DIY Astronomy
Increasing Sensitivity of Radio Telescope

Doug Holland

Purpose –
Discuss methods to increase the sensitivity of a Radio Telescope

Unit of flux density (or spectral flux density): Jansky, Jy

$$1\ \text{Jy} = 10^{-26}\text{W}\ m^{-2}\ Hz^{-1}$$

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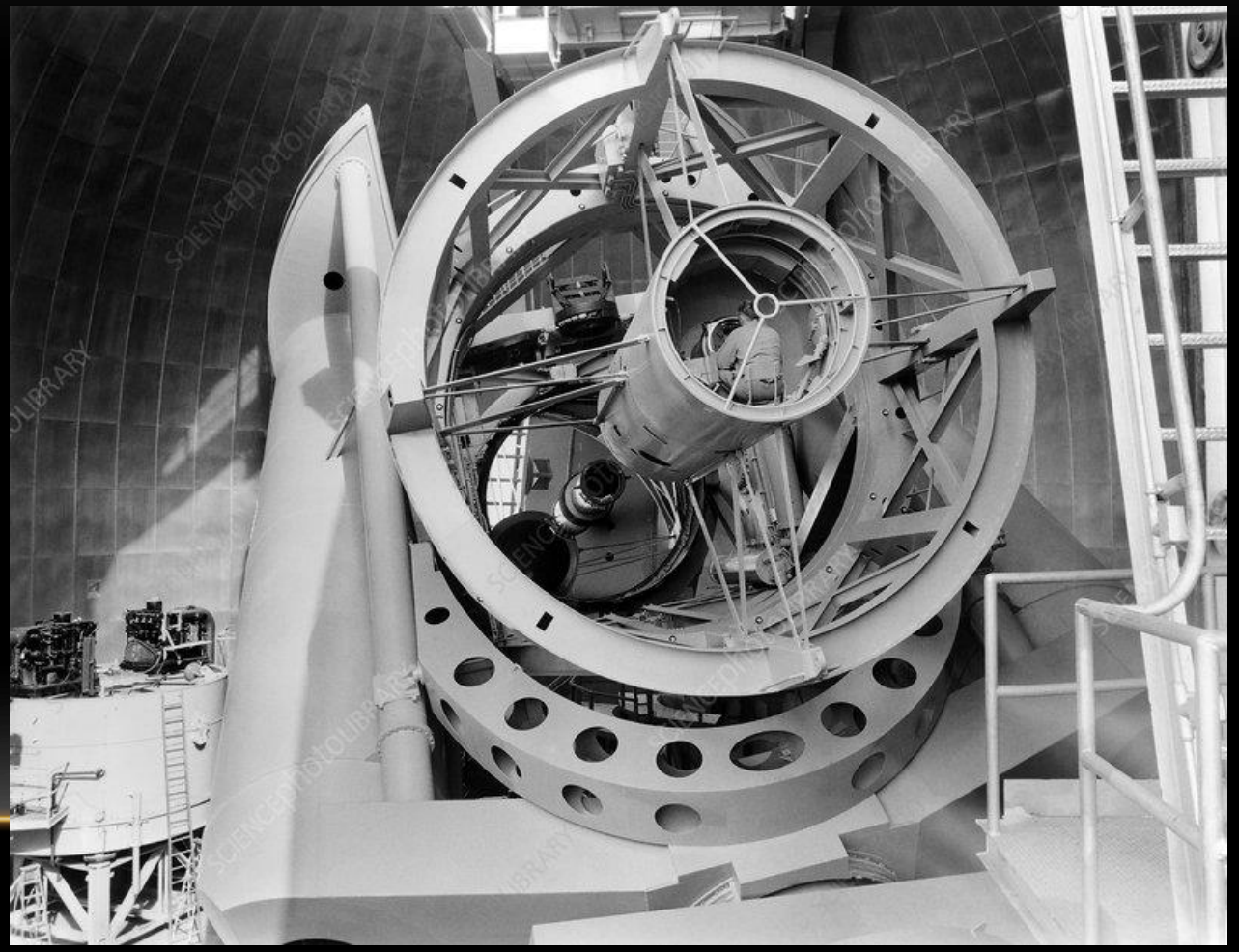
To increase sensitivity, we could either increase our collecting area (aperture)…

Same as with optical telescopes



Same for radio telescopes

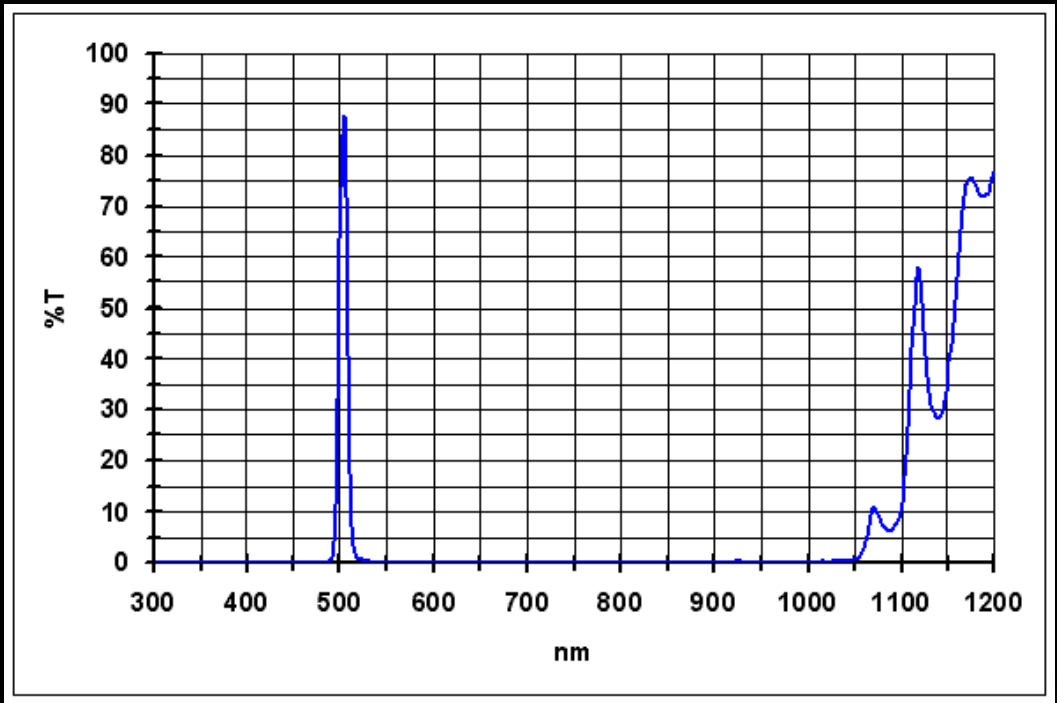
storage.googleapis.com

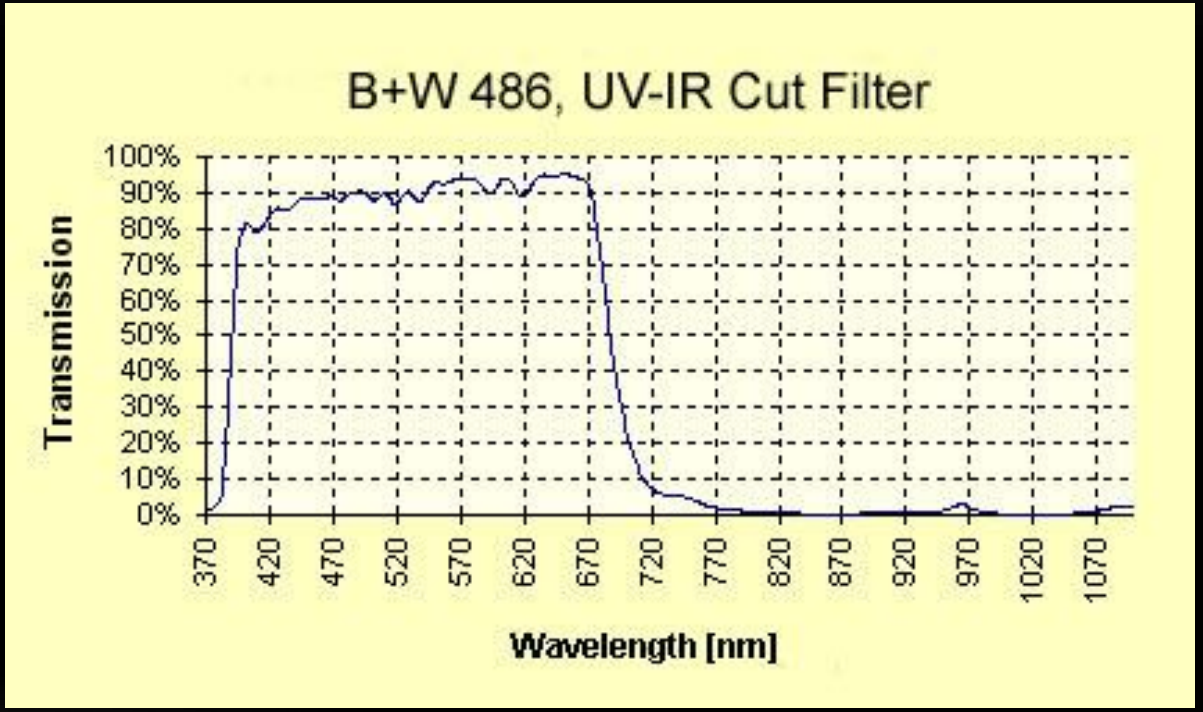
Green Bank Telescope – National Radio Astronomy Observatory

$1\ \text{Jy} = 10^{-26}\text{W}\ m^{-2}\ Hz^{-1}$

Same as with optical telescopes

… or, we could increase our bandwidth.

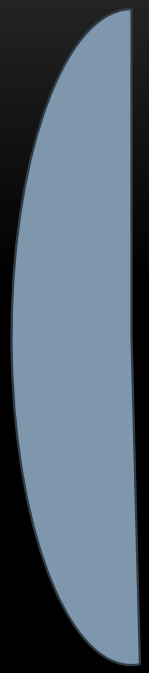




Narrow band filter –
requires longer integration time =>
Less sensitive - - -

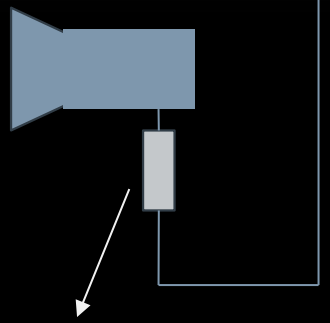
Wide band filter –
requires less integration time =>
More sensitive - - -

Explore increasing bandwidth for radio telescopes to increase sensitivity



Parabolic Reflector
Gather & Focus
Electromagnetic Radiation

Feed Antenna
Transform free space wave to guided wave to electric current



Low Noise Amplifier (LNA) + Bandpass Filter (BPF)
Note – 65MHz Bandwidth
{1376 to 1441MHz}

Low loss cable

Receiver:
Software Defined Radio (SDR)
Note – 4.8MHz Bandwidth

Computer gathering, storing, processing & displaying radio telescope signal

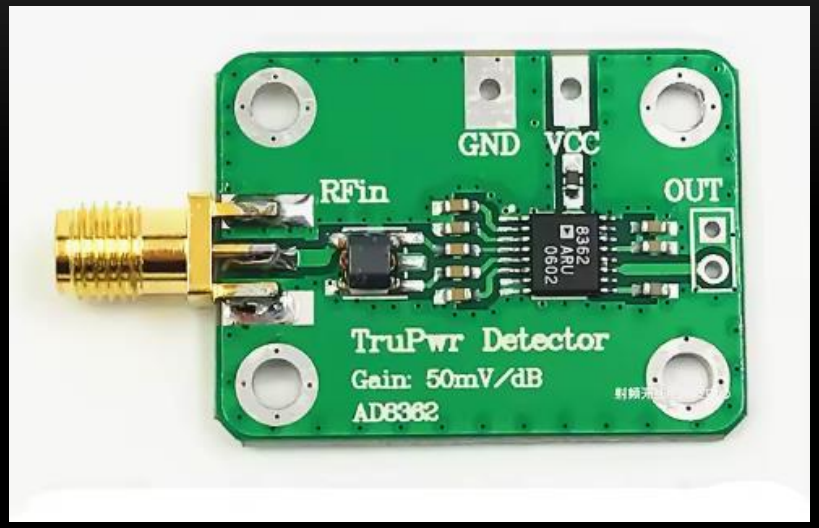
!!! Bandwidth limited by SDR !!!

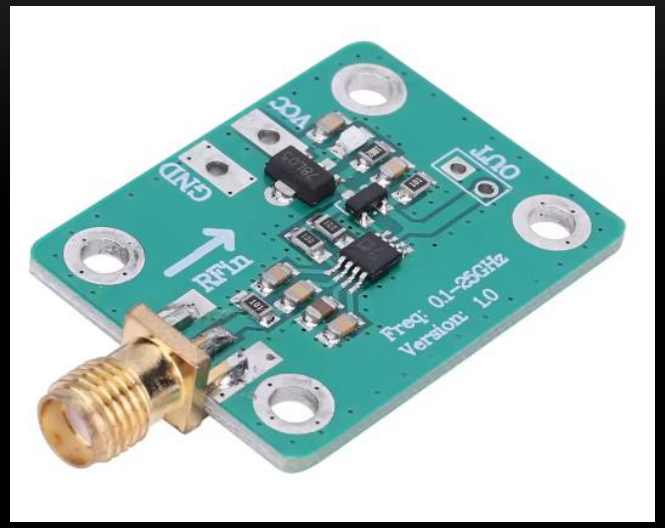
General architecture of amateur radio telescope

What if there were a receiver that allowed the full bandwidth of the LNA?

How about using a Power Detector + Arduino as receiver?

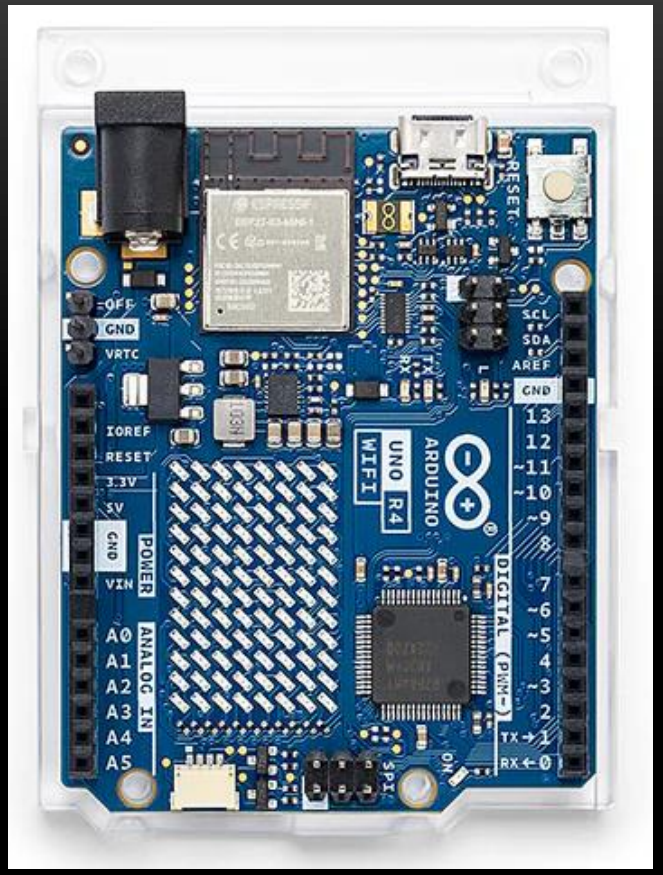
Two possible Power Detectors





AD8362
50Hz to 3.8GHz
-52dBm
50mV/dB

AD8313
0.1GHz to 2.4GHz
-72dBm
18mV/dB



Arduino UNO R4 WiFi
14 bit analog to digtal converter (ADC)
WiFi
Onboard OpAmp

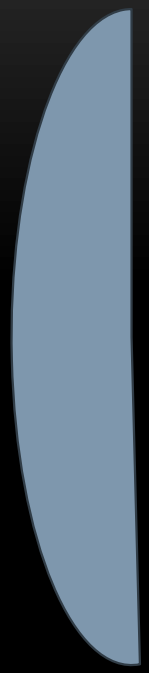
Power Detector: RF (radio frequency) in, Quasi-DC out

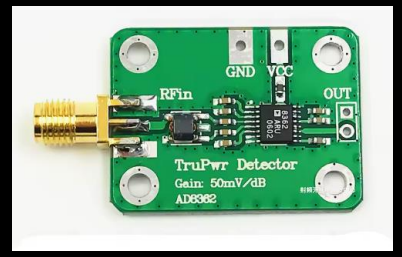
Idea of using Power Detectors as receiver from Klaus Henning, facebook Amateur Radio Astronomy Group

Receiver:
Power Detector + Arduino
Full LNA 65MHz Bandwidth

Feed Antenna
Transform free space wave to guided wave to electric current

Low loss cable





+

WiFi

Reflector
Gather & Focus
Electromagnetic Radiation

Low Noise Amplifier (LNA) +
Bandpass Filter (BPF)
Note – 65MHz Bandwidth

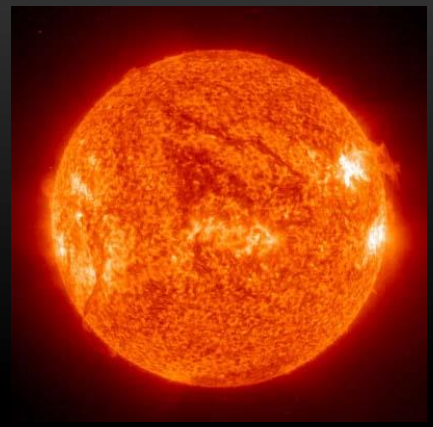
Computer gathering, storing, processing & displaying radio telescope signal

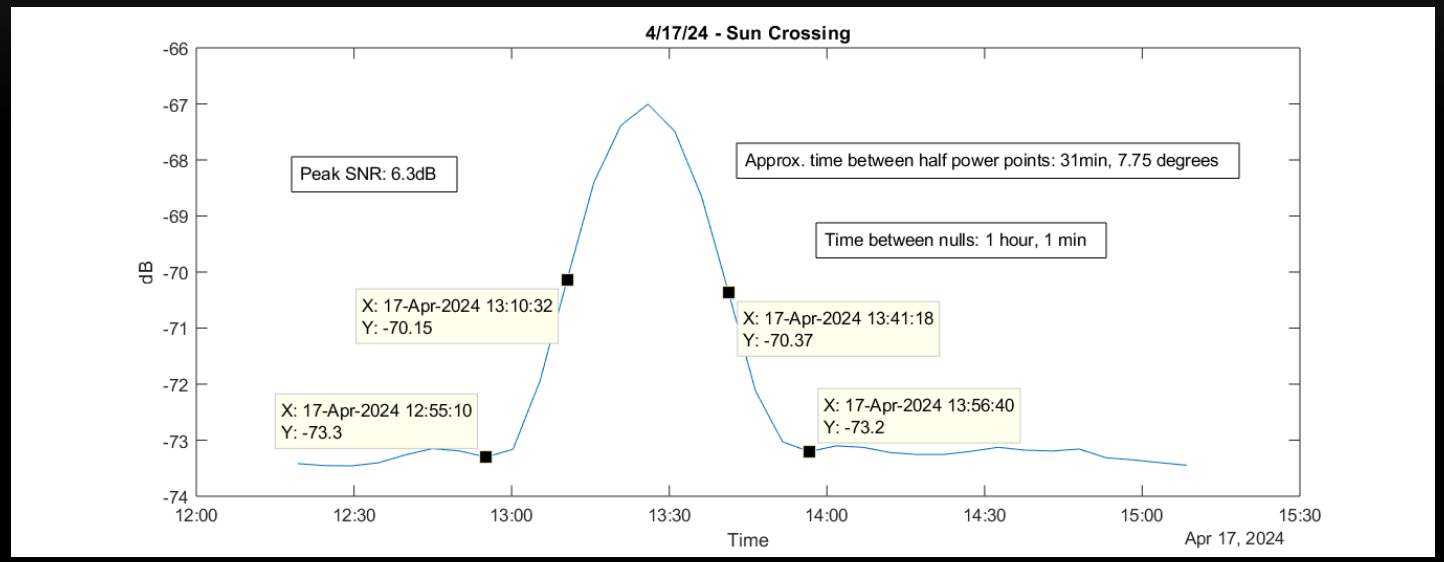
Power Detector for Receiver

Let's test it to see if we gained anything =>

Start with something that will produce a good signal:

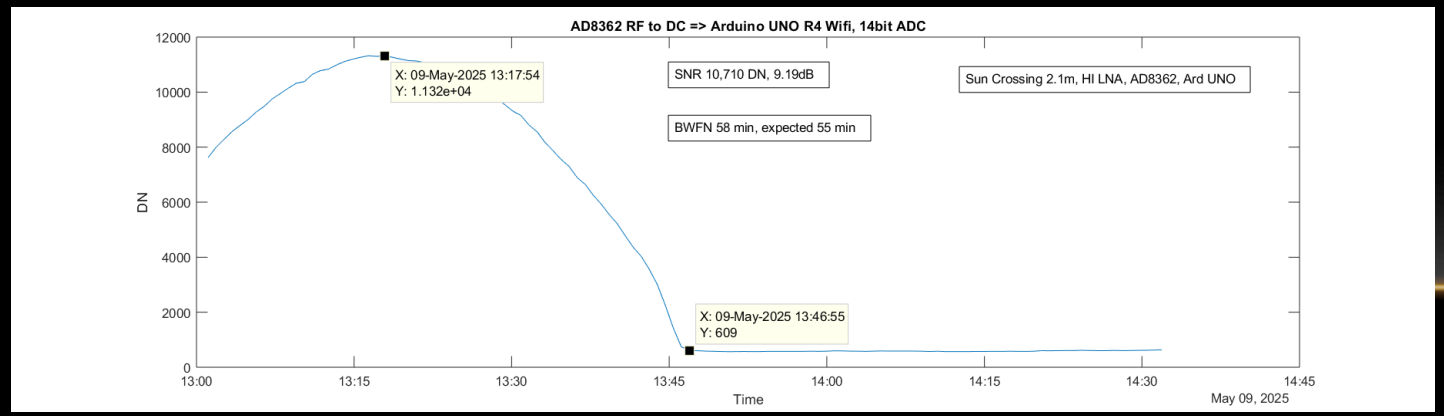
Sun





SDR Receiver
4.8MHz BW
Sun: 6.3dB

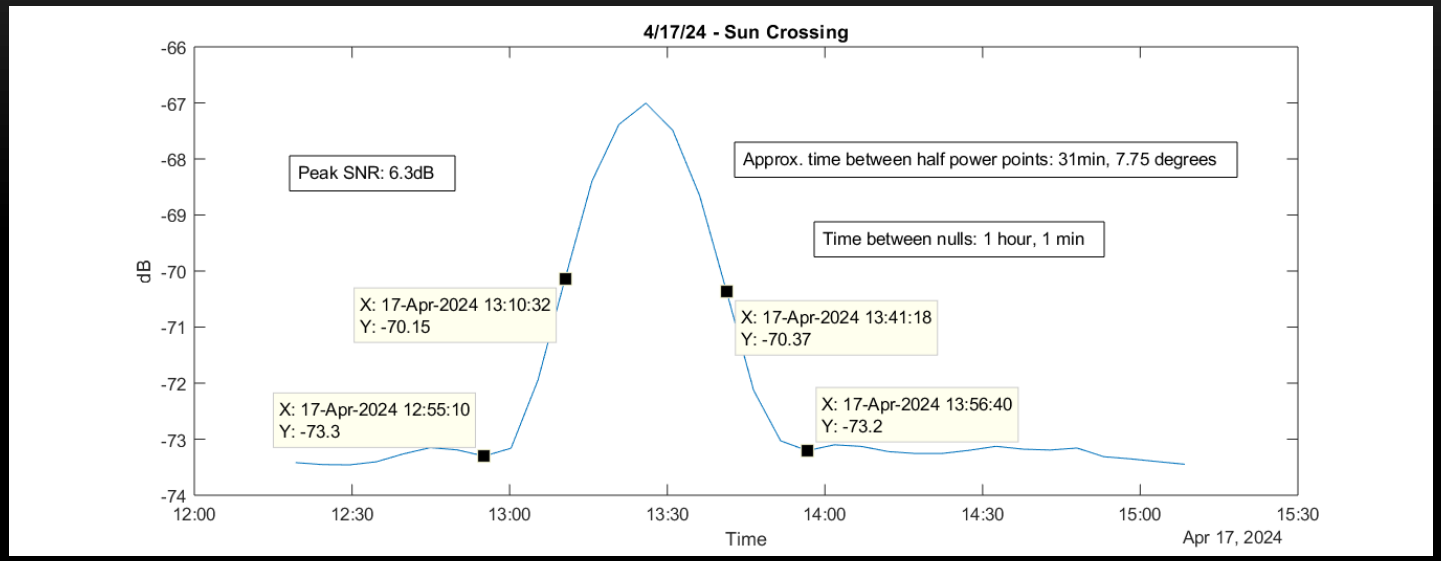
Success !!!



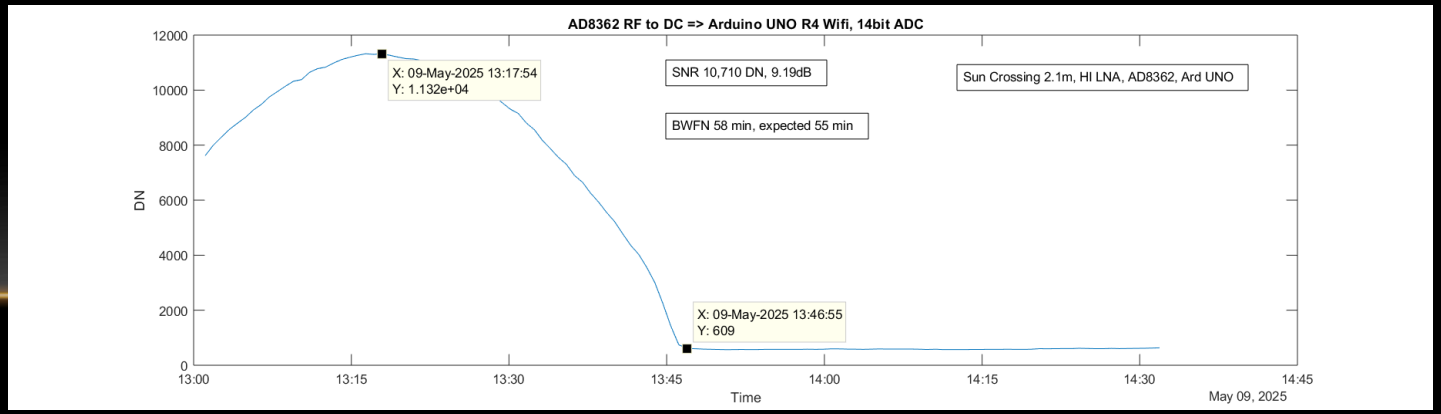
Pwr Detector Receiver
65MHz BW
Sun: 9.19dB
(AD8362)

Same config for both except receivers

Satisfied with results… for about 2 seconds



- Is this what we would expect?
- Is there some way to quantitate our result?



4/17/24: 4.8MHz => 6.3dB …….. 5/9/25: 65MHz => 9.19dB

1. Could the Sun be putting out different power on these two days?
   - Thanks to Forest, we are now aware of '*Solar Flux Unit*', SFU
     - The Sun puts out different power at different frequencies each day
     - 1 SFU = 10,000 Jy
     - NOAA website lists the Sun's SFU for each day:
       https://services.swpc.noaa.gov/text/solar_radio_flux.txt
       {I use the one at 1415MHz which is close to my frequency range.}

$$4/17/24,\ SFU_{1415} = 135 \Leftrightarrow 5/9/25,\ SFU_{1415} = 97$$

NOAA (National Oceanic and Atmospheric Administration)

4/17/24: 4.8MHz => 6.3dB ..... 5/9/25: 65MHz => 9.19dB

Math is Fun !!

4/17/24, SFU_{1415} = 135 ⇔ 5/9/25, SFU_{1415} = 97

1 SFU = 10,000Jy

Using the dB formula:

$$XdB = 10\ log \frac{1{,}350{,}000\ Jy}{970{,}000\ Jy}$$

$$Xdb = 1.44dB$$

4/17/24: 4.8MHz => 6.3dB …….. 5/9/25: 65MHz => 9.19dB

4/17/24, SFU_{1415} = 135 ⇔ 5/9/25, SFU_{1415} = 97

so …

To normalize each reading for changes in SFU =>

6.3dB – 1.44 dB = 4.86dB vs. 9.19dB

Oh no,,, this is getting worse rather than better

4/17/24: 4.8MHz => 6.3dB …….. 5/9/25: 65MHz => 9.19dB

4/17/24, SFU_{1415} = 135 ⇔ 5/9/25, SFU_{1415} = 97

BUT … *Our objective is to evaluate effect of increasing bandwidth !!*

$$Tmin = \frac{Ksens * Tsys}{\sqrt{bw * nt}}$$

$$10 \log \frac{\sqrt{65MHz * 2097152 * 1}}{\sqrt{4.8MHz * 3605000 * 1}} = 4.48dB$$

$Tmin = minimum\ detectable$
$Ksens = sensitivity\ constant$
$Tsys = system\ noise$
$bw = bandwidth$
$n = number\ of\ subsamples$
$t = sampling\ time\ (unknown)$

6.3dB – 1.44dB_{SFU} + 4.48dB_{BW} = 9.34dB

9.34dB ⇔ 9.19dB *Close enough…*

Wait –

- The purpose of this presentation was to discuss increasing the sensitivity of a radio telescope.?.

But, we are pointing at the Sun, the brightest thing in the sky.?.

How about Supernova Remnant: Cassiopeia A?

2400Jy (at 1.4GHz)

vs.

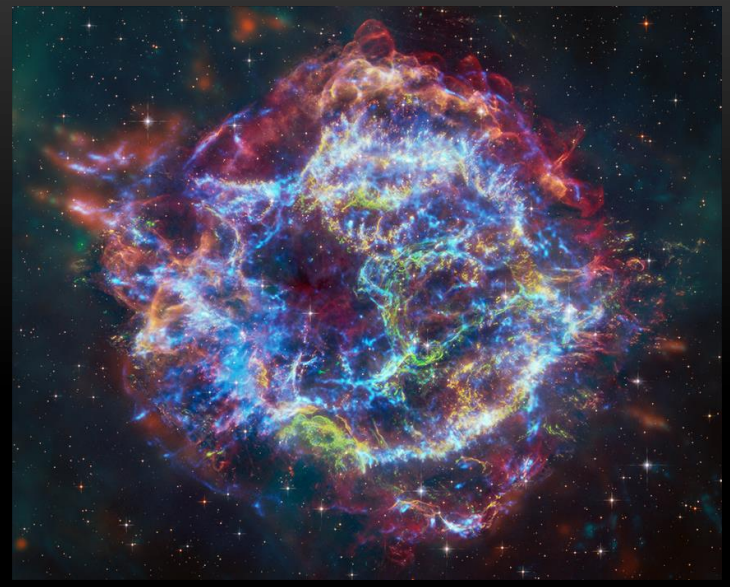
Sun was =>

1,350,000Jy

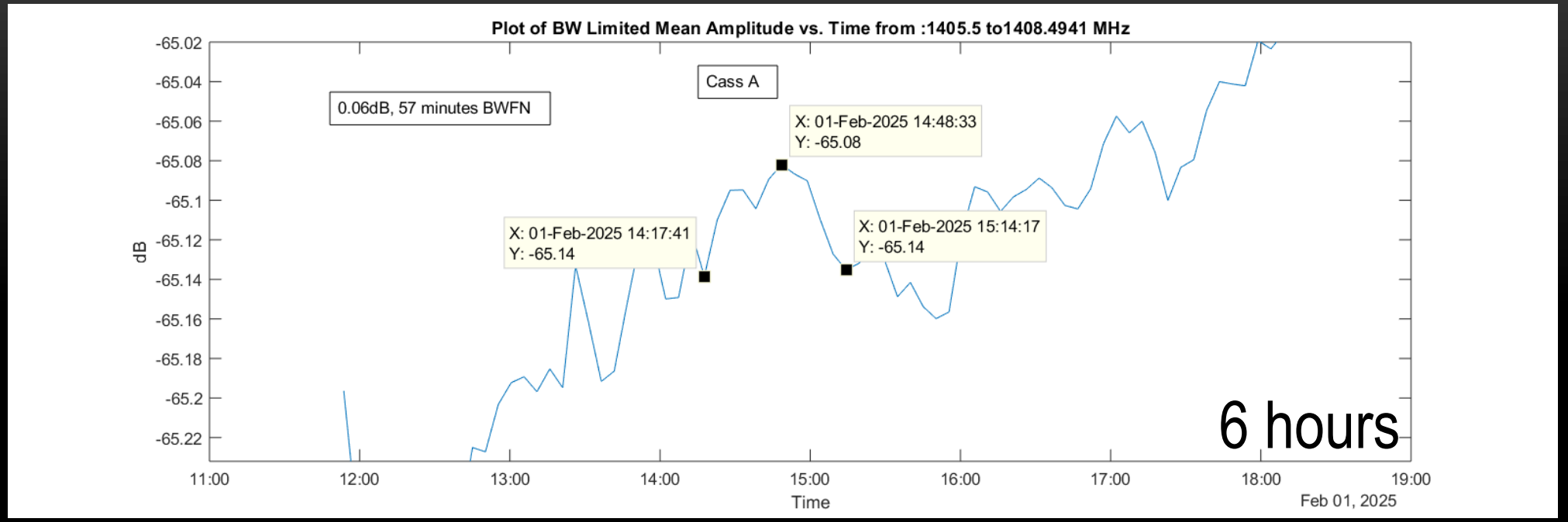
4/17/24

970,000Jy

5/9/25

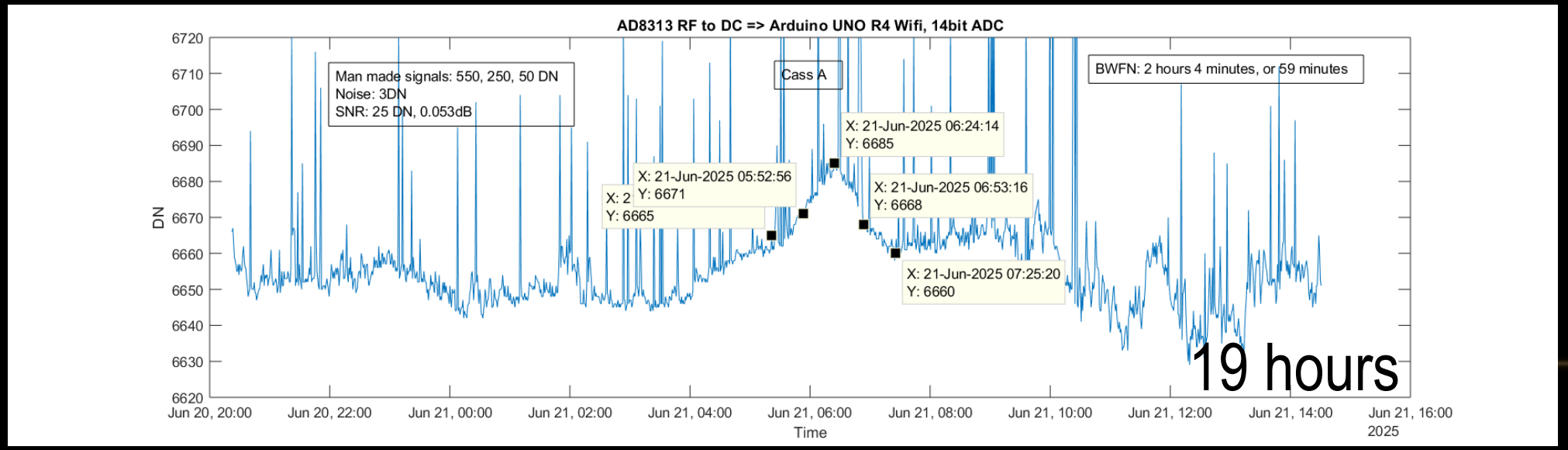


https://chandra.harvard.edu/photo/2024/casa/casa.jpg



Cass A SDR Receiver

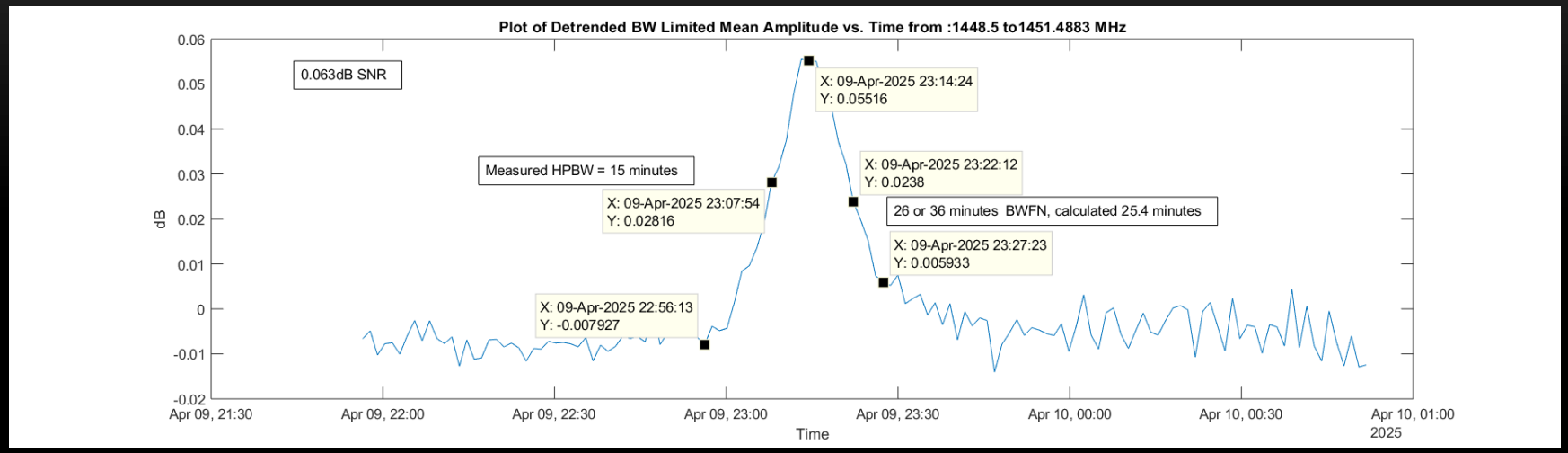
Noise floor noise roughly same amplitude as signal



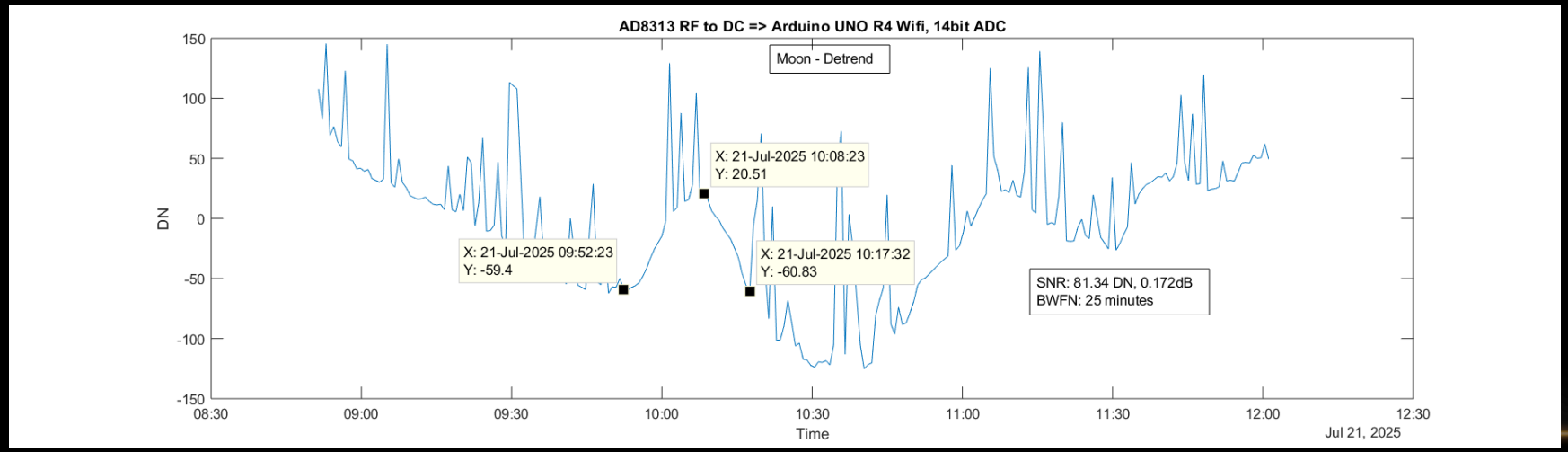
Cass A Pwr Detector Receiver

Noise floor noise much smaller than signal. Large man-made signals.

How about the Moon with a Satellite TV Dish antenna?



SDR Receiver



Pwr Detector Receiver

Signal is larger, 0.172dB vs. 0.063dB, but much higher man-made noise

One more thing =>

If we can increase sensitivity by either:

1. Increasing size / area of aperture
2. Increasing bandwidth

How much would we have had to increase the size of our antenna to match the gain from increasing bandwidth?

$$F_v(\text{min}) = \text{SNR}\left(\frac{4k}{A_{eff}}\frac{T_{sys}}{\sqrt{bw * nt}}\right)$$

A_{eff} scales with $\sqrt{bw}$

Unit of flux density (or spectral flux density): Jansky, Jy

$$1\ \text{Jy} = 10^{-26}\text{W}\ m^{-2}\ Hz^{-1}$$

A_{eff} scales with $\sqrt{bw}$

A_{eff} = effective aperture = $A_{physical}$ * 0.82 = $2.84m^2$

$\sqrt{\frac{65MHz}{4.8MHz}}$ = 3.6799 → Same as A_{eff} * 3.6799

$$A_{physical(new)} = \frac{2.84m^2 * 3.6799}{0.82} = 12.74m^2$$

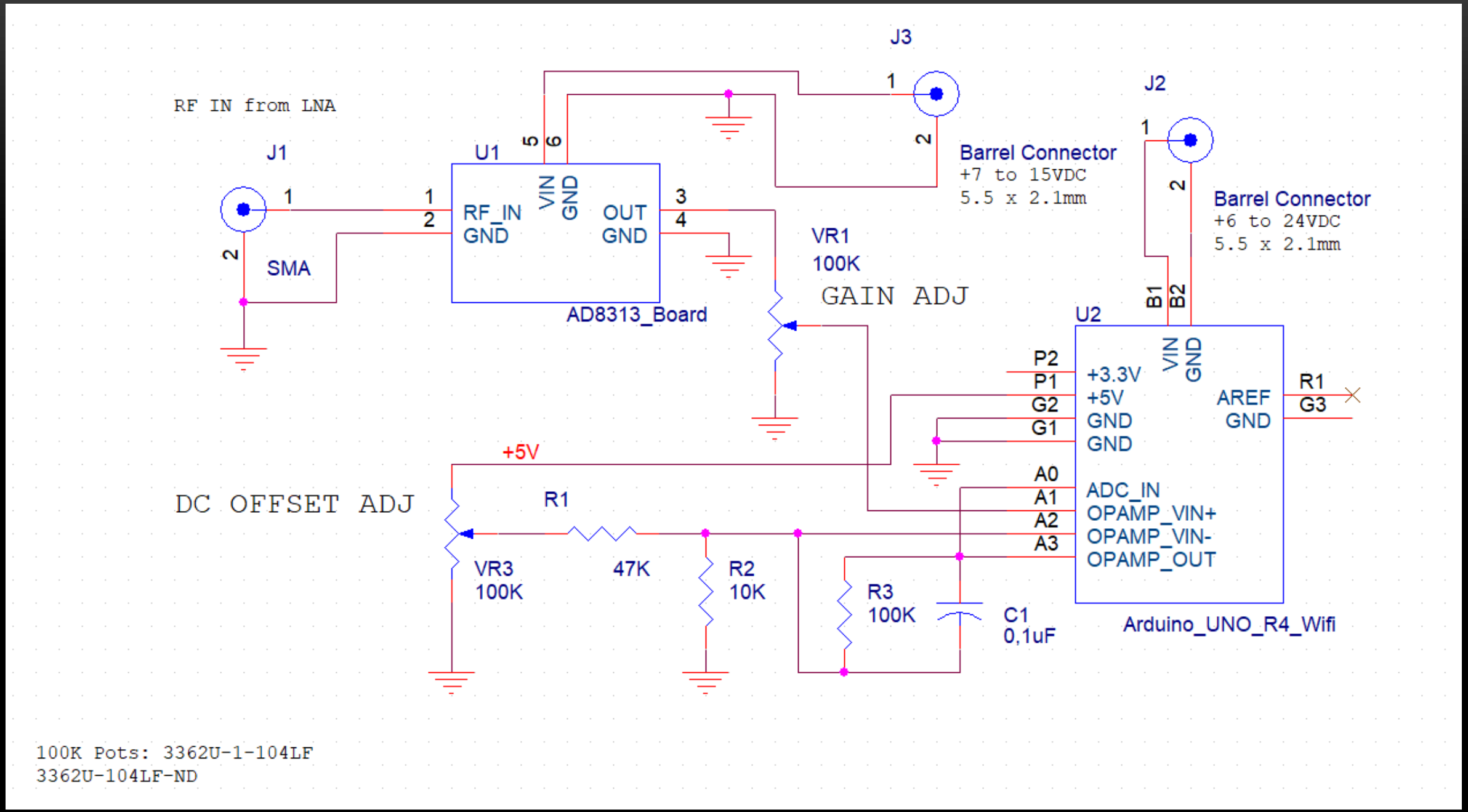
$$A = \pi r^2 \qquad Diameter = 2 * radius\ (r)$$

$Diameter$ = 4.028m or 13’ 2.4”;
Original diameter = 2.1m or 7’

Conclusion

Yes – We can increase sensitivity by increasing bandwidth

But – Increasing bandwidth adds unwanted noise



For completeness – schematic of Power Detector Receiver configuration

www.holland-observatory.net