Implementation of a Total Power Radiometer in Software Defined Radios

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- Sensitivity
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Introduction

Presentation Goals

The goal of this thesis and presentation is to explore other methods that could be used for a remote sensing radiometer and specifically the implementation of a software defined radio as a total power radiometer. The end goal is to develop a radiometer that is more flexible than most radiometers and still maintain the accuracy and stability of a traditional radiometers if not exceed these specifications.

Related Works

Shirleys Bay Radio Astronomy Consortium

- Radio Astronomy is very close radiometer remote sensing
- Main difference is between looking at specific objects or general trend

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SBRAC

The Shirleys Bay Radio Astronomy Consortium (SBRAC) located in Smiths Falls, Ontario is currently using a USRP software defined radio in conjunction with GNU-radio. SBRAC has successfully used this configuration to obtain radio astronomy data by looking at the hydrogen line at 1420.4058 MHz [Leech, 2007]. The person in charge of this facility, Marcus Leech, contributed software to the GNURadio specifically for radio astronomy applications. It was this software branch that was used as the base for the GNURadio program that was used in this thesis.

General Theory

Traditional Radiometer

The primary goal of a radiometer is to measure power. While that statement sounds easy, there are in fact many factors that go in to how well a radiometer can measure the power it sees. A better statement would be that a radiometer's primary goal is to accurately measure power within a certain degree of accuracy. In order to accurately and within a high degree of precision measure power, a radiometer must take into account various factors such as the system noise, the bandwidth of the signal and the stability of the system as a whole.

General Theory

Measuring power

To measure power in a radiometer, several factors are taken into consideration. To begin with we have the noise signal coming from the antenna. Our antenna is assumed to be looking at our target of interest and it is assumed that we can relate the antenna noise to the noise from the source. It is often easier to refer to this noise as the brightness temperature. Therefore the brightness temperature of the source can be related to the brightness temperature at the antenna. We will refer to this brightness temperature as T_A.

ISU Radiometer

ISU currently owns a total power radiometer centered at 1.4 GHz with a fixed bandwidth of 20 MHz. This radiometer is unique in that it does a total power evaluation by under-sampling the A/D converter. This current radiometer however has experienced a number of issues that hindered its performance.

Future Work

Future Items

- Make improvements to the ISU RF Front End
- Make improvements to the support HW for the ISU Radiometer
- Correlation
- Noise Injection

References

Niels Skou and David Le Vine (2006)
Microwave Radiometer Systems Design and Analysis
Artech House

F. T. Ulaby, R. K. Moore and A. K. Fung (1981)
Microwave Remote Sensing
Artech House

Marcus Leech and David Ocame (2007)
A year of Gnu Radio and SDR astronomy: experience, practice and observations
http://www.sbrac.org/documents/gnuradio_at_one_year_20070401.doc

The End

Extra Slides

Secondary goal

A secondary goal was to use off the shelf components and components that are generally more accessible. This would allow radiometers to be more accessible to a wider scope of researchers in this field.

Tertiary goal

And finally a tertiary goal was to ensure that the system as a whole is fairly easy to use. This ties to our secondary goal of making radiometers more accessible to a wider range of researchers and research topics.

Ideal Radiometer

Figure on slide 7 shows us an ideal radiometer. That is a radiometer that has an input from the antenna, T_A, a known bandwidth denoted as B and a known gain denoted as G. At the end of the block is the detector, which measures the power from the radiometer.

Bandwidth

Only a certain selection of the radio spectrum is observed by the radiometer. This is referred to as the bandwidth of the radiometer and is denoted as B or as β. This bandwidth is then centered around a center frequency. In our case, we center around 1.405 GHz as this falls in a protected frequency range often used for radiometry.

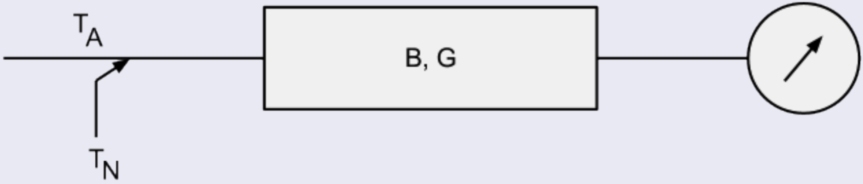
Power

The power coming from the antenna is amplified so it is easier to determine changes in the brightness temperature. The overall gain of the radiometer system is referred to as G in this case. Finally, we need to apply Boltzmann's constant, referred to as k. With these values, we can now compute the power the radiometer will see for an ideal radiometer. This can be shown in equation 1

$$P = k * \beta * G * (T_A) \tag{1}$$

Noise

However, since we do not have an ideal radiometer, we have another key component that needs to be addressed and that is the noise added to the system from the radiometer itself. Most of the additional noise is from the Low Noise Amplifiers (LNA) that are used to increase the signal while attempting to keep the noise added to a minimum. The Figure below shows the additional noise that is injected into the system.



Antenna Noise

As it can be seen, this additional noise is added to the noise coming from the antenna source. Therefore T_N is added to T_A and our final equation for the power measured is shown in equation 2.

$$P = k * \beta * G * (T_A + T_N) \tag{2}$$

Sensitivity

The ability of a radiometer to detect these small changes is the radiometer's sensitivity, or the standard deviation of the output signal from the radiometer. This sensitivity is also referred to as the Noise Equivalent Δ Temperature or NEΔT.

$$NE\Delta T = \frac{T_A + T_N}{\sqrt{\beta + \tau}} \tag{3}$$

SDR

A software defined radio (SDR) attempts to mimic radio functions in software instead of relying on dedicated hardware. A radiometer is a radio that can detect changes in power. Therefore the SDR needs to be able to measure power coming from the source that we are looking at.

Implementing a TPR

The SDR is able to implement a total power radiometer, but in a slightly different way than a traditional radiometer. A traditional radiometer will use a device called a square-law detector to measure the incoming RF signal power. For the SDR, the incoming signal is sampled and converted to IQ values. The IQ values represent the amplitude and phase information of the signal. In GNURadio we are then able to square these values within software. This block in GNURadio mathematically performs the following:

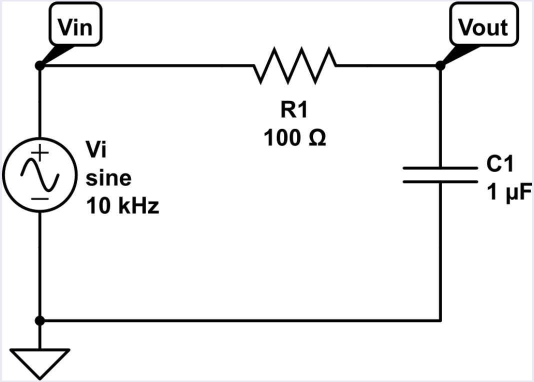
$$I^2 + Q^2 = P_{out} \tag{4}$$

IIR Filter

This signal will fluctuate rapidly and to improve the sensitivity of the radiometer we wish to integrate this signal. A RC filter is analogous to an integrator where the R and C values determine our time constant and our integration time for the filter. A SDR however operates in the digital domain at discrete intervals. One type of filter that can be used in the Infinite Impulse Response (IIR) filter.

RC Filter

To begin with, we look at what an analog RC filter looks like.



RC Filter Eqs

This circuit can be represented by the following equation.

$$\frac{V_{in} - V_{out}}{R} = C\frac{dV_{out}}{dt} \tag{5}$$

FIR Filter

A Finite Impulse Response (FIR) filter is a digital filter that can take an impulse signal and decays to zero after a finite number of iterations. This type of digital filter can be represented by the following equation:

$$y_n = \sum_{i=o}^{P-1} c_i x_{n-i} \tag{6}$$

IIR Filter

An Infinite Impulse Response (IIR) filter is the same as the FIR filter, except that we add an additional summation term which feeds back the previous output.

$$y_n = \sum_{i=o}^{P-1} c_i x_{n-i} + \sum_{j=1}^{Q} d_j y_{n-j} \tag{7}$$

It can be seen that a FIR filter is really a IIR filter except that $Q = 0$.

IIR and RC Filter

To get a better understanding on how our digital IIR filter relates to our RC filter analog, we can look at the Fourier Transform and the relationship of the input to the output in the frequency domain.

$$H(f) = \frac{\sum_{j=o}^{P-1} c_j e^{-2\pi ijfT}}{1 - \sum_{k=1}^{Q} d_k e^{-2\pi ikfT}} \tag{8}$$

Here f is our frequency in Hz and T is the time between samples in seconds.

Link between RC and IIR

We now want show the link between our analog RC circuit and the IIR filter. Looking at equation 5, which represents the differential equation relating the input voltage V_{in} to the output voltage V_{out}, we can substitute for input and output of our IIR filter. Since we are now in the time domain, we need to define what T is.

$$T = timebetweensamples = \frac{1}{samplingrate} \tag{9}$$

input voltage to IIR

We can now relate our input voltage to the input to our IIR filter and the output voltage to the output of our IIR filter.

$$x_n = v_{in}(nT) \tag{10}$$

$$y_n = v_{out}(nT) \tag{11}$$

Rewrite difference eq

We can now rewrite our difference equation with x_n and y_n.

$$\frac{x_n - y_n}{R} = C\frac{y_n - y_{n-1}}{T} \tag{12}$$

Now, we can solve for y_n which results in our final equation for showing how a IIR filter is related to an RC filter.

$$y_n = \frac{T}{T + RC}x_n + \frac{RC}{T + RC}y_{n-1} \tag{13}$$

IIR and RC filter

It can be seen that an IIR filter can have the same frequency response as we would expect from an analog RC filter. As our sampling rate approaches infinity, the approximation gets closer to the original response from the analog RC circuit.

Bullet Points

- Lorem ipsum dolor sit amet, consectetur adipiscing elit
- Aliquam blandit faucibus nisi, sit amet dapibus enim tempus eu
- Nulla commodo, erat quis gravida posuere, elit lacus lobortis est, quis porttitor odio mauris at libero
- Nam cursus est eget velit posuere pellentesque
- Vestibulum faucibus velit a augue condimentum quis convallis nulla gravida

Multiple Columns

Heading

1. Statement
2. Explanation
3. Example

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Integer lectus nisl, ultricies in feugiat rutrum, porttitor sit amet augue. Aliquam ut tortor mauris. Sed volutpat ante purus, quis accumsan dolor.

Table

Treatments	Response 1	Response 2
Treatment 1	0.0003262	0.562
Treatment 2	0.0015681	0.910
Treatment 3	0.0009271	0.296

Table : Table caption

Verbatim

Example (Theorem Slide Code)

```
\begin{frame}
\frametitle{Theorem}
\begin{theorem}[Mass--energy equivalence]
$E = mc^2$
\end{theorem}
\end{frame}
```