Development of Radio Telescope Receiver Based on GNU Radio and USRP

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***Abstract*—This paper presents the development of radio telescope receiver based on GNU radio and Universal Software Radio Peripheral (USRP). Usually an existing radio telescope receiver is only able to be used for fixed frequency and signal processing system; hence the other different frequency receiver needs to be carried out with different types of observation. Here, the development of radio telescope receiver includes the hardware system and the signal processing system. Then, the design of radio telescope receiver is developed based on GNU Radio and implemented by using USRP. From the result, it shows that the implemented radio telescope receiver which is applied for continuum observation can clearly detect signals at frequencies of 322MHz and 406MHz n which those frequencies are usually used in radio telescope.**

Keywords*—GNU radio; radio telescope receiver; software defined radio; universal software radio peripheral.

I. Introduction

Basically radio telescope is a device that is used by astronomer to observe celestial objects by radio waves [1]-[2]. It is comprised of some components typically used in radio communication such as antenna, amplifier and receiver [2]. In actual, there are several methods to observe celestial objects such as using light waves, infrared waves, microwaves, or gamma rays [3]-[4]. All of these tools have respective roles in the observation. Radiation of electromagnetic waves in radio frequency, for example, can not be detected by optical telescopes; however it is detectable by radio telescopes and vice versa. So the use of different methods for observing celestial object is complementary.

Furthermore, the advantage of using radio telescope rather than optical telescope is the observation could be held anytime. Meanwhile, the exiting radio telescope system is usually designed only for specific application for example spectral observation or spectrograph observation. Therefore, for observing other application, it requires another system. This circumstance gives a big restriction since the economical value of the radio telescope receiver is usually very expensive. One method in overcoming the problem is using software defined radio (SDR) technology which allows the user to design radio transceiver by software. There are some applications that can be realized using SDR, such as transceiver system, base transceiver station (BTS) system, and radar system [5]-[8].

In principle, an SDR is a radio device which its part of components can be set through the software. It usually consists of two components, namely software components and hardware components. Some SDR frequently used is WiNRADiO and GNU radio. By using SDR, the selection of operating frequency can be conducted freely and easily with the condition of antenna and amplifier having fairly wide frequency range. Therefore, an SDR can be an alternative solution to be implemented in the design of radio telescope system since it can be applied as a receiver that accommodates multiple techniques.

In this paper, the development of radio telescope receiver design using SDR is presented. Here, the SDR used for developing radio telescope receiver is based on GNU radio. Meanwhile, the implementation of radio telescope receiver is using USRP. The development of radio telescope receiver includes the hardware system and the signal processing system. Some brief description of telescope system is pointed out at first before the radio telescope receiver design. Then some discussion related the implementation of radio telescope receiver using USRP and its results are presented, and then followed by the conclusion.

II. Radio Telescope System

A. Basic System of Radio Telescope Receiver

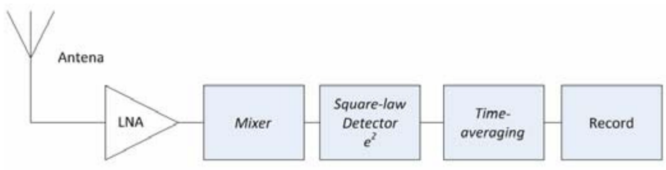

Figure 1. Block diagram of basic radio telescope receiver

Fig. 1. shows a block diagram of basic system of radio telescope receiver which comprises of antenna, low noise amplifier (LNA), square-law detector and time-averaging processor [1]. The signal from celestial objects is catch by the antenna and then amplified by the LNA. The square-law detector gives the power of received signal and the integrator takes a range of times to integrate the signal so it can be expected the mean value of signal at the integrator output. This

basic system is only can be used to observe the continuum properties of celestial objects. Meanwhile, to implement the receiver system for other properties, it is required to modify the receiver form basic system.

B. Radio Telescope Observation Techniques

There are two observation techniques which uses a single dish of radio telescope, namely continuum observation and spectral observation [1]. The continuum observation only observes the signal power of celestial objects, whilst the spectral observation is observation that gives us the spectral properties of a celestial object. All of those techniques have a different challenge in which the continuum observation is often used to make an image of the sky so the challenge is the resolution of the antenna, whereas the spectral observation is used to determine what chemical compounds that exist in the celestial object. For example at frequency of 1420MHz, it can be determined whether the object has a hydrogen component or others. The challenge of spectral observation is the power of the signal which is very weak.

III. Design of Radio Telescope Receiver

A. Radio Telescope Receiver for Continuum Observation

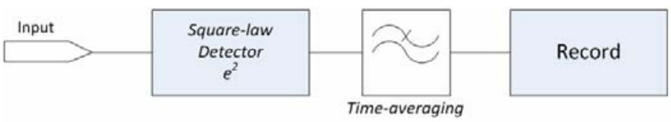

Figure 2. GNU radio flow graph of radio telescope receiver for continuum observation

In order to be implemented as radio telescope receiver for continuum observation, the basic system of radio telescope receiver flow graph shown in Fig. 1 should be modified. The modification of flow graph based on GNU radio is illustrated in Fig. 2 in which the flow graph of radio telescope receiver brings the signal from USRP to be processed. The first flow graph records the signal in frequency domain. The flow graph obtains the magnitude of signal and multiplies it by the signal itself. Then, the signal is convoluted by single-pole infinite impulse response (IIR) filter where the filter works as time-averaging. The difference equation of single pole IIR filter is expressed in (1).

$$y(n)-(1-\alpha)y(n-1)=\alpha x(n) \tag{1}$$

It shows that the single pole IIR filter gives the past output and input in a specific weight that can be determined from the integration time. If the value of alpha equals 1 by sample rate, for example, it is obtained one second of integration time.

B. Radio Telescope Receiver for Spectral Observation

The main idea of signal processing in radio telescope receiver for spectral observation is in obtaining the averaging signal magnitude at various frequencies. So the flow graph of radio telescope receiver for spectral observation illustrates in Fig. 3 begins the process by transforming signal from time domain form to frequency domain. Here, the frequency domain signal is presented as a vector. Then the convolution is performed between the signal and single pole IIR filter. Fig. 4 shows how the convolution works. The output of the single pole IIR filter is an average signal in frequency domain. Thus, the sub sampling process is performed in order to push the recorded file size.

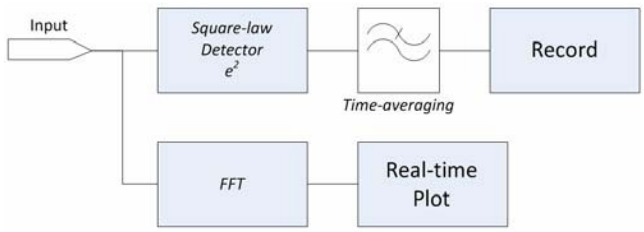

Figure 3. GNU radio flow graph of radio telescope receiver forspectral observation

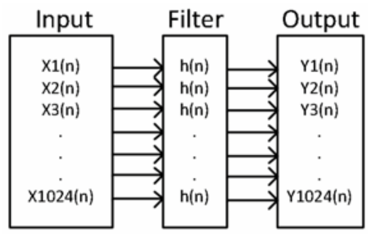

Figure 4. Convolution of a vector

C. Hardware System of Radio Telescope Receiver

As shown in Fig. 5, hardware system of radio telescope receiver is constructed by an antenna, LNA, jumper, and coupler. The important rules of arranging the hardware system are to amplify the weak signal and to keep the noise power as little as possible. To amplify the signal, the high gain antenna and high gain LNA are used for the system. To keep the noise low, it is required to minimize noise generation by hardware component. Therefore, an LNA with very small noise figure is employed; therefore the output SNR is not much different with the input SNR. The configuration of hardware system for radio telescope receiver is tabulated in Table 1, while the antenna and USRP used for implementation of radio telescope receiver are shown in Figs. 6 and 7, respectively.

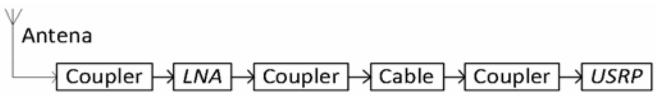

Figure 5. Block diagram of hardware system for radio telescope receiver

TABLE I. Hardware System of Radio Telescope Receiver

Component	
Antenna	LPDA antenna for continuum observation and parabolic antenna for spectral observation
LNA type	Mini Circuit ZX60-33LN+, RAS1420MHz LNA
Cable	LMR-400

Figure 6. Antenna for radio telescope receiver, LPDA for continuum observation (left), parabolic antenna for spectral observation (right)

Figure 7. USRP for implementation of radio telescope receiver

IV. Result and Discussion

Fig. 8 depicts the result of GNU radio based radio telescope receiver for continuum observation implemented using USRP. Two sinusoid signal corrupted by noise signal is set for the system. Both of those signals have the same amplitude. It is shown that the value recorded by the system provide a constant power value which means the system can detect the total power among given bandwidth. At the early samples, it is difficult to see the differences between noise and signal, however after so many integration, the system can determine whether the received signal or the noise.

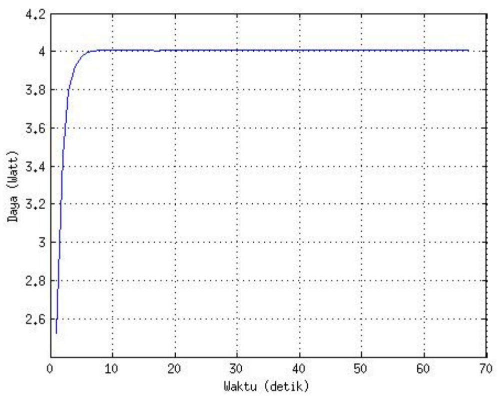

Figure 8. GNU radio result for continuum observation

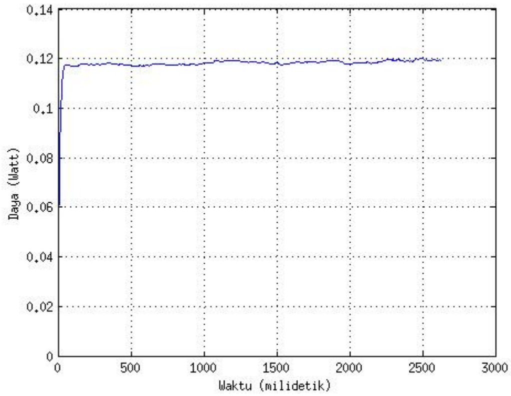

Figure 9. Average output power recorded at frequency of 322MHz

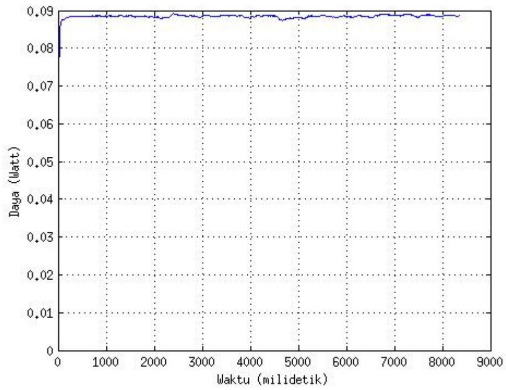

Figure 10. Average output power recorded at frequency of 406MHz

Figs. 9 and 10 plot the result of continuum observation at frequency of 322MHz and 406MHz with bandwidth of 5MHz, respectively. The figures show that the implemented radio telescope receiver successfully produces the total power of received signal. It indicates that the signal power at frequency of 322MHz is stronger than the signal power at frequency of 406MHz. It is noticeable that the result is similar to the galactic background noise which has a peak value at frequency of 30MHz and a minimum value at frequency of 1400MHz.

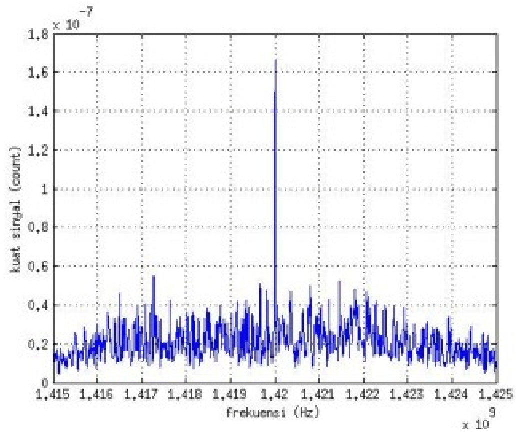

Figure 11. Integration result at first 500 samples

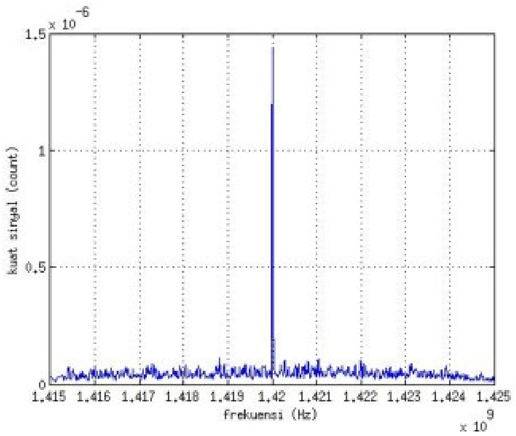

Figure 12. Integration result at first 6000 samples

Furthermore, Figs. 11 and 12 show the comparison between the result of integration at first 500 samples and 600 samples, respectively. It is noted that the longer integration time the noise is getting down. This complies with the prediction and can be proven by standard error equation in which the error equals with variance of- and inversely to sampling number.

V. Conclusion

The development of radio telescope receiver based on GNU radio and USRP has been presented. The developed system of radio telescope receiver has covered the hardware system and the signal processing system. It has been shown that the implemented radio telescope receiver which was applied for continuum observation can detect signals at frequencies of 322MHz and 406MHz which are usually used in radio telescope. In addition, to compensate the sensitivity of USRP, it is necessary to have a very high gain of. Meanwhile, the longer integration time of system is required since for more complicated system the noise will be higher.

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