-noise ratio (SNR) at each receiver channel output. The signal to noise ratio is defined as the ratio between the desired signal power and noise power, and is widely used as a standard measure of signal quality for communication systems[9]. An information signal as a communication medium will experience a lot of interference by noise, so that it can damage the information signal. Signals that experience this interference experience a decrease in quality. The quality of this signal can be determined from the value of the Signal to Noise Ratio (SNR) measured in decibels (dB)[10]. Calculation of signal to noise ratio can be through a reduction between the noise value and the power of a frequency[11]. The steps to calculate SNR are as follows:

![Figure 1. Calculate SNR in GNU Radio and spectrum analyzer](image)

In figure 1 Block Counter SNR value of the signal obtained by calculating the Root Mean Square (RMS) value of each original signal and the noise signal. This RMS value is the signal power value. Thus, the original signal RMS value (RMS1) and the noise signal RMS value (RMS2) are obtained. To get the SNR value of the signal is by dividing RMS1 with RMS2 then made in decibels (dB).
2.2. Fourier analysis

Fourier analysis is a mathematical way to determine the frequency and amplitude of harmonics. This process is used to solve the problem of complex waveforms which decompose the waves into sinusoidal components [12]. Each complex wave consists of a number of frequencies, at various amplitudes and phase angles. Analyzing the effects (e.g., gain/attenuation and phase angle) of electronic circuits on such functions can be simplified if each component can be considered separately. This periodic function analysis method is called Fourier analysis which was developed by French mathematicians. In figure 2 below shows the polar representation (e.g., Phase) of a single frequency signal, amplitude R and angular velocity [13].

![Figure 2: Polar representation of a single frequency signal][13]

Fourier analysis can also be implemented in equation 1 [13]:

\[
v(t) = R\text{e}^{i(\omega t + \phi)} = R\sin(\omega t + \phi)
\] (1)

If there are other signals added to other frequencies and phases so the sum of the two signals is implemented by equation 2 [13]:

\[
f(t) = v_1 + v_2 = R\sin(\omega t + \phi_1) + R\sin(\omega t + \phi_2)
\] (2)

The addition of more frequencies will produce more complex wave forms. The expansion shown in equation 3 below is called the Fourier Series, where \(a\) and \(b\) are called the Fourier Coefficients and are usually written in the format [13]:

\[
f(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(n\omega t) + \sum_{n=1}^{\infty} b_n \sin(n\omega t)
\] (3)

Fast Fourier Transform (FFT) uses the repeated properties of Discrete Fourier Transform (DFT) and reduces the number of additions to produce the same results by evaluating DFT directly; the most significant difference is that FFT is a more efficient method for achieving the same results. Whereas IFFT (Inverse Fast Fourier Transform) is a method of solving discrete signals that works the opposite of FFT. IFFT is a fast computational algorithm for calculating IDFT (Inverse Discrete Fourier Transform). The subcarrier in IFFT has a frequency integer multiple of its base frequency as well as the Fourier series component in the composite signal. One of the uses of IFFT is the OFDM (Orthogonal Frequency Division Multiplexing) system [14].

3. Hardware and Software for Simulation

Hardware & Software for simulation requires some hardware such as a waveform generator, SDR, Spectrum Analyzer and laptops with the specifications which will be explained below. While the software used is GNU Radio to process the incoming signal. The simulation will be performed as in Figure 3 below.
3.1. **Spectrum analyzer (hardware)**

In this study the spectrum analyzer used is the spectrum of the GW-Instek gsp-730, measurements made in the frequency range of 60-80 MHz. Specifications on the spectrum analyzer used are, frequency range 150 kHz-3GHz, Noise floor 100 -100dBm, RBW (30kHz, 100kHz, 300kHz, 1 MHz) and support interfaces can support USB Device / Host, RS-232C[15]. Spectrum analyzer is used to compare signal results with GNU Radio from audio waveform. The spectrum analyzer used is shown in Figure 4.

![Figure 4. Spectrum analyzer GSP-730](image)

3.2. **Waveform generator (hardware)**

Waveform generator functions to make waves with a certain frequency, the waveform generator used is owned by Agilent 33250A with specifications, 80 MHz sine, square, ramp, triangle, noise and DC, 12bit, 200 Msa / s, 64 K point arbitrary waveform, GPIB & RS -232 Interfaces, BenchVue Enabled[16]. The waveform generator can be seen in Figure 5.

![Figure 5. Waveform generator](image)
3.3. **RTL-SDR**

In this measurement the link between the waveform generator and the computer / GNU Radio uses the RTL2832U device with frequency specifications 24 - 1766 MHz bandwidth 3.2 MHz ADC Resolution 8 bits [17]. RTL devices have block diagrams like Figure 6.

![Figure 6. Block diagram of RTL-SDR[18]](image-url)

3.4. **GNU radio (software)**

Simulation using GNU Radio tiper software 3.7.11.1 in this type already has various blocks such as source, sinks, and graphical sinks to misc. This simulation uses several blocks, namely RTL-SDR Source, Multiply Cons, and WX GUI FFT Sink. With the functions as follows in table 1.

| Block                 | Function                                                                 |
|-----------------------|---------------------------------------------------------------------------|
| RTL-SDR Source        | Link RTL-SDR Hardware with GNU Radio Software                            |
| Multiply Cons         | Multiplying the input data with the desired number variable              |
| WX GUI FFT Sink       | Displays a signal graph with Power and Frequency parameters              |

4. **Simulation Spectrum Analyzer**

Spectrum analyzer simulation measures 2 parameters namely power and noise. Noise measurement is used to determine the value of the Signal to Noise Ratio (SNR).

4.1 **Power simulation with spectrum analyzer**

The first simulation uses the Spectrum Analyzer as a comparison of GNU Radio with the frequency described. Figure 7a-7e is a simulation result for measuring power in the spectrum analyzer at various frequencies.
Figure 7. Power measurement on spectrum analyzer monitor

In figure 7a measurement of power value with a frequency of 80MHz, 7b measurement of power value with frequency of 75 MHz, 7c measurement of power value with frequency of 70 MHz, 7d measurement of power value with frequency of 65 MHz and 7e measurement of power value with frequency of 60 MHz.
4.2 Noise simulation with spectrum analyzer

The second simulation is measuring noise in a spectrum analyzer at the same frequency as power measurements. In figure 8a-8e is the result of simulation for noise measurement to determine the signal to noise ratio.

Figure 8. Noise measurement on spectrum analyzer monitor
In figure 8a the measurement of noise values with a frequency of 80 MHz, 8b is the measurement of noise values with a frequency of 75 MHz, the measurement of noise 8c with a frequency of 70 MHz, the measurement of noise 8d with a frequency of 65 MHz and the measurement of noise 8d with a frequency of 60 MHz.

5. Simulation GNU Radio
The third simulation uses the GNU Radio as a comparison of the Spectrum Analyzer with the frequency that has been explained, before carrying out the simulation, it needs several blocks that must be in GNU Radio, for more details, shown in Figure 9.

![Figure 9. RTL-SDR block for spectrum analyzer](image)

5.1 Power simulation with GNU radio
The simulation is using RTL-SDR which is connected to the waveform generator using a BNC connector to see the power value in GNU Radio. Figure 10a-10e is the result of experiments on GNU Radio on various frequencies.

![Figure 10a](image)
![Figure 10b](image)
![Figure 10c](image)
![Figure 10d](image)
Figure 10. Power measurement on GNU Radio

In figure 10a shows a measurement with a frequency of 80 MHz, 10b shows a measurement of 75 MHz, 10c shows a measurement with a frequency of 70 MHz, 10d shows a measurement with a frequency of 65 MHz, 10e shows a measurement with a frequency of 60 MHz.

5.2 Noise simulation with GNU radio
The fourth simulation is measuring noise in the spectrum analyzer at the same frequency as the power measurement. Figure 11a-11e is a simulation result for noise measurement to determine the signal to noise ratio.
Figure 11 shows the measurement of noise on GNU Radio with, 11a using 80 MHz frequency, 11b using 75 MHz frequency, 11c using 70 MHz frequency, 11d using 65 MHz frequency, 11e using 60 MHz frequency.

6. Analysis of Simulation for GNU Radio & Spectrum Analyzer
The value that has been collected from the above simulation will be displayed will be analyzed namely the difference in power, signal to noise ratio in the spectrum analyzer and GNU Radio.

6.1 Power measurement analysis
The power measurements are shown in table 3 below, because the power units in the spectrum analyzer and GNU Radio are different so they must be converted to the same unit, in this case the unit will be equated to dBm.

| Frequency (MHz) | GNU Radio (dB) | GNU Radio (dBm) | Spectrum Analyzer (dBm) |
|----------------|----------------|-----------------|-------------------------|
| 80             | -45.0          | -15.0           | -15.2                   |
| 75             | -45.0          | -15.0           | -15.2                   |
| 70             | -45.5          | -15.5           | -15.2                   |
| 65             | -45.2          | -15.2           | -15.2                   |
| 60             | -45.2          | -15.2           | -15.2                   |

The validity of the spectrum analyzer and GNU Radio will be taken with an average of the five values in table 2 above. The first is on GNU Radio media $\bar{X} = \frac{(-15.0)+(-15.0)+(-15.5)+(-15.2)+(-15.2)}{5}$ so that the GNU Radio has an average value of -15.28 for the second one using the spectrum analyzer media $\bar{Y} = \frac{(-15.2)+(-15.2)+(-15.2)+(-15.2)+(-15.2)}{5}$ so the spectrum analyzer has an average of -15.2. The average deviation ($D$) is taken from $\frac{|\bar{X} - \bar{Y}|}{\bar{Y}} \times 100\%$ the equation is:

$$D = \frac{|-15.28 - (-15.2)|}{15.2} \times 100\% \Rightarrow D = 0.5\%$$

6.2 Signal to noise ratio measurement analysis
Noise measurements in the GNU Radio are shown in table 3, after the noise exchange is carried out, the signal to noise ratio (SNR) value can be obtained.
Noise measurements in the spectrum analyzer are shown in table 4 below. Reduction between power and noise will get the value of the signal to noise ratio (SNR).

### Table 3. SNR measurement with GNU Radio

| Frequency (MHz) | Power (dB) | Noise (dB) | Signal to Noise Ratio |
|----------------|------------|------------|-----------------------|
| 80             | -45.1      | -99.2      | 54.1                  |
| 75             | -45.0      | -99.0      | 54.0                  |
| 70             | -45.4      | -98.4      | 53.0                  |
| 65             | -45.5      | -100.4     | 55.4                  |
| 60             | -45.5      | -100.6     | 55.1                  |

The validity of the spectrum analyzer and GNU Radio will be taken with an average of the five values in table 2 above. The first is on GNU Radio media $\bar{x} = \frac{(54.1) + (54.0) + (53.0) + (55.4) + (55.1)}{5}$ so that the GNU Radio has an average value of 54.32, for the second one uses the spectrum analyzer media $\bar{y} = \frac{(54) + (54) + (53) + (55) + (55)}{5}$ so the spectrum analyzer has an average of 54.2. The average deviation ($D$) is taken from $\frac{|\bar{x} - \bar{y}|}{\bar{y}} \times 100\%$ the equation is:

$$D = \frac{|54.32 - 54.2|}{54.2} \times 100\%$$

$$D = 0.22\%$$

### 7. Conclusion

This paper proposes measurement of power and signal to noise ratio using RTL-SDR and GNU Radio as a substitute for the spectrum analyzer function because costs are more affordable and RTL-SDR is easily found on the market while GNU Radio can be downloaded on the GNU Radio website for free.

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