Development of a Low Cost Multichannel Spectrometer for the Study of Ozone in the Mesosphere

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Outline

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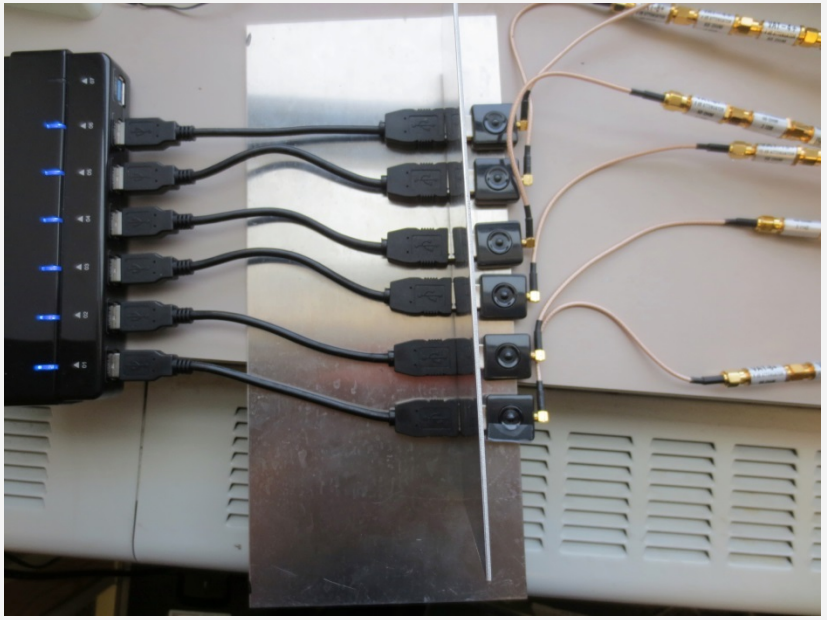
Introduction/Motivation

- Haystack Observatory has developed an ozone spectrometer using satellite TV dishes and a low noise block down converter feed (LNBF) for observations of ozone in the mesosphere.
- Provides unique data about the composition and dynamics of the atmosphere at an altitude of 100 km
- Increased sensitivity can shorten measurement time as well as enable measurement of wind velocity and temperature of the ozone in the mesosphere
- The development of a new instrument using 3 dual-polarization LNBFs on a single dish would improve the sensitivity by a factor of $\sqrt{6}$ to allow a measurement at each site in about 2 hours.

Side view of Antenna and LNBF

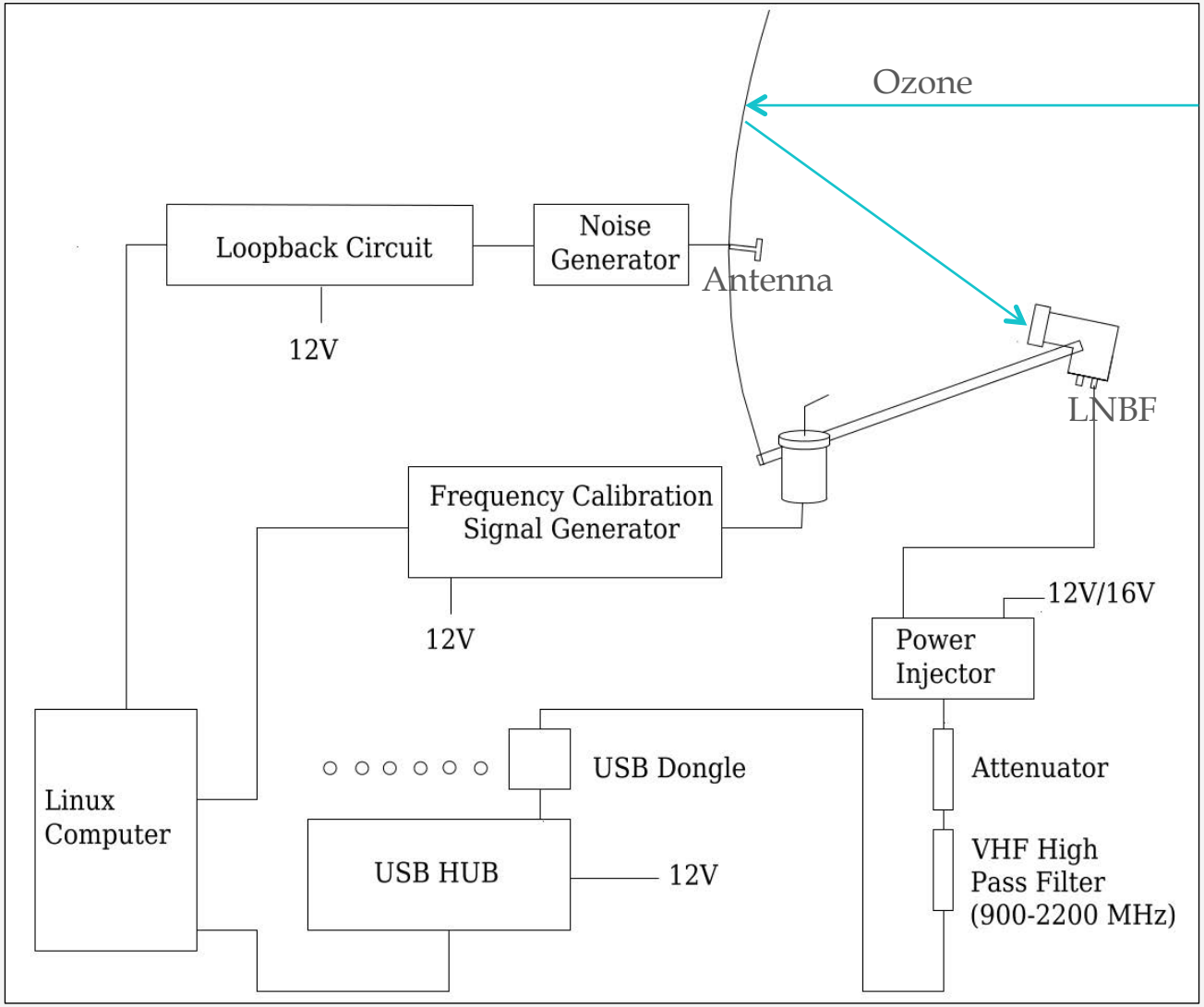


Heat sink for USB TV SDR dongles

Computer

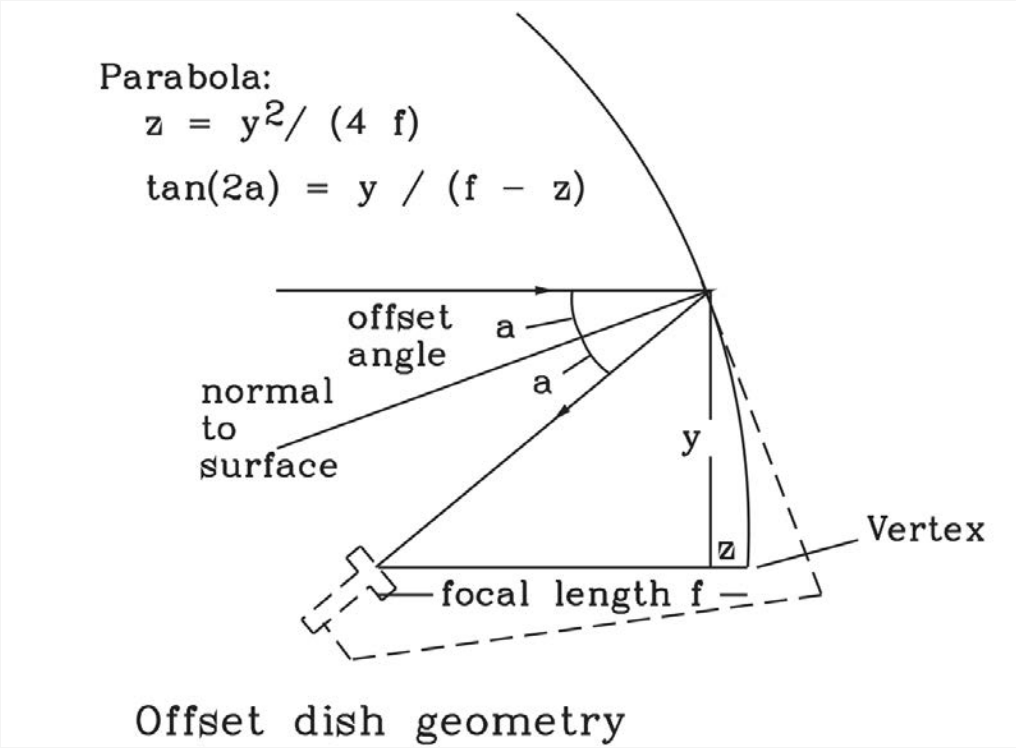
Multichannel Ozone Spectrometer

System Overview



Satellite Dish

- Winegard 60cm DS-4060
- Oriented at 12° elevation
- Offset Parabola
- Focal Length: 13.87 in



Offset dish geometry

Performance of Dish

- Performance of dish depends on spillover and Y-factor
- Ideally low spillover and high y-factor
- Spillover: 5%

Table 1: Y-Factor Values

LNBF	Middle	Middle	Left	Left	Right	Right
	Voltage		Voltage		Voltage	
	12	16	12	16	12	16
Without Absorber	53.2	56.2	53.1	55.1	54.6	56.1
With Absorber	58.1	60.9	57.6	59.9	59.2	60.8
Without Absorber	53.3	55.8	52.9	54.9	54.6	56.0
With Absorber	58.1	60.7	57.4	59.8	59.4	60.7
Without Absorber	53.2	55.6	52.8	54.8	54.7	55.9
With Absorber	58.0	60.7	57.4	59.8	59.4	60.6
Y Factor	4.8	4.9	4.5	4.9	4.7	4.7

A Y factor of 4.8 dB corresponds to system temperature of 144K

Low Noise Block Down Converter Feedhorns

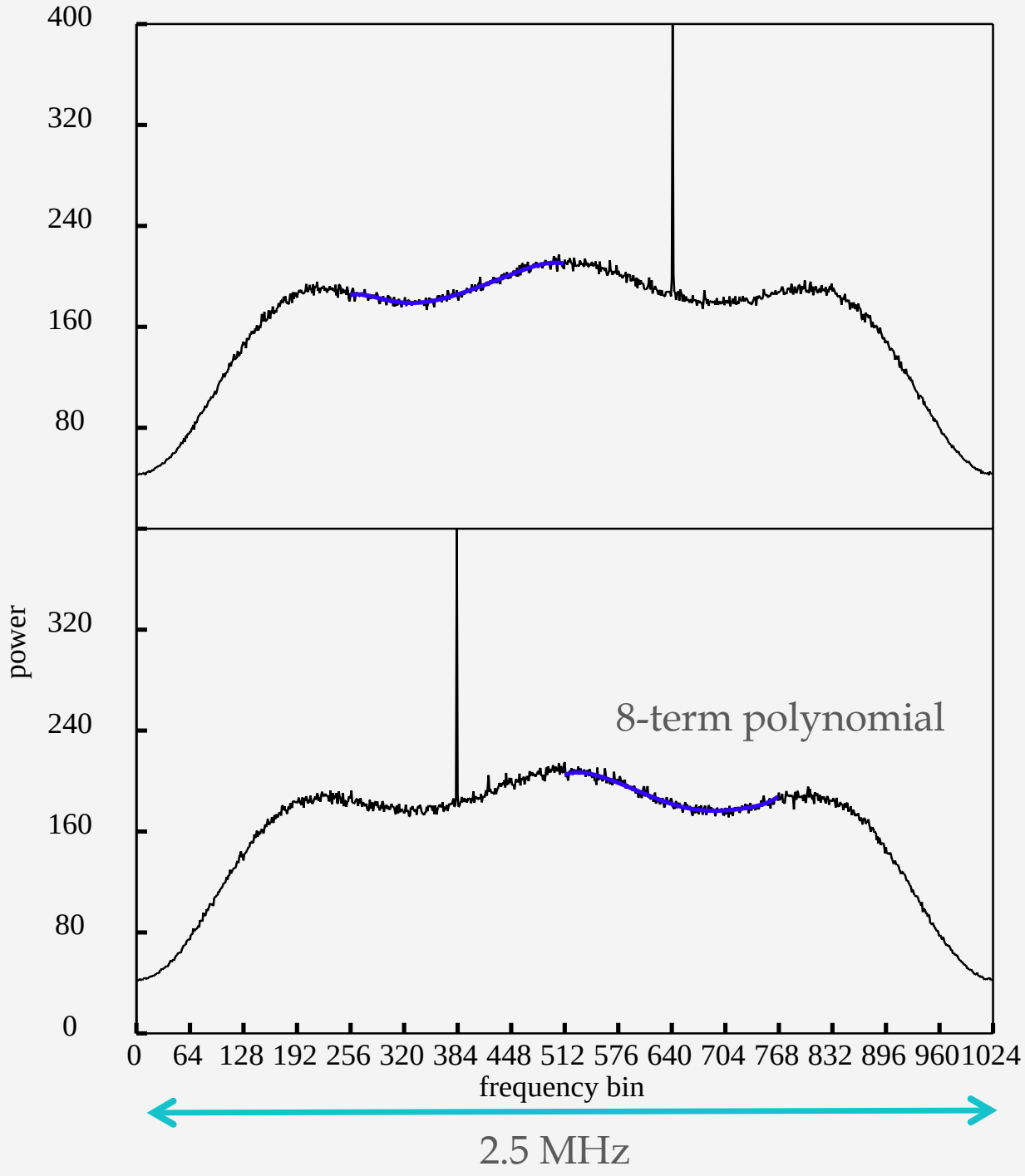
- Star Com's SR3602 Mini digital KU-band Universal LNBFs
- Set of three LNBFs each with two channels
- Dual Polarization based on input voltage
- Six channels: Increases sensitivity by a factor of √6

Frequency Switching

- We employed a frequency switching technique to remove receiver band pass and systematics
- The ozone line spectrum is extracted by subtracting the spectrum from an adjacent frequency band which acts as a comparison and then dividing by the comparison.
- A “first order” calibration is then obtained by multiplying this “fractional” spectrum by the system temperature to convert the units to degrees kelvin.

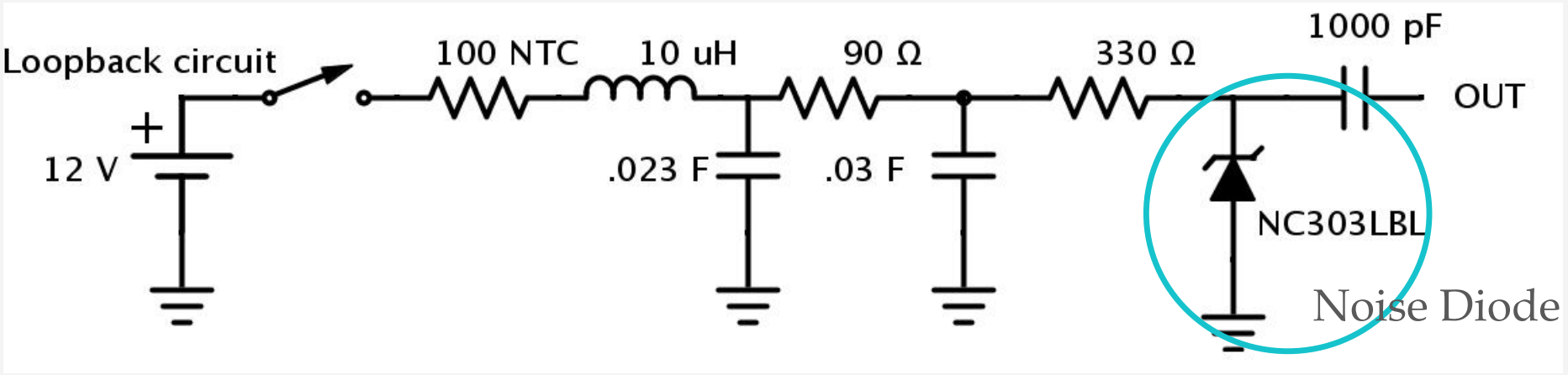
Frequency Smoothing

- The comparison spectrum is smoothed using a low order polynomial to remove the noise in the reference spectrum without affecting the bandpass
- This results in an improvement in the SNR by a factor of $\sqrt{2}$


400
320
240
160
80
power
320
240
160
80
0
8-term polynomial
0 64 128 192 256 320 384 448 512 576 640 704 768 832 896 960 1024
frequency bin
2.5 MHz

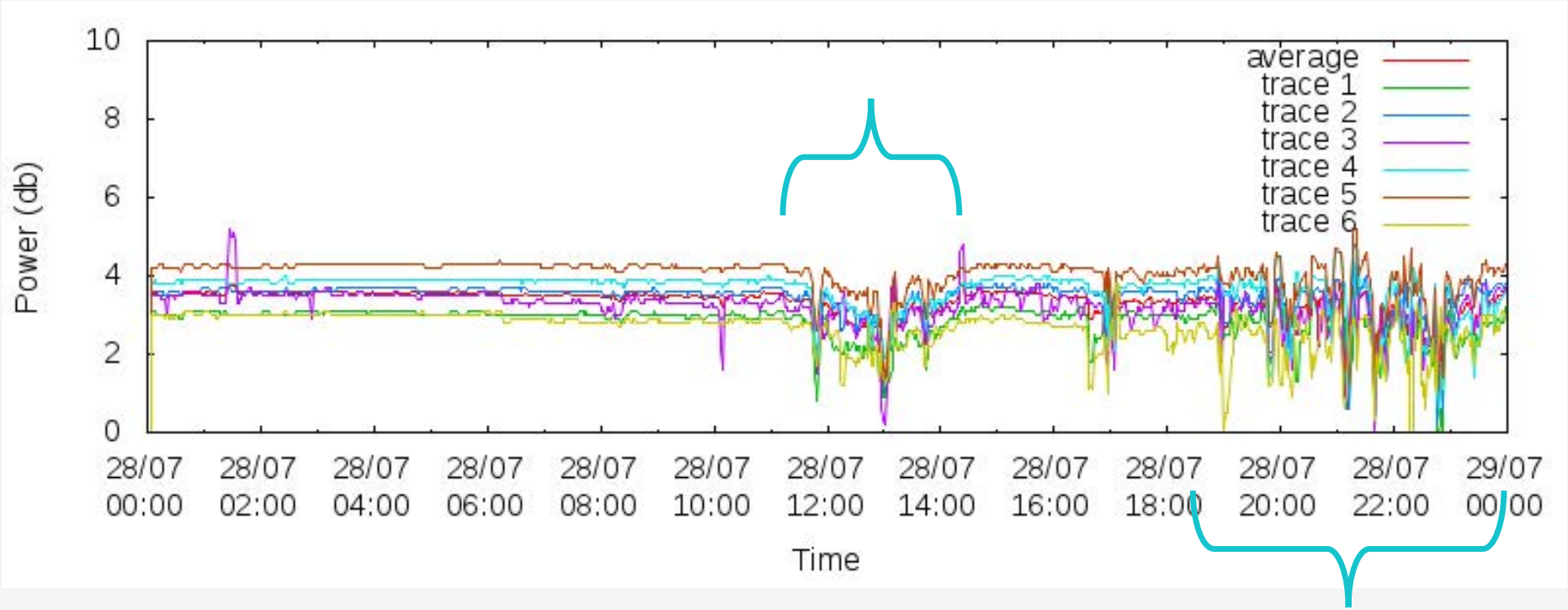
Noise Calibration

- Noise calibration is employed to be able to correct for changes in the system noise due to weather and drifts in the LNA
- Consists of a circuit and a half-wavelength dipole antenna ¾ wavelength above ground plane
- Added a ferrite toroid which acts as a balun for additional uniformity in output



Noise Calibration

Noise due to rain



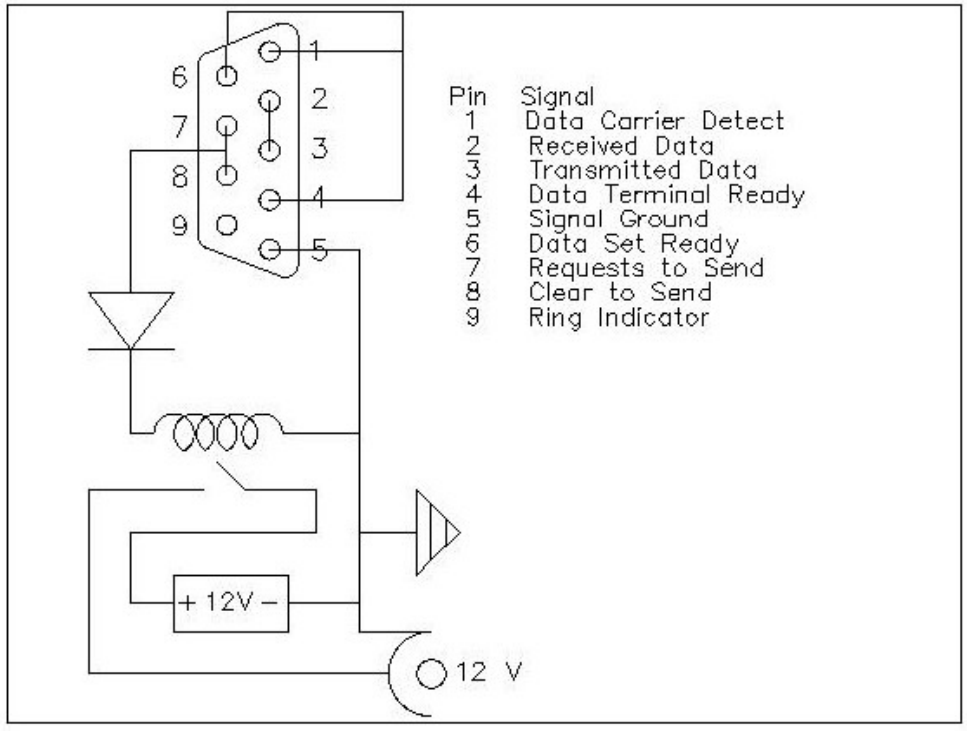
Noise due to interference from other radio sources

Frequency Calibration

- Need to correct for frequency drifts due to changes in temperature
- By measuring the Doppler shift of the ozone line, we can determine the wind velocity in the mesosphere
- However in order to get an accurate figure for wind velocity, you need a very precise frequency for comparison
- Current oven crystal is insufficient for this measurement (approx. 100 ppb off, which is equivalent to an error of 30 m/s)
- Recommendation: Chip Scale Atomic Clock (0.05 ppb accuracy on shipment, <0.3 ppb/month aging rate)

USB to RS232 Convertor

- Both Frequency and noise calibrators use a USB to RS232 to turn on and off
- A method is needed to differentiate them
- Loop back circuit used for the noise calibrator

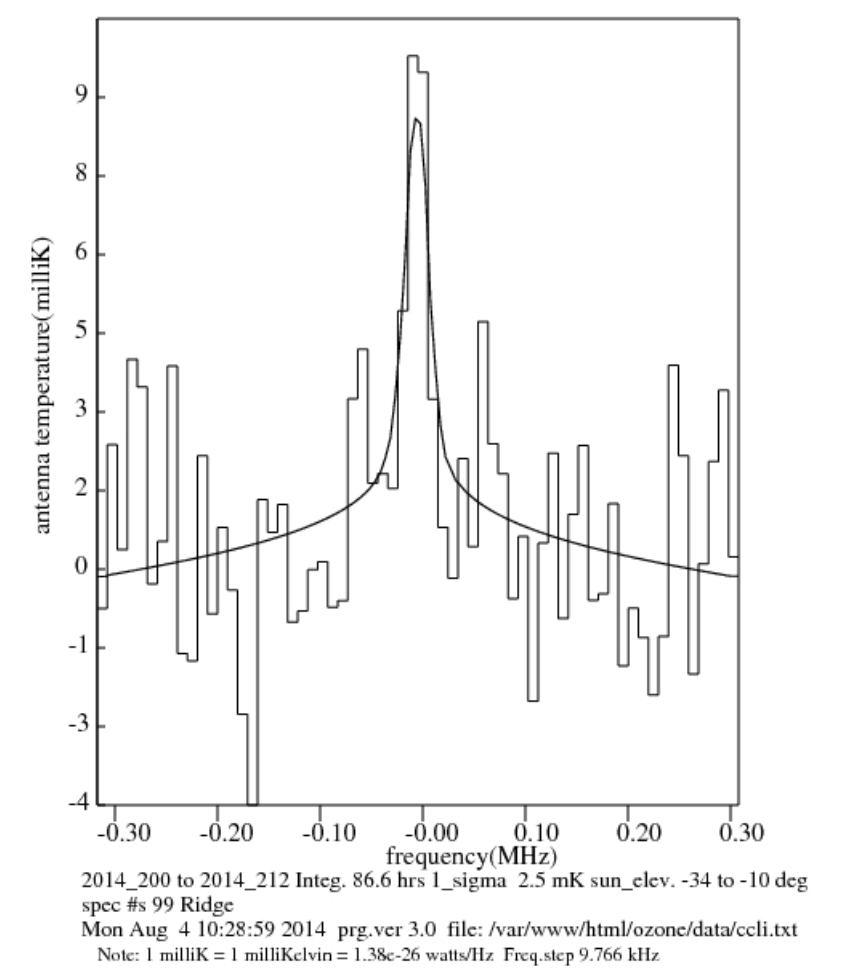


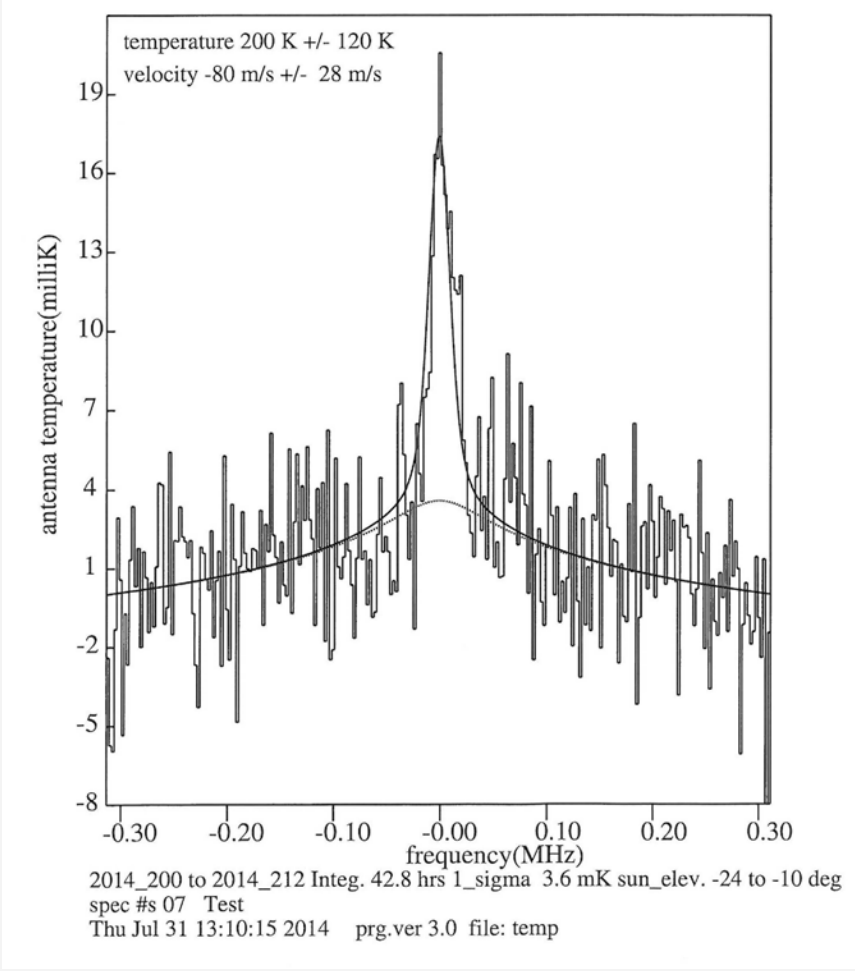
Cost Analysis

Component	Unit Cost	Quantity	Total
Satellite dish	$60.00	1	$60.00
LNBF	$10.95	3	$32.85
Coax cable	$8.00	6	$48.00
USB SDR TV dongle	$7.70	6	$46.20
Power Injector	$2.00	6	$12.00
Attenuator	$2.00	6	$12.00
VHF High Pass Filter	$25.00	6	$150.00
USB Hub	$50.00	1	$50.00
Noise Diode	$50.00	1	$50.00
USB to RS232	$10.00	2	$20.00
Linux PC	$400.00	1	$400.00
Total			$881.05

*If we choose to purchase the atomic clock chip the total cost of the system will jump by $1450 to $2331.05

Conclusion


antenna temperature(milliK)
frequency(MHz)
2014_200 to 2014_212 Integ. 86.6 hrs 1_sigma 2.5 mK sun_elev. -34 to -10 deg
spec #s 99 Ridge
Mon Aug 4 10:28:59 2014 prg.ver 3.0 file: /var/www/html/ozone/data/ccli.txt
Note: 1 milliK = 1 milliKelvin = 1.38e-26 watts/Hz Freq.step 9.766 kHz


temperature 200 K +/- 120 K
velocity -80 m/s +/- 28 m/s
antenna temperature(milliK)
frequency(MHz)
2014_200 to 2014_212 Integ. 42.8 hrs 1_sigma 3.6 mK sun_elev. -24 to -10 deg
spec #s 07 Test
Thu Jul 31 13:10:15 2014 prg.ver 3.0 file: temp

Where We are Now

- Spectrometer is able to detect the ozone line with greater resolution and less time is needed to detect the signal than the previous system
- Wind velocity measurements are not good enough unless we replace the oven crystal oscillator with the Chip Scale Atomic Clock

Next Steps

- Replace the oven crystal oscillator with the Chip Scale Atomic Clock to attain wind velocities
- Move to Moran Building to minimize interference from HAX radar

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  - Jason Soohoo
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References

- A.E.E. Rogers, et. al., “VSRT and MOSAIC Memo Series”. MIT Haystack Observatory. http://www.haystack.mit.edu/edu/undergrad/VSRT/VSRT_Memos/memoindex.html
- G. Beig, “Trends in the mesopause region temperature and our present understanding—an update,” Physics and Chemistry of the Earth, vol. 31, no. 1-3, pp 3-9.
- J. T. Houghton, Global Warming: The Complete Briefing, 3rd ed. NewYork: Cambridge University Press, 2004.
- J. T. Houghton, The Physics of the Atmosphere, 3rd ed. New York: Cambridge University Press, 2002.
- M. Allen, J. I. Yung, Y. L. Yung, “The Vertical Distribution of Ozone in the Mesosphere and Lower Thermosphere,” Journal of Geophysical Research, vol. 89, no. D3, pp. 4841-4872, 1984

Questions?