Amateur Pulsar Detection on a shoestring

using the
RTL2832U DVB-T
Dongle

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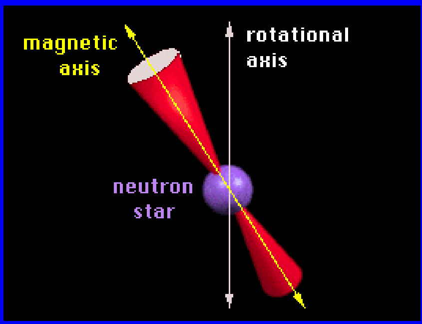
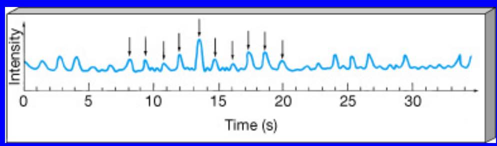
www.y1pwe.co.uk/RAProgs/Pulsars.html

Introduction

- Pulsars
- Motivation
- Detection Issues and the RTL
- Some Successes
- An Affordable Pulsar Telescope
- Challenges and Improvements
- Conclusions

Pulsar Basics





In 1967 Jocelyn Bell

Discovered the first pulsar PSR J1919+21 with a

4 acre array of 2000 dipoles tuned to 81.5MHz

Neutron stars

Fast rotation

High Magnetic field

Wide band energy bursts

The Plan - 2014

Beg real Data from a Big Antenna

Write some software, check SNR

Understand Radio Telescope Performance

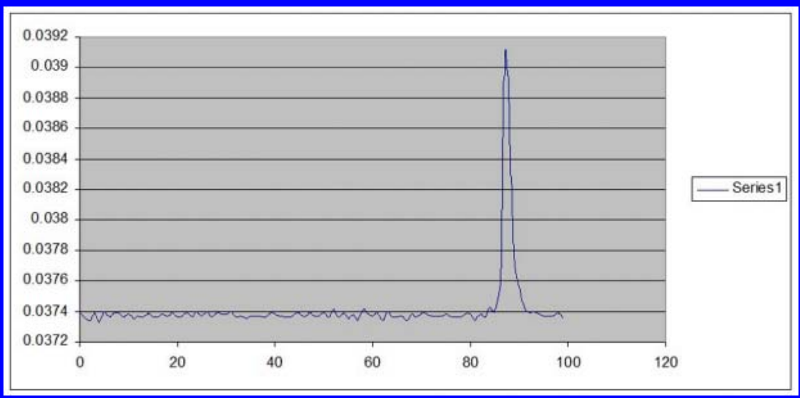
Scale the System Parameters

Design Cheap Receiver and Antenna

Try it out

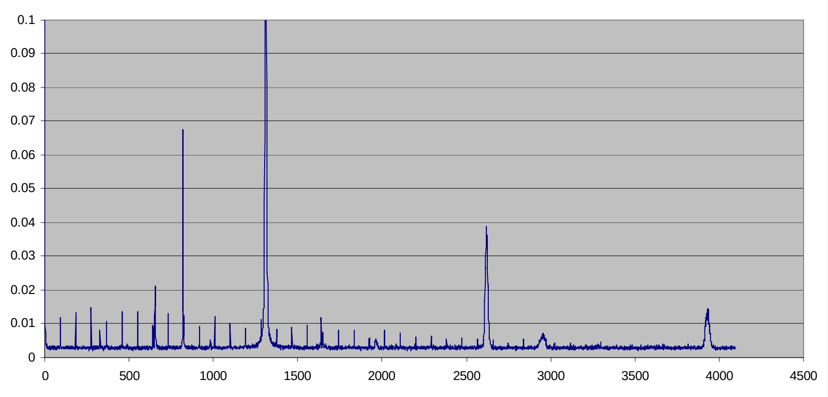
Argentine 30m Telescope

Vela Pulsar B0833-45



Data Source (30m): Guillermo Gancio

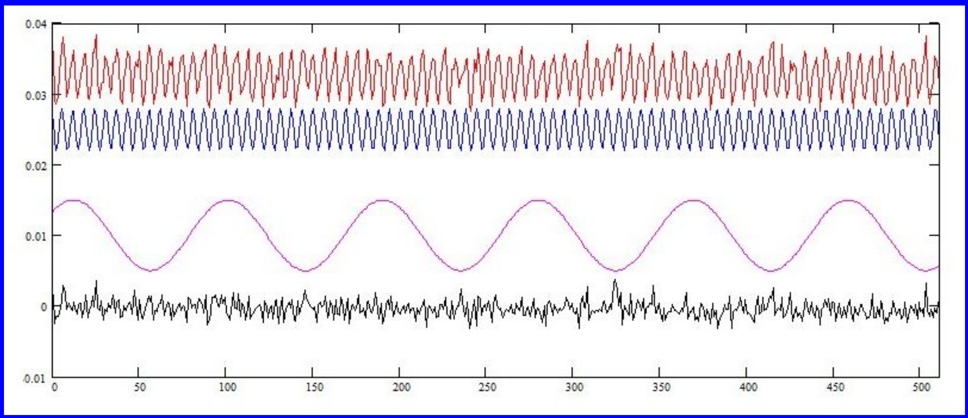
Vela Video Spectrum



pafft2 500.bin 500.txt 2 1 8192

Data Source (30m): Guillermo Gancio

Vela Individual Pulses



Data Source (30m): Guillermo Gancio

Pulsar Flux

- Pulsar power ~ 25 Jansky peak
- 1 Jansky = 10^{-26} watts per square metre per hertz.
- T_J = J x A/1380 °K
- 1 Jansky = 0.00072°K/m^2
- 25J (both polarisations) = 0.018°K/m^2

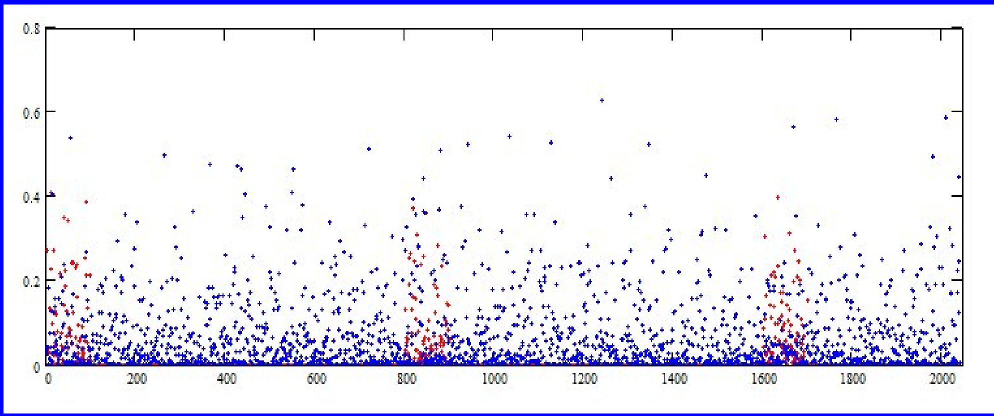
http://www.y1pwe.co.uk/RAProgs/AmateurPulsarDetectionF.doc

Digital Radiometer Equation

$$\Delta T = \frac{T_{sys}}{\sqrt{Bt}} = \frac{T_{sys}}{\sqrt{Bt / N}}$$

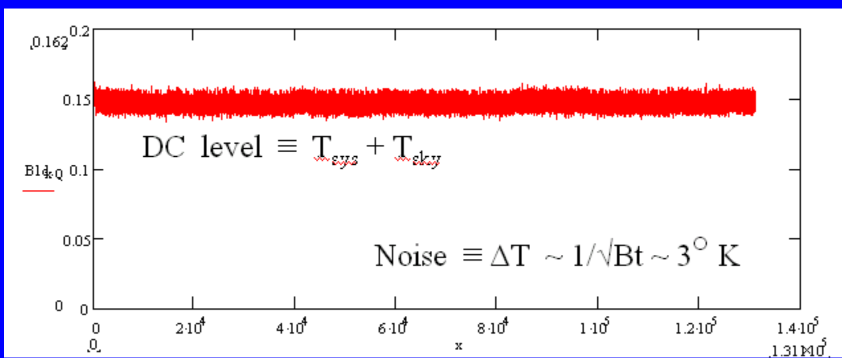
$T_{sys} = T_{LNA} + T_{sky}$
B = RF bandwidth
t = Integration time
N = Number of digital bins

Detected Pulsar Data



Noise ~ T_{sys} - say 100°K and Pulsar 0.04°K

Detected Video



B = 2MHz, t = 1ms, and here, $(T_{sys} + T_{sky})/\Delta T = 50$

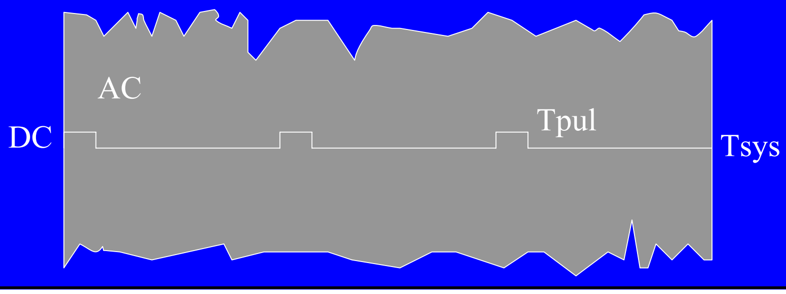
Detection Process

Within the pulsar pulse:

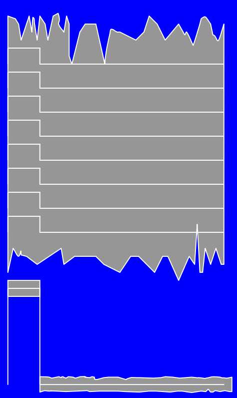
The receiver noise $= k(Tpul + Tsys)B$

and outside $= k(Tsys)B$

Tpul and *Tsys* - pulsar and system noise temperatures.
k is Boltzmann's Constant, *B* the RF bandwidth
Squaring the I and Q components (square-law detection) results in both AC ($\sqrt{BBv}$) and DC (B) components.



Folding



- Pulse adds linearly
- Noise adds as square root
- SNR improves as √(No. Folds)

  SNR= √ (BT/N) x Tp/Tsys

- Optimum No. bins = Period/Pwidth
- Highly tuned period filter

RTL2832U USB Dongle

- The RTL2832U is a ‘high-performance’ DVB-T (Digital Video Broadcasting - Terrestrial) demodulator with a USB 2.0 interface.
- It outputs 8-bit I/Q-samples at bandwidths up to 2.4MHz and tunes over 25-1800MHz

RTL SDR Features

RTL SDR is cheap and cheerful

- but can be made better

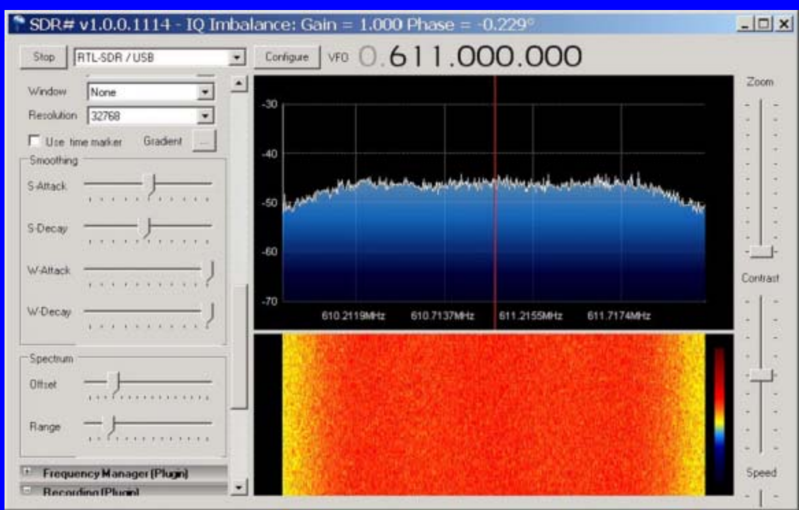
Main Limitations:

- Basic crystal accuracy - few parts /million
  - - replace with TCXO ~ 0.1ppm
- Temperature drift - dissipates heat in use
  - - heatsinking and fans

Available Software

Data: Osmocom rtl tools rtl_sdr.exe
from: sdr.osmocom.org
Folding: rapulsar2.exe
from: y1pwe.co.uk/RAProgs
Display: Excel/MathCad
Testing: SDR# + Zadig Driver
from: sdrsharp.com
Professional: Tempo, Presto, Sigproc
from: pulsarastronomy.net

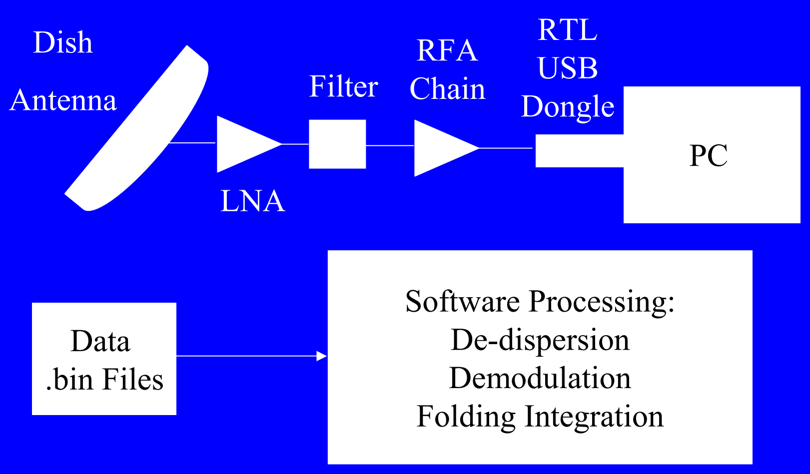
SDR#



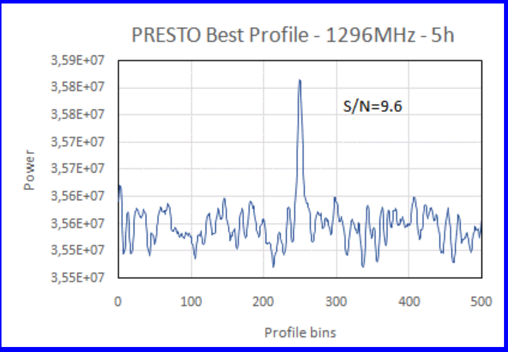
Amateur
Pulsar Detection Systems

Dish Diam	30m	3m	3m
RF Bandwidth	2MHz	2MHz	6 Mhz
Pulsar: 25Jy Peak	4ºK	0.04ºK	0.04ºK
Observation Time	100sec	10800sec	7200sec
ΔT (100ºK Tsys)	0.07ºK	0.007 ºK	0.005 ºK
SNR (100bin Fold)	56	6	8

RTL Pulsar Radio Telescope

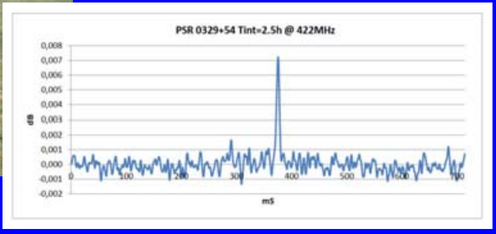


Hannes - Austria
1296MHz + 2MHz + 5Hrs
3m offset dish



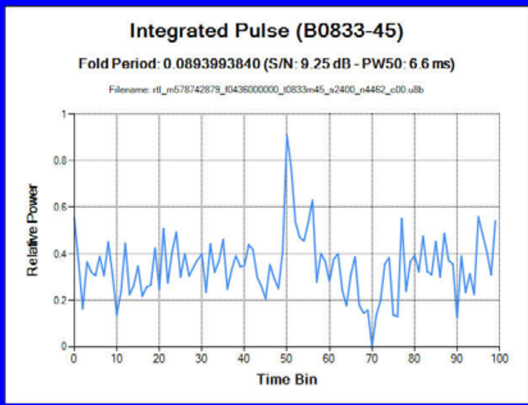
Andrea - Italy
422MHz + 2.4MHz + 3Hrs
2m Corner reflector

Automatic Daily Observatory



Steve - Australia
436MHz + 2.4MHz + 3Hrs
5.7m CP 42-element Yagi

Planning Quad Glitch Detection



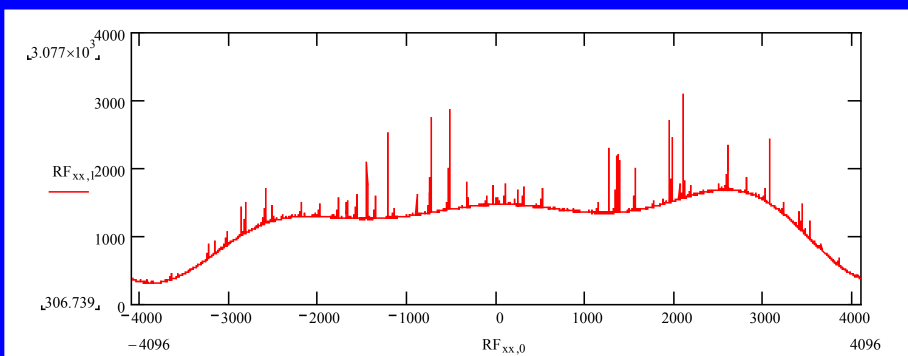
A Minimal RTL SDR System

- What can be achieved with the minimum outlay?
- Easy home construction
- Free software
- Just enough signal to detect and identify
- Can add daily results to improve SNR
- Open to all

RT Band Options

- 322-329MHz
- 406-410MHz ~ 0.75 Jansky mean
- 608-614MHz
- 1400-1427MHz ~ 0.1 Jansky mean
- 1660-1668MHz

RFI



610MHz to 612MHz

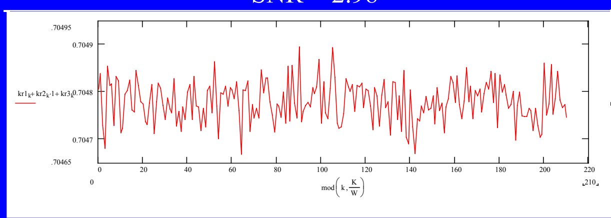
Antenna Choice

- Dish - Drift scan or tracking
  - ~ 50-65% efficient
  - Apertures >1.5m need solid base
  - Can be motorised - may need to track source
  - Reflector wideband
- Yagi
  - ~ 90% efficiency
  - Electrical aperture greater than physical area
  - Cheap, light and portable - can be stacked
  - Narrow band

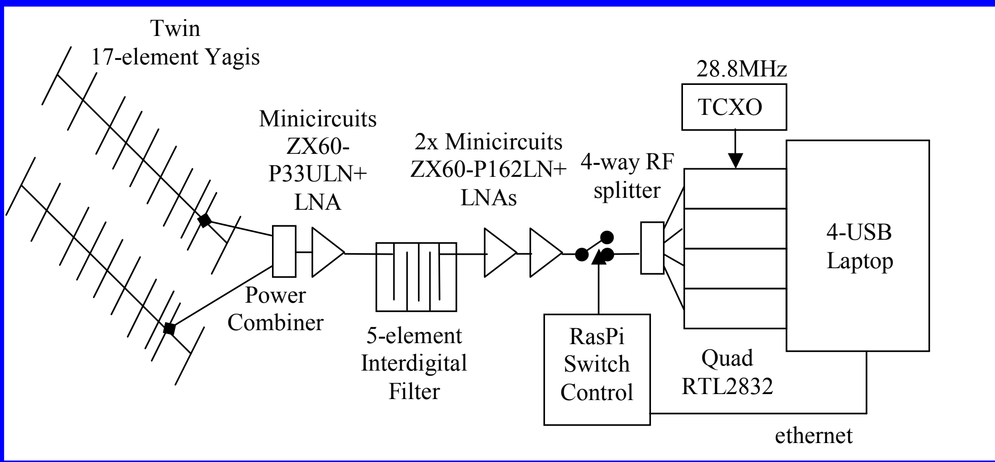
611MHz + 6MHz (3x2.4MHz) + 2Hrs
Twin 2.5m Yagis

Minimal Affordable System

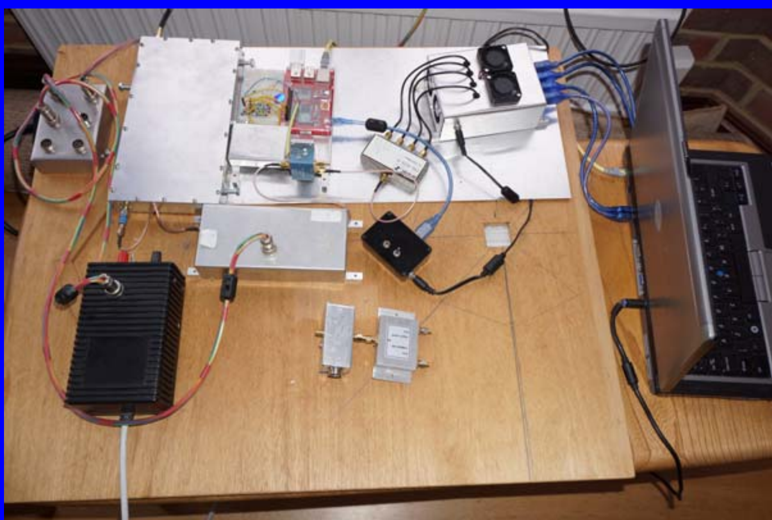
B0329+54 Pulsar period: 714.47694ms
SNR = 2.98



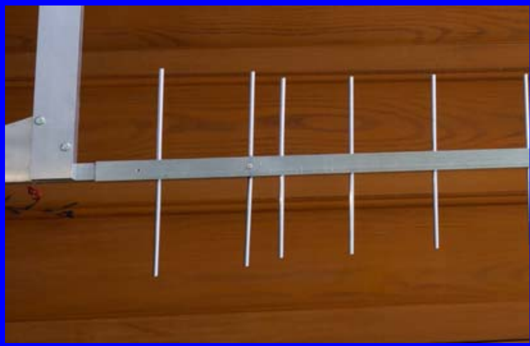
Basic Pulsar RT



The Control Room



Antenna



http://www.yagicad.com/yagicad/YagiCAD.htm

611MHz Filter

http://www.changpuak.ch/electronics/interdigital_bandpass_filter_designer.php

Quad RTL Rx

http://www.y1pwe.co.uk/RAProgs/pdf/QuadRTLReceiver.pdf

Data Processing – DOS cmd.exe

OsmoCom rtlsdr library & capture tool: 'rtl_sdr.exe'.
The capture tool generates files containing raw IQ ADC data from the dongle in hex form (viewing software: 'hexdump.exe').

rtl_sdr22r data.bin -f 611e6 -g 42 -n 18e9

rapulsar2.exe processes this to carry out folding.

- It breaks data into blocks equal in time to the pulsar period
- Sums the blocks.
- Outputs a text file that can be viewed in Excel or MathCAD.

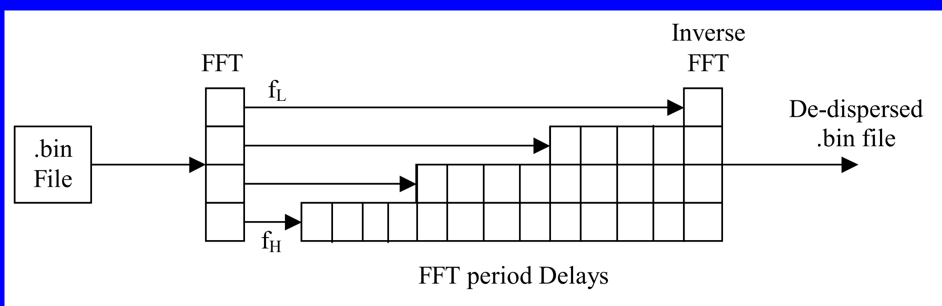
rapulsar2 data.bin data.txt 109 714.46389

RTL Data Processing Software

- rafft2.exe – RF spectrum analysis
- filetrim2.exe – Data file trimming
- cor_tim2_n – File start correlation
- pdetect2.exe – square-law video detection
- rapulsar2.exe – Pulsar period folding
- pafft2.exe – Pulsar video spectrum analysis
- RFImit.exe – RFI spectral line blanking
- pdetfilt2.exe – Video RFI spectrum blanking
- de-dispers2co.exe – Pulsar data de-dispersion

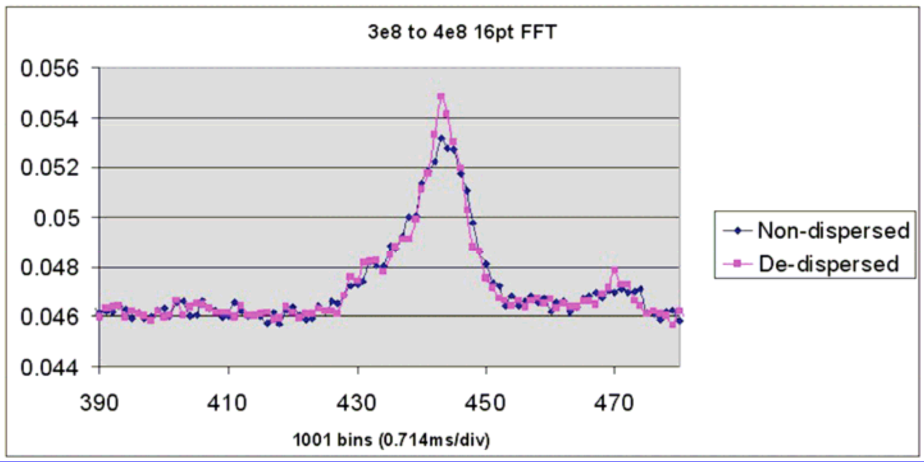
http://www.y1pwe.co.uk/RAProgs/RTLSoftwareToolsU4-6.doc

Digital De-dispersion



http://www.y1pwe.co.uk/RAProgs/pdf/SoftDispers.pdf

PSR B0329+54

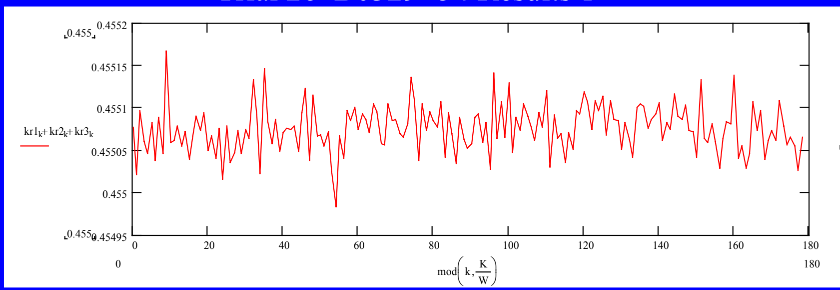


Data Source (25m): Michiel Klaassen

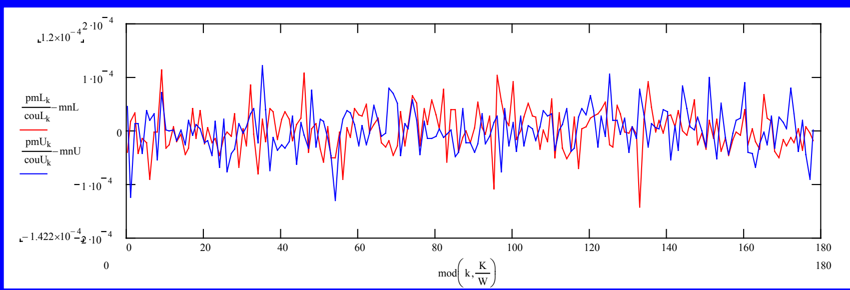
Finding and Validating

- Strong signal – period search peak
- Weak Signal
  - Period search peaks
  - Shift data by one record - optimise and compare
  - Change number of bins
  - Divide record in two and correlate sections
  - Cross correlate multiple bands
  - Two/three-period fold
  - Check improvement with within band de-dispersion
  - Check degradation with negative de-dispersion
  - Check pulse width

Trial 26 B0329+54 Results 1

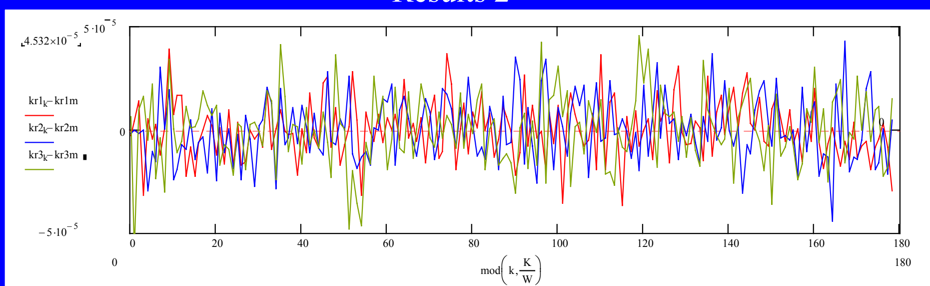


summed detected data

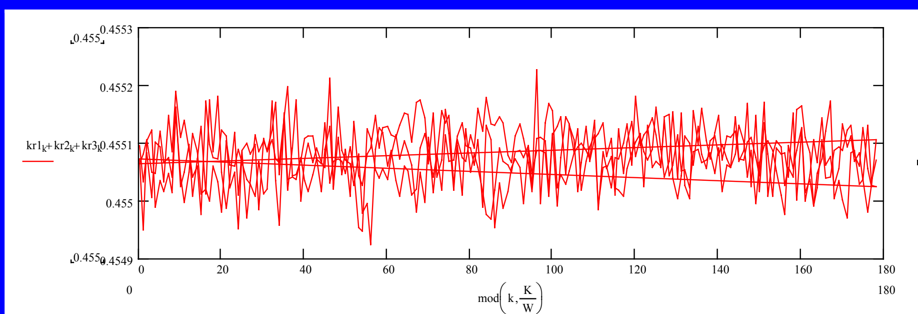


First/second half-file correlation

Results 2

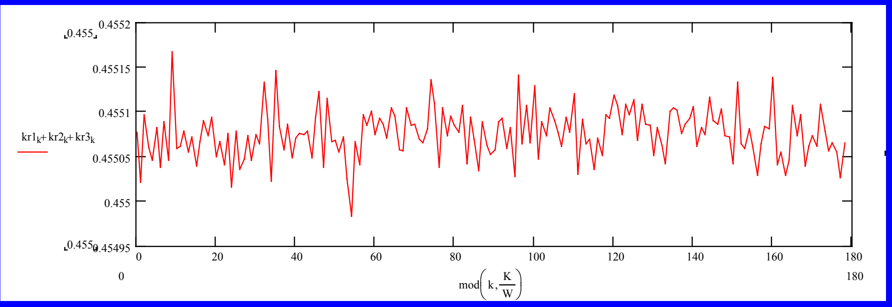


3-band correlation

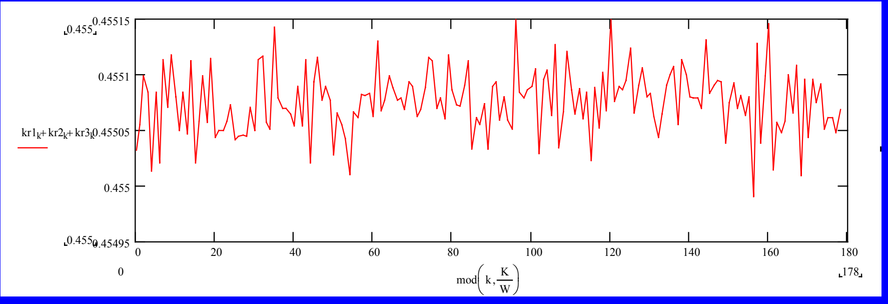


Three-period fold and overlap

Results 3

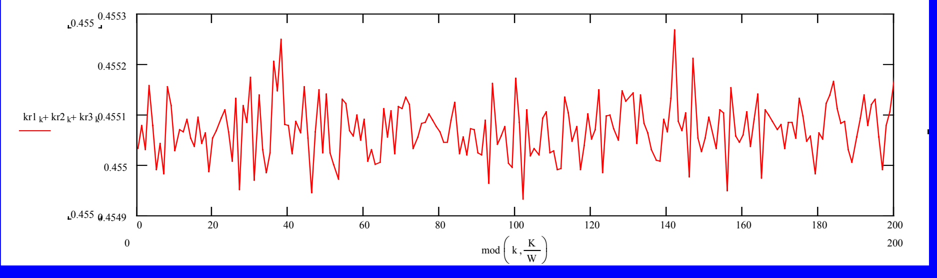


De-dispersed response



Raw data response

Results 4



6ms Pulse visible on 1ms scale

Challenges

- Scintillation - frequency and time
- RF Interference - RF and Video
- Transient spikes
- Weak Signals - Folding process can find peaks in noise
- Validating low SNR Detections

Improvements

- Lower Tsys - direct SNR improvement
- RTL Band flattening
- Longer Data Records
- Spectrum folding
- Rubidium/GPS locking - multiple sessions
- User-Friendly/Automatic GUI

Conclusion

- Amateurs can detect strong Pulsars
- 3m Dish systems work well
- Detection with home-made Yagis is possible but more difficult
- RTLs make for an inexpensive Receiver
- Freely Available Acquisition and Processing Software

Or, if you have a problem,

- Find a friend with a BIGGER DISH

Pulsar Amateur Links

- Neutronstar Group
  - http://neutronstar.joataman.net/index.html
- Barga Observatory
  - http://iw5bhy.altervista.org/
- Y1PWE
  - http://www.y1pwe.co.uk/RAProgs/Pulsars.html