Getting the most out of your FFT

Paul Boven[1,2]
p.boven@xs4all.nl
[1] CAMRAS, Dwingeloo, the Netherlands
[2] JIVE, Dwingeloo, the Netherlands

Introduction

The galaxies in our universe consist largely of atomic hydrogen, which emits radiation at 21 cm. This radio signal was predicted by v.d. Hulst[1] in 1944, and first detected by Ewen & Purcell[2] in 1951. Nowadays, detecting the signature of the 21 cm radiation is well within the means of amateurs using simple means such as a small antenna, low-noise amplifier and a SDR. The hardware required for such experiments is well known. This presentation instead is focused on how the digitized signal can be processed for best sensitivity in the Gnu Radio Companion.

GUI FFT

As the 21 cm radio signal presents itself as an excess of noise at a particular frequency in the spectrum, the easiest way to detect it is by using an FFT[3]. A naive approach would be to feed the recorded data directly in to the GUI FFT block to display the spectrum. This however is a very inefficient method, because the GUI FFT blocks only process a very small sample of the data. In the default settings the FFT is only performed 15 times per second, discarding the majority of the samples unused.

Full FFT

Modern PCs have sufficient computing power to perform the FFT in GnuRadio in real-time for all incoming samples, for up to tens of MHz of spectrum. As a second approach, the stand-alone FFT block will be used, followed by a vector integration that accumulates the power per frequency bin. The importance of the FFT windowing function and its effects on sensitivity and resolution will also be discussed.

The vector sink block is used to display the received spectrum, but with increased integration times, its output starts to become lagged significantly because data will only flow between GR blocks upon filling a block buffer. This can be side-stepped by simply repeating the signal between the output of the integrator and the vector display block, forcing an immediate redraw at the cost of an insignificant increase in CPU usage.

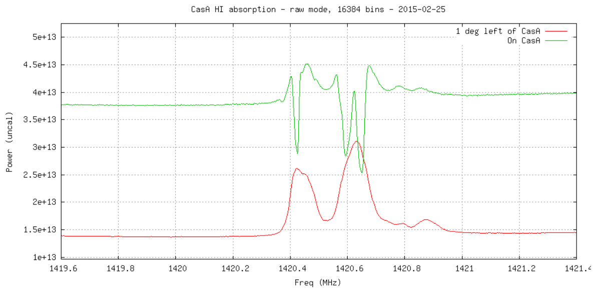

Figure 1: Hydrogen signal at 21 cm in emission and absorption

WOLA

The repeated application of the FFT window function means that data at the edges of its window do not really contribute to the FFT output, and are in a sense wasted. This causes a small loss in sensitivity. By sliding the FFT window by less than a full window size, all samples will be contributing equally. Shifting the window by less than a full stride over the data would require scaling the number of FFT operations per second by the overlap factor. A more computationally efficient approach is the Weight-Overlap-Add (WOLA) algorithm, where the sampled data, weighted by the window function, is folded and added prior to the FFT block. The WOLA algorithm has been implemented as a flowchart in GnuRadio companion.

All three approaches will be demonstrated on recorded data from a small antenna, or from the Dwingeloo 25m dish.

References

[1] Hulst, H.C. van de, *Radiostraling uit het wereldruim: II. Herkomst der radiogolven* (Radio Waves from Space: II. Origins), Ned. Tijd. Natuurkunde, vol.11, p210, 1945

[2] Ewan, H. I.; Purcell, E. M. *Observation of a line in the galactic radio spectrum.* Nature. 168 (4270): 356.

[3] Cooley, James W.; Tukey, John W. *An algorithm for the machine calculation of complex Fourier series*, Mathematics of Computation. 19 (90): 297301.