The Development of Remote Receiver Stations for TARA

Samridha Kunwar, The University of Kansas

For the Telescope Array Radar Project (TARA)

TeV Particle Astrophysics, Irvine 2013

Outline

- Cosmic Rays & Bi - static Radar.
- Antenna
  - Design, Simulation and Verification.
  - Noise Calibration
- Detection Of Cosmic Ray Echoes
  - An alternate triggering mechanism

Typical Detection (Ground Array)

Cerenkov Detector

Scintillator Counter

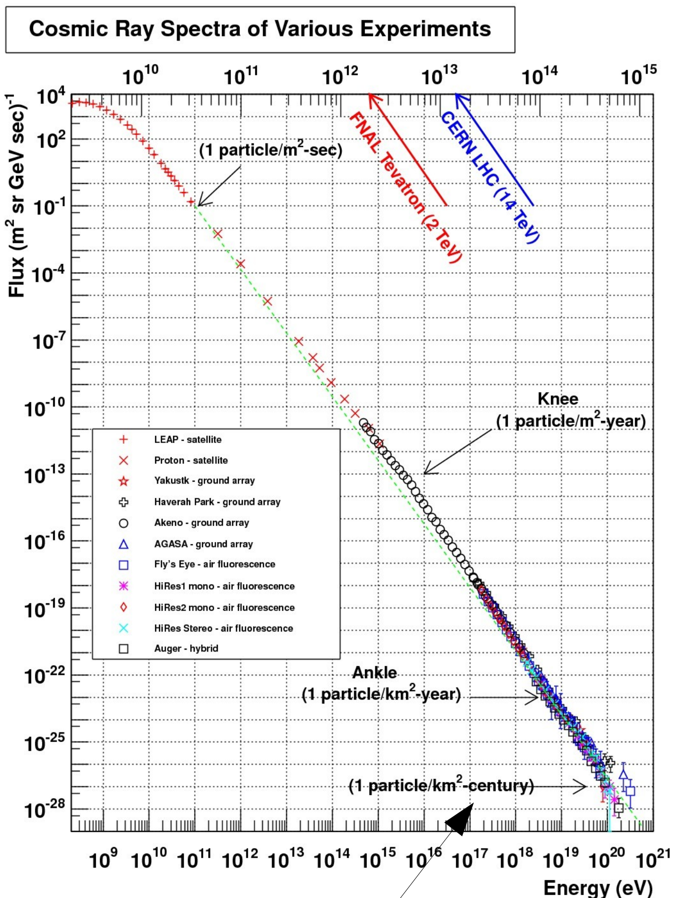
Requires significant land coverage (TA for instance covers roughly the land area of NYC). Can be expensive!

Typical Detection (Fluorescence)

Excitation energy emitted due to ionization of atmospheric gas molecules.

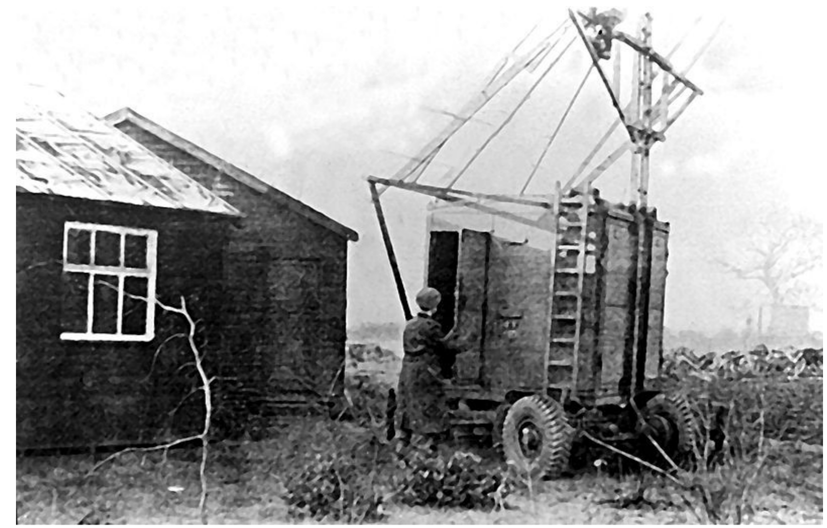
Duty cycle of ~10% (need clear moonless night!)

Motivation for Radar Detection



W. Hanlon, 2013

$Small\ Flux : Energy > 10^{18}\,eV$

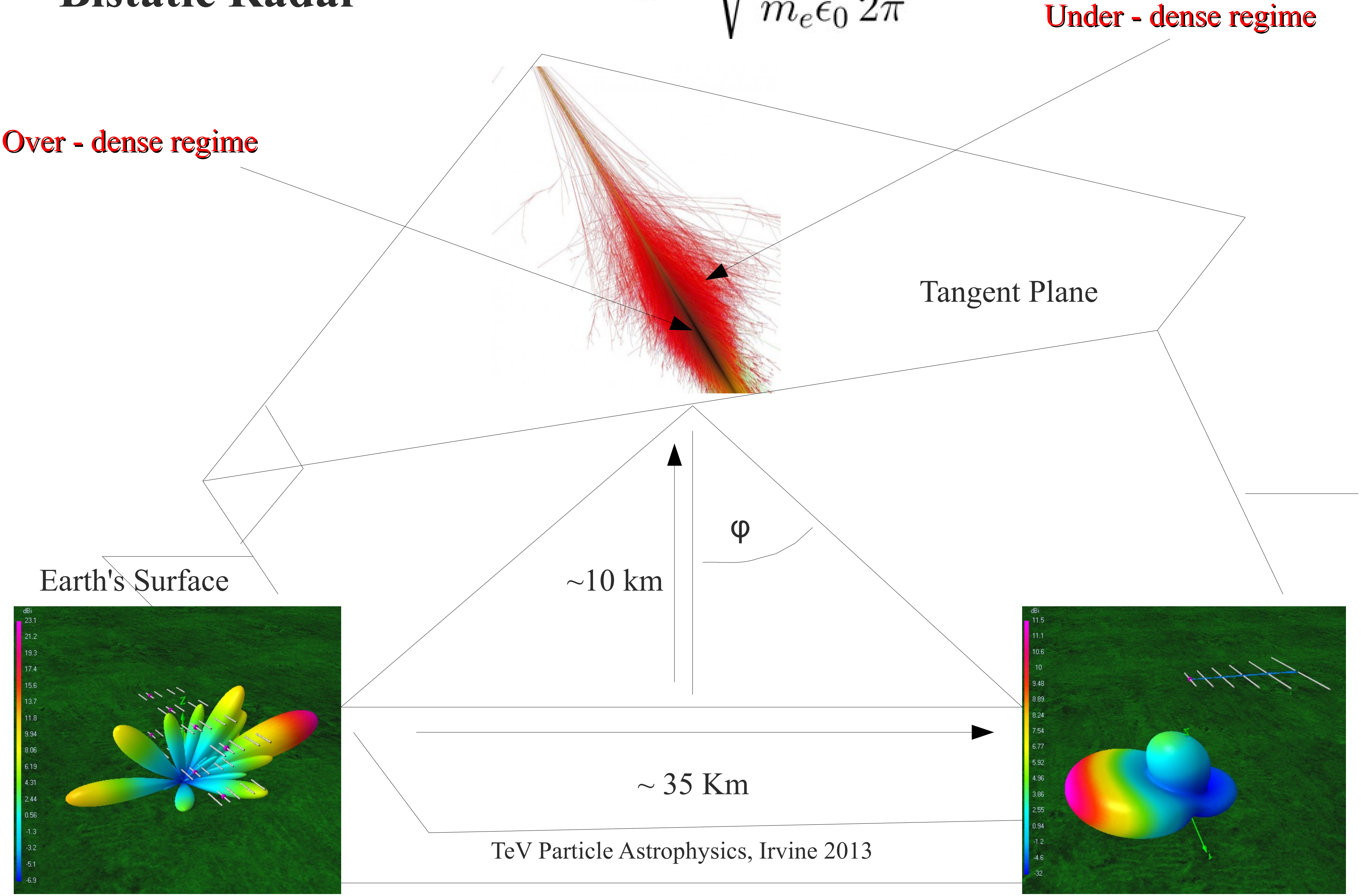


Jodrell Bank Radar Cosmic Ray Observatory

Blackett & Lovell (1940) – Explain anomalies
In atmospheric radar data.
No signal reported.

Bistatic Radar

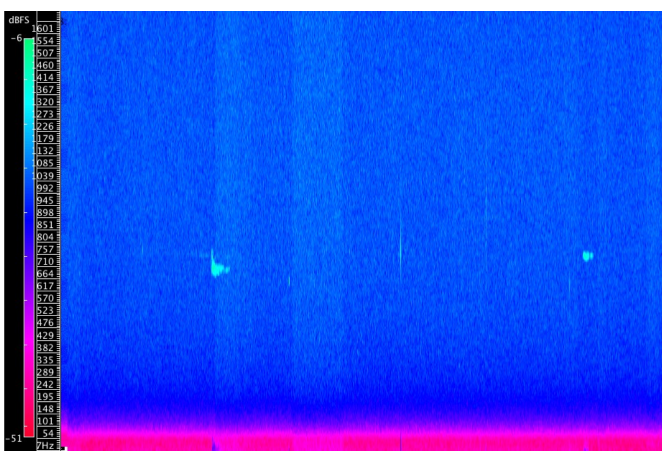
$$\nu_e = \sqrt{\frac{n_e e^2}{m_e \epsilon_0}} \frac{1}{2\pi}$$



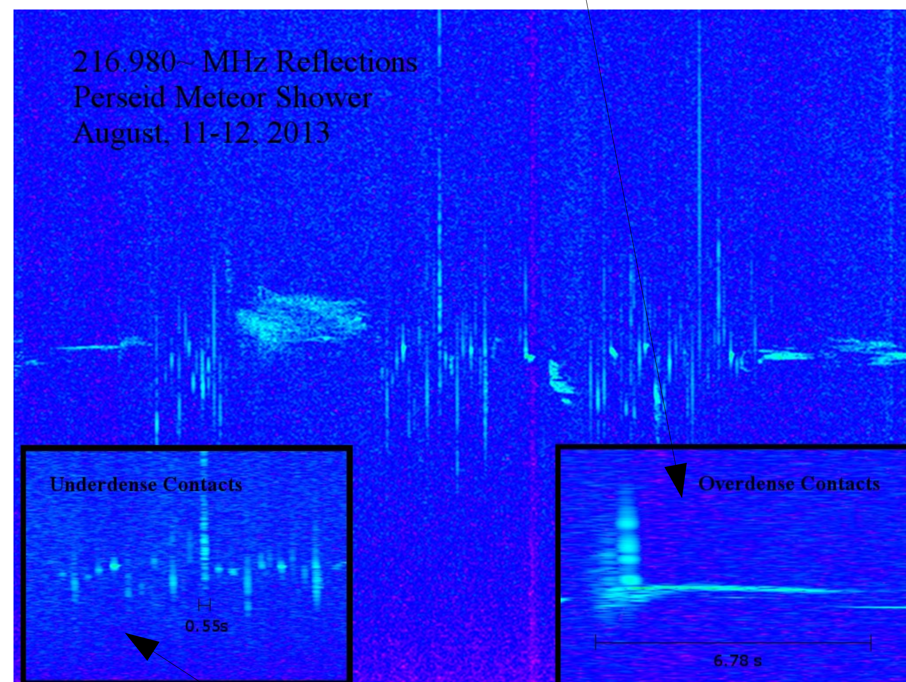
Bi – Static Meteor Detection (Over - dense Vs. Under – dense)

Steven Prochyra & KU - Quarknet

PCR 1500 radio



Over – dense (~ >1s)



Perseid Meteor Shower (Aug 11 – 12, 2013)

"Transmitter of Opportunity" (Naval Space Surveillance System)

Under – dense (~ 0.1 – 1 s)

Transmitter

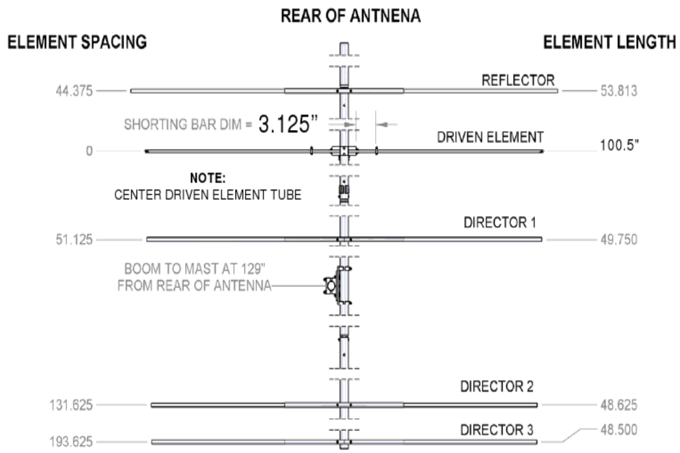
Low Pass Filter

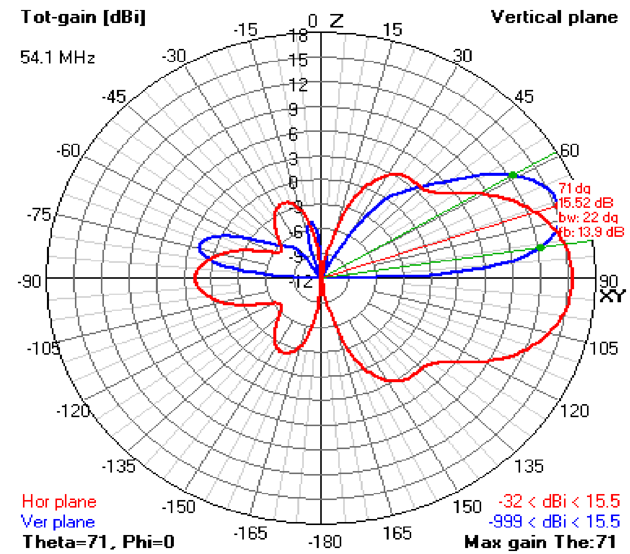
Power Combiner

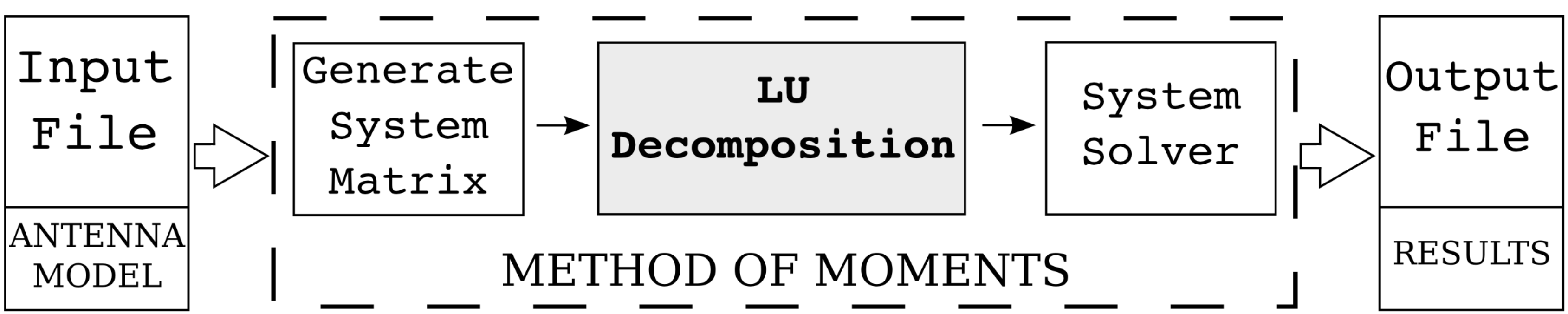
KTVN (20 KW)

KUTV (20 KW)

Transmitter Antenna (Tapered 5 – element Yagi)

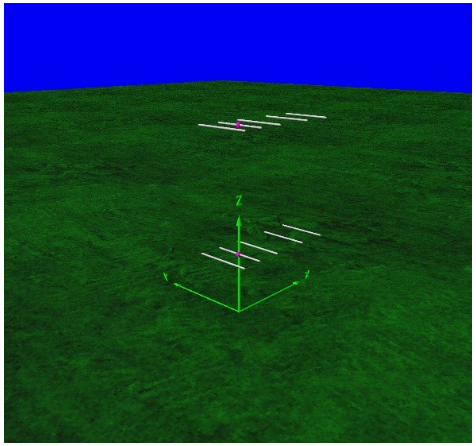


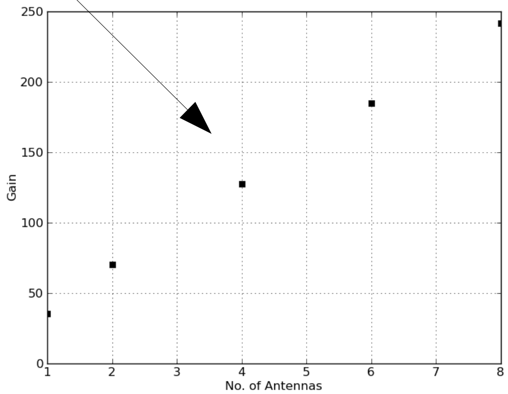




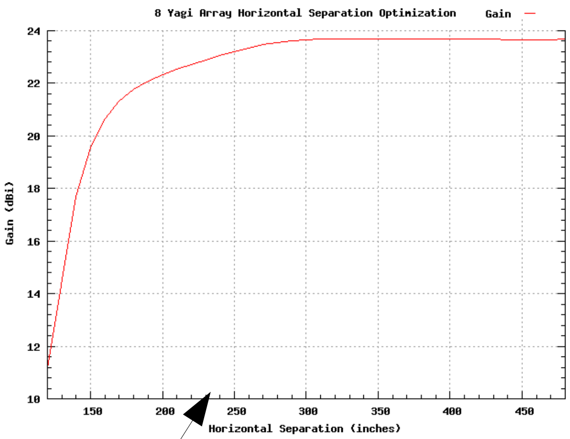
Transmitter Antenna (Phased Array)

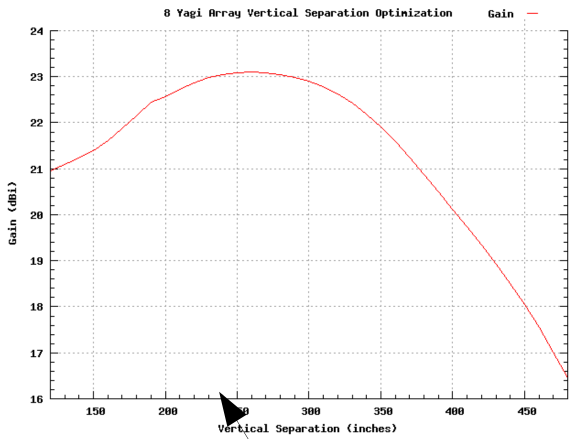
Gain increases linearly with number of antenna





Cost

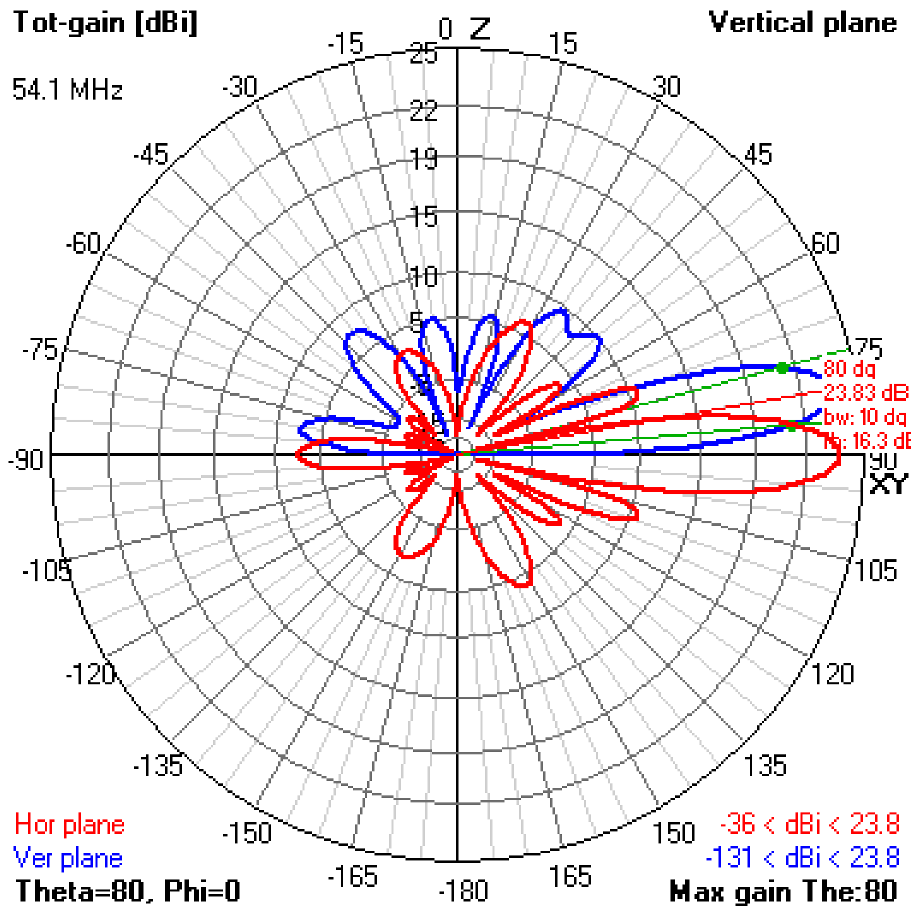




Horizontal Separation 240”

Vertical Separation 240”

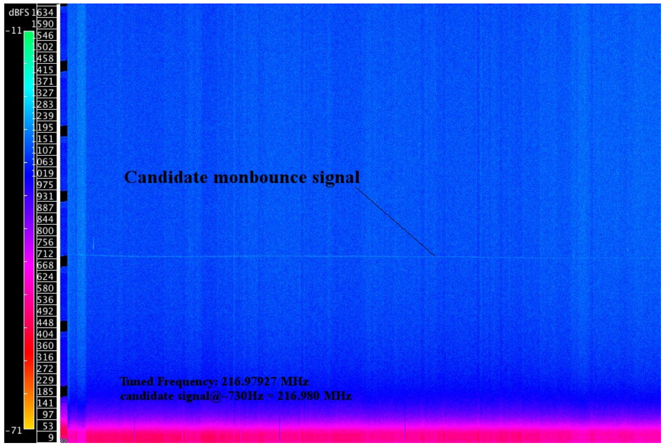
Transmitter Antenna (8 Yagi Phased Array)



Delta, UT

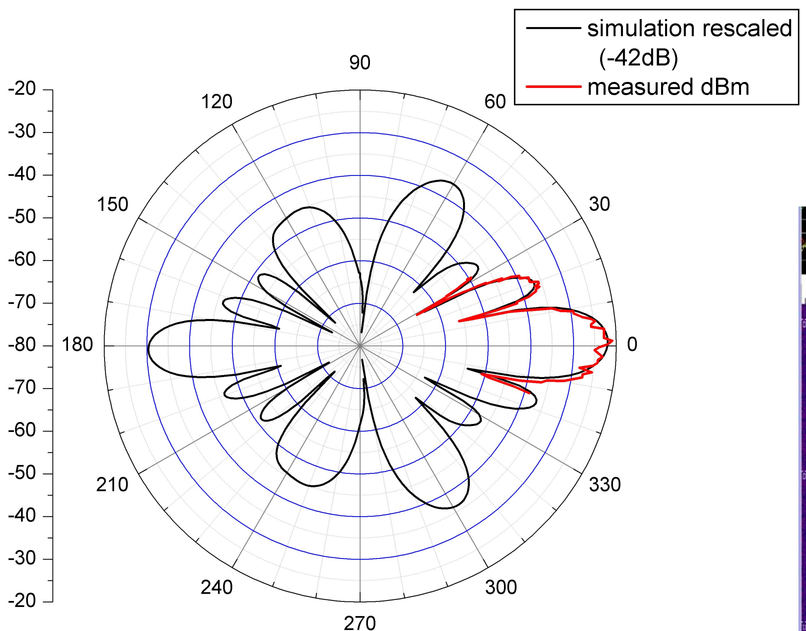
Tx Radiation Pattern

Moon – bounce θ

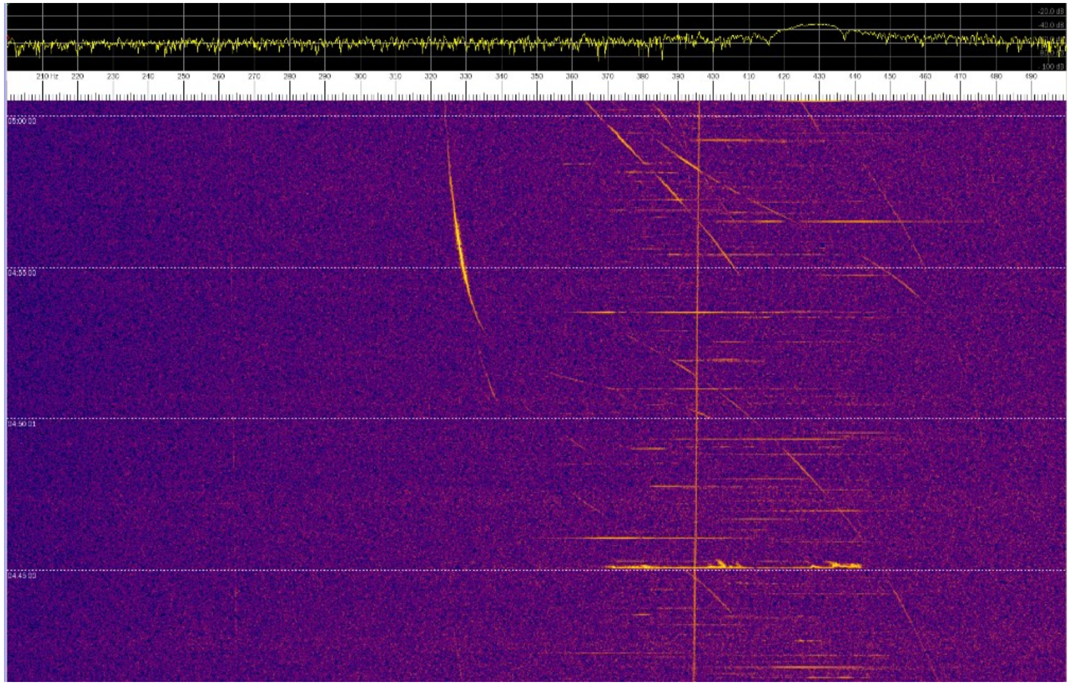


Steven Prochyra and KU - Quarknet

φ

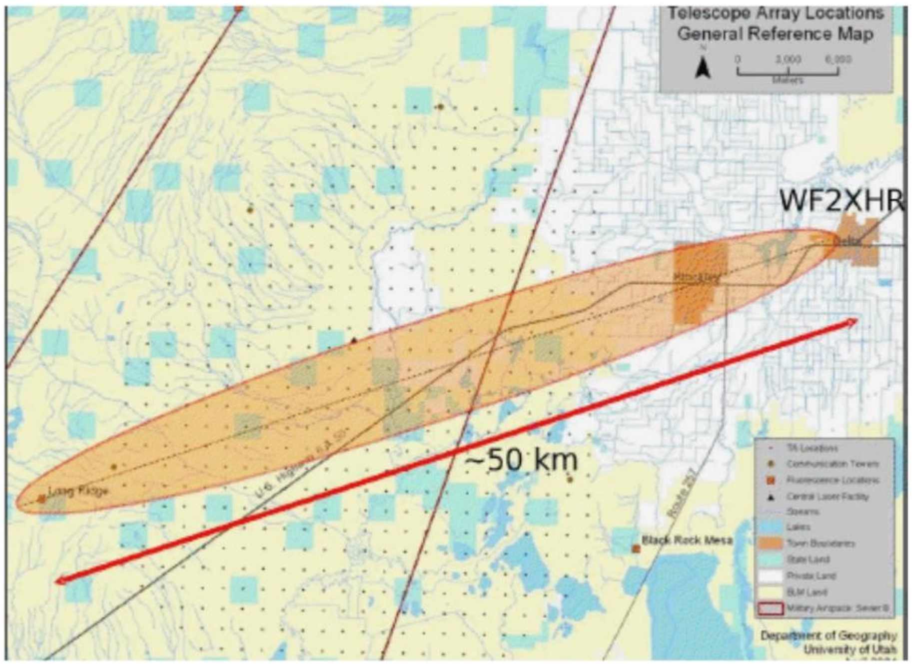


Drew Maluski



Lora Beard

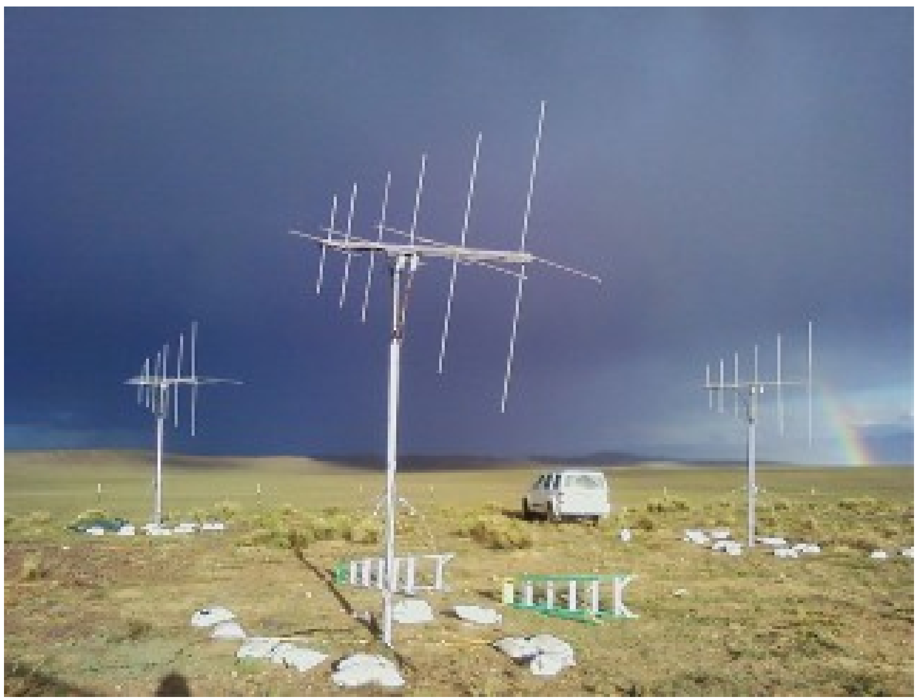
Spring 2013

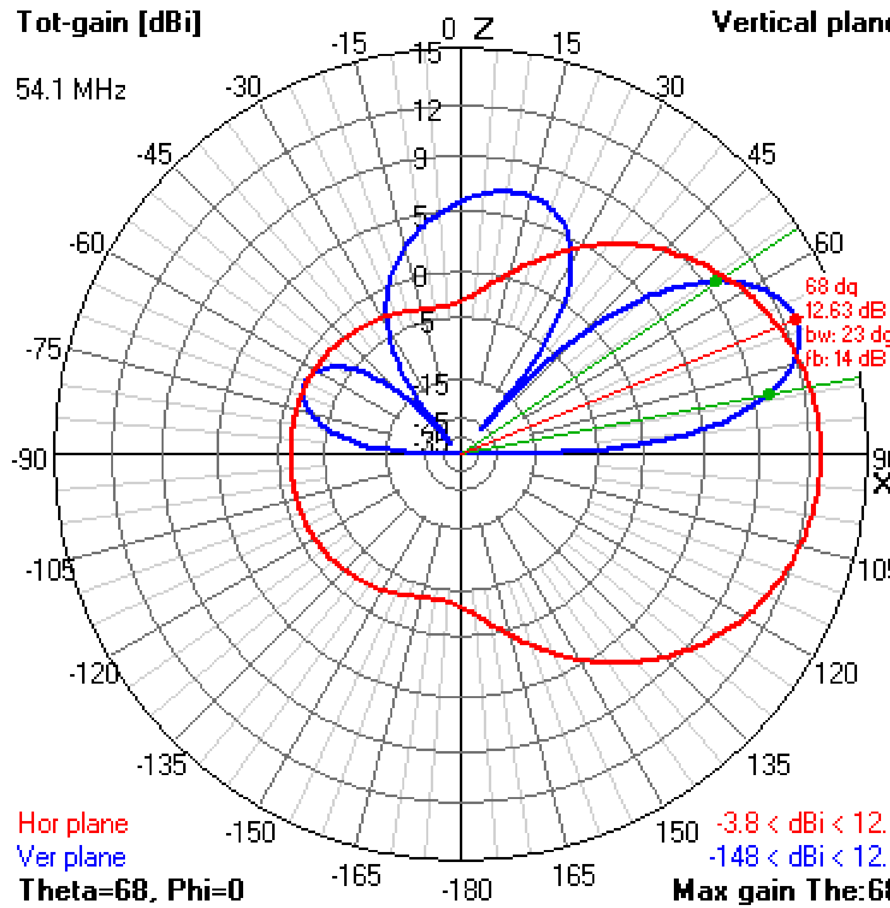


	WF2XHR	WF2XZZ
Baseline	50 KM	35 KM
Power	2 KW (1.5 KW)	40 KW
Transmitter	3 element single Yagi	5 element 8 Yagi Array

Several key upgrades made in the late spring of 2013

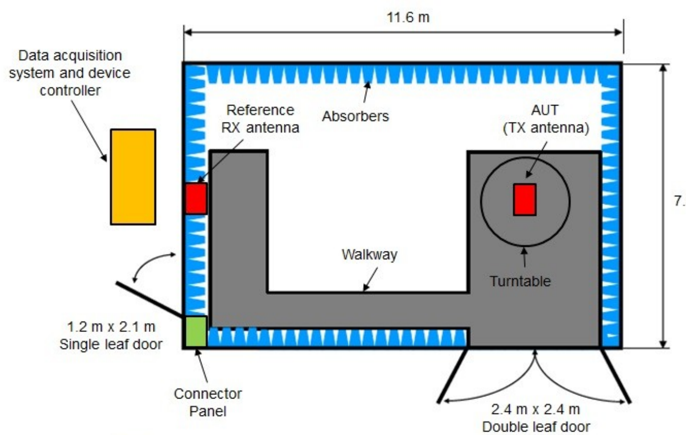
Receiver Antenna (Log Periodic Dipole Antenna – Dual Polarization)

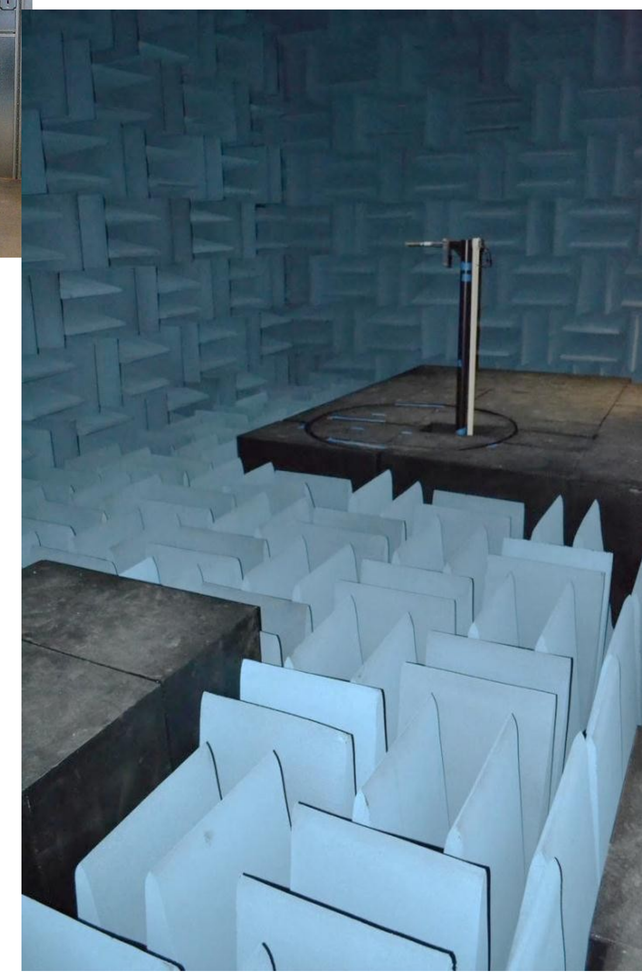




Longridge, UT

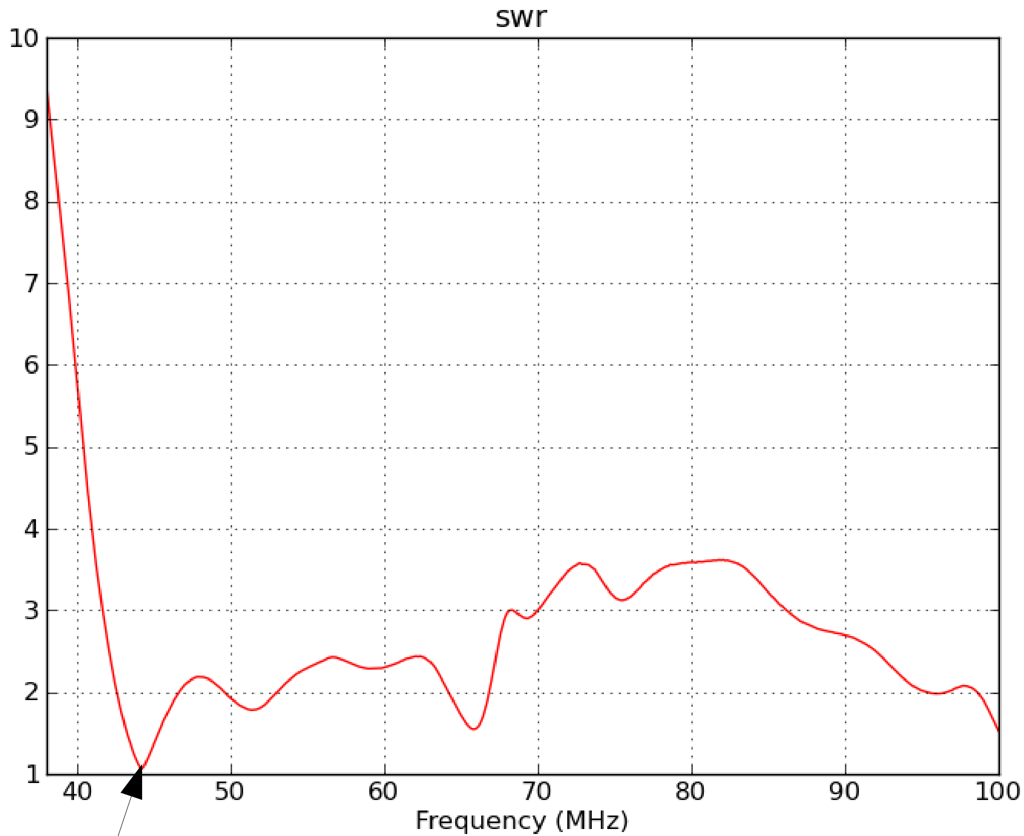
Anechoic Chamber(LPDA Response)





- Agilent N5230C PNA-L 4 port Network Analyzer (10 Mhz – 20 GHz)
- Agilent E4446A PSA Spectrum Analyzer (3 Hz – 44 GHz)

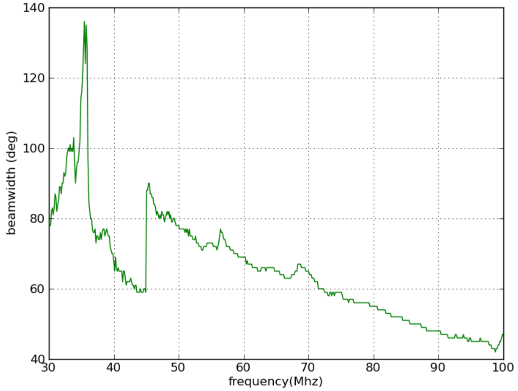
Receiver Antenna (H-pol. LPDA in Anechoic Chamber)

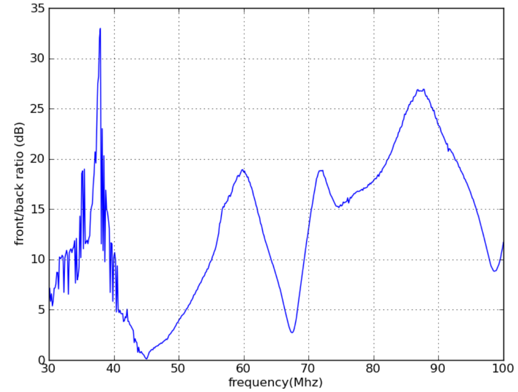


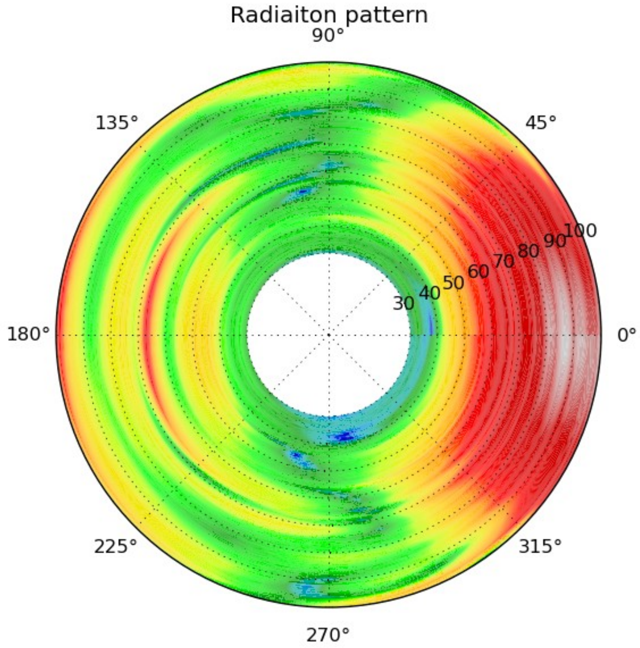
$$SWR = (1 + S11) / (1 - S11)$$

Cuts in at ~ 44 Mhz

Receiver Antenna (H-pol. LPDA in Anechoic Chamber)

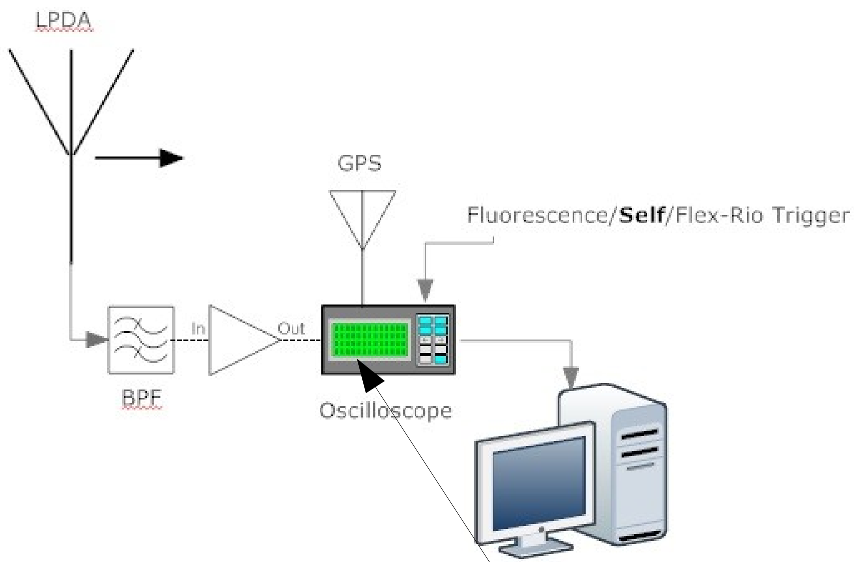


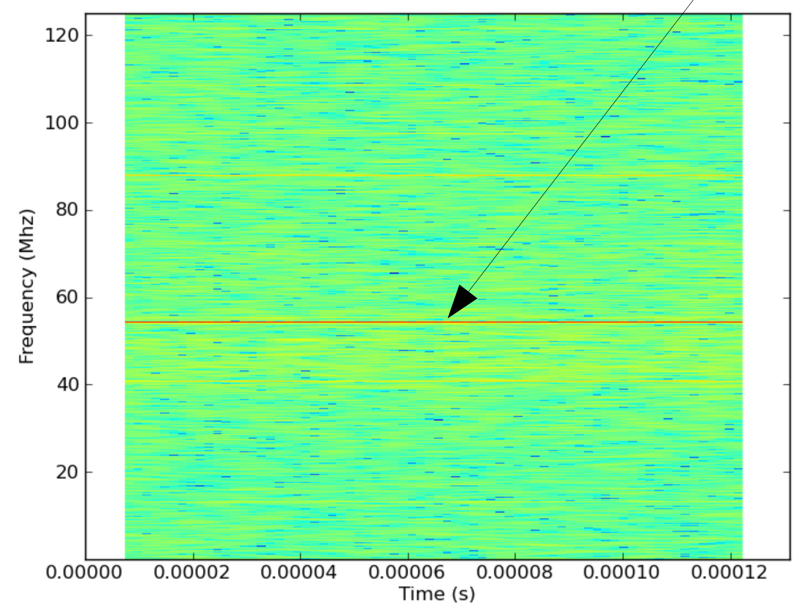




Noise Calibration (w / Oscilloscope DAQ)

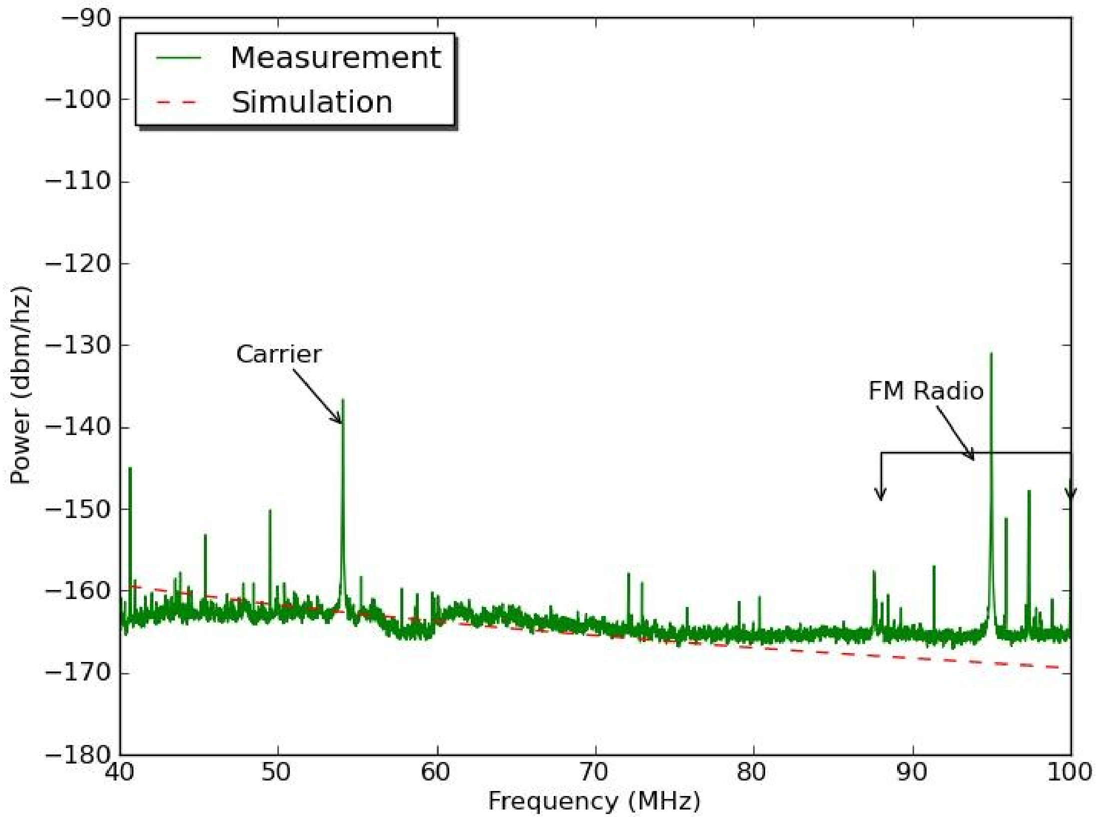
Carrier at 54.1 Mhz

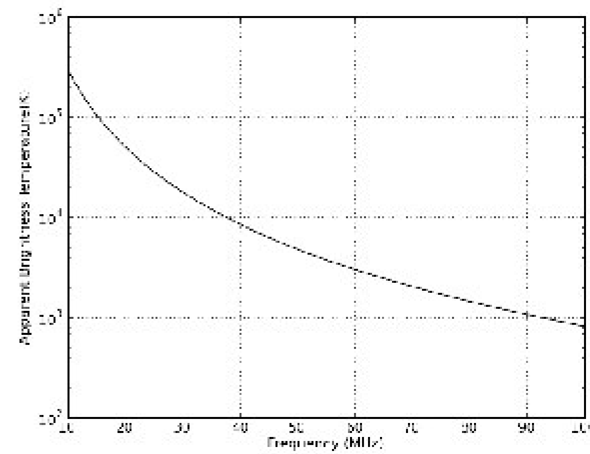




250 MSa/s sampling rate and 125 us window

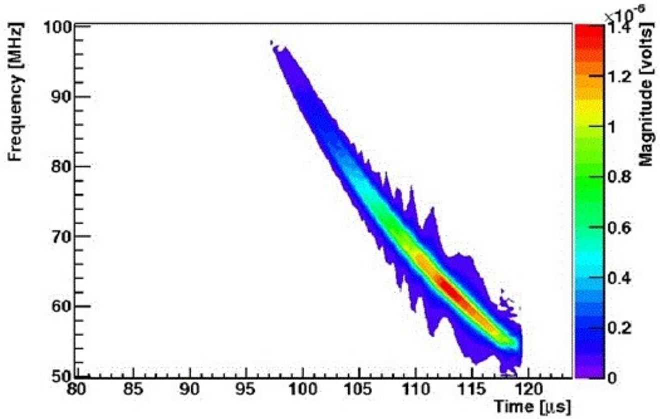
Noise Calibration (w / Oscilloscope DAQ)



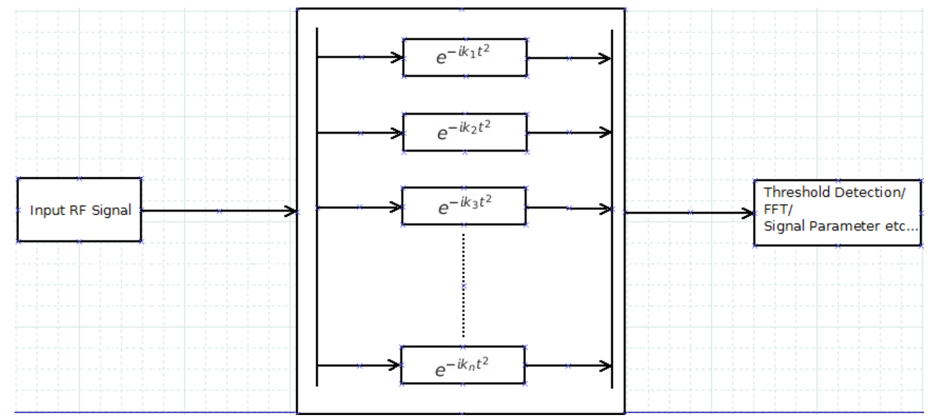


Measurement Compared To Simulated Galactic Floor.

Chirp Signal & Chirp – Matched Filter



Input RF Signal correlated with known signal!



$$f(t) = f_0 + kt$$

$$x(t) = \sin\left[\phi_0 + 2\pi\left(f_0 t + \frac{k}{2}t^2\right)\right]$$

Flex - Rio

250 Msa/s,14 bit resolution, 4 analog channels, 500 MHz BW.

Match – filter / Fluorescence detector triggered.

Antrhpogenic Noise Sources (for instance CB radio) in receiver building.

Transient and high amplitude signals cause event trigger.

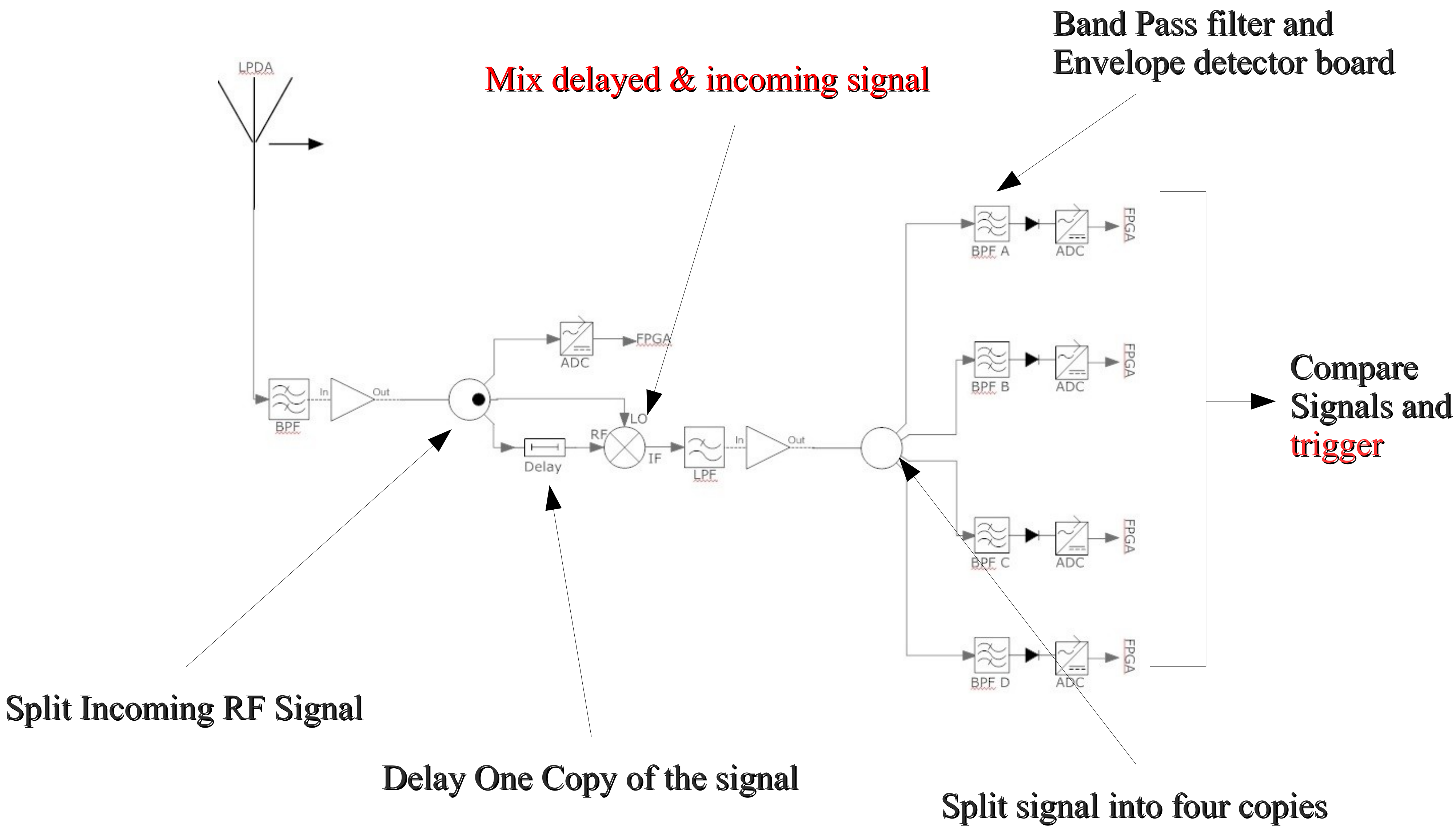
Expensive ~ $ 20 K

Power Consumption ~ 400 W

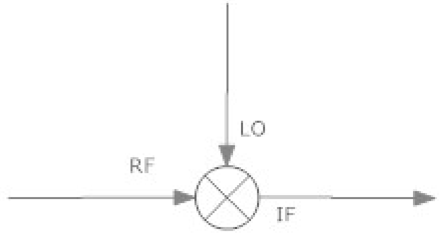
Computationally Expensive

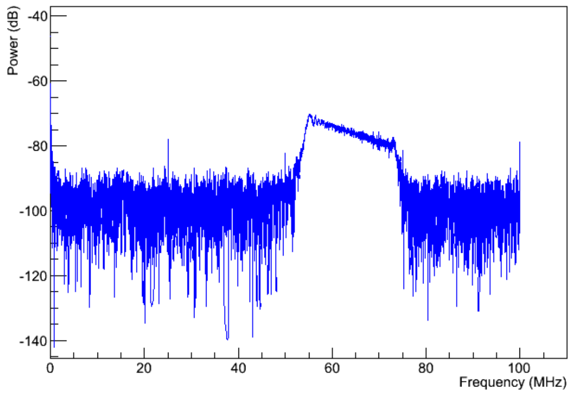
Excellent performance and ideal absent financial / noise constraints!

An Alternate low -powered and largely analog DAQ



Chirp Signal → Monotone



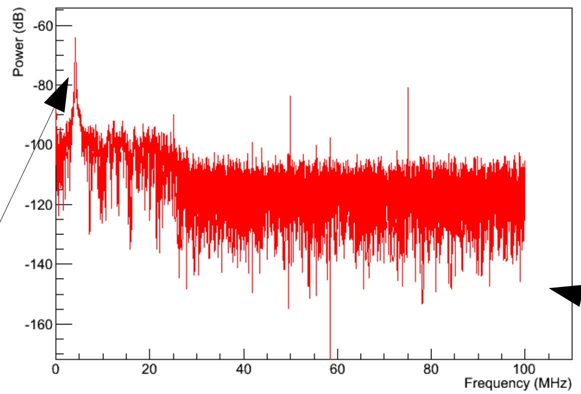


→ Chirp signal

↓

Signal split; **original signal mixed with delayed copy of itself**

↓

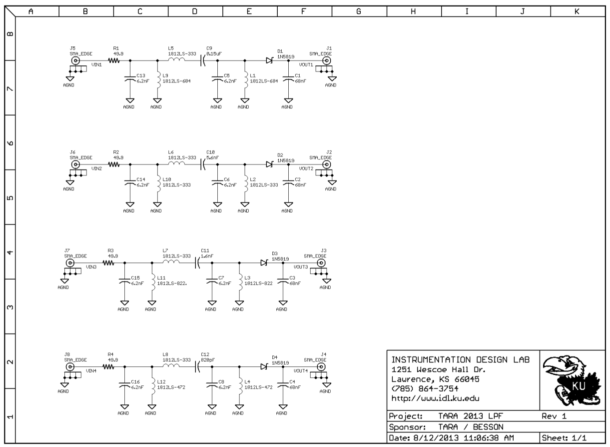


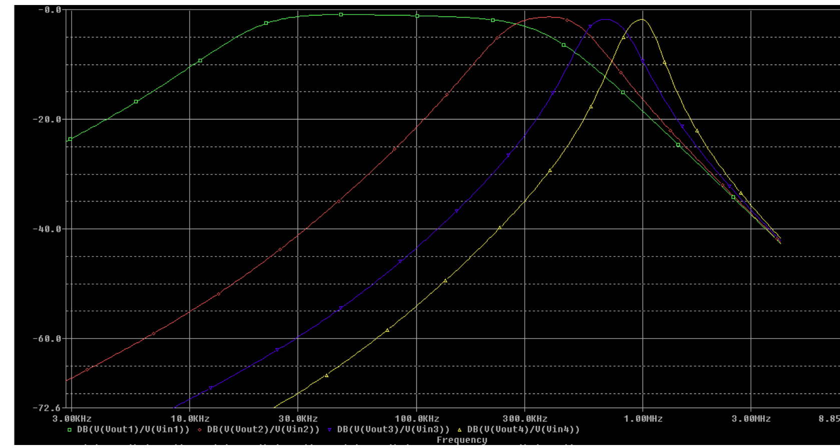
→ Chirp Signal
+
"Beat" frequency (monotone) observed.

Low Pass Filtered

"Beat" Frequency

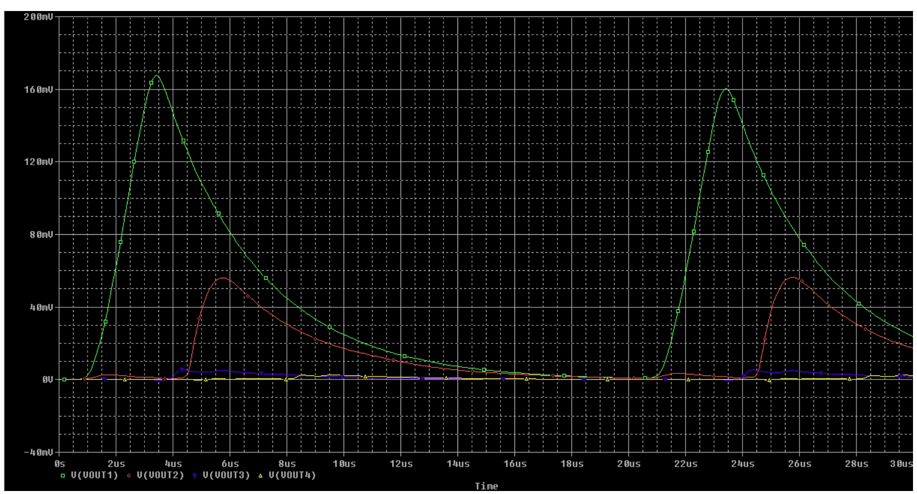
Band Pass Filter and Envelope Detector





Bode Plot of Band Pass Filters

Band width of each filter ~ 300 Khz.
Range from ~ 18 Khz – 1.23 Mhz

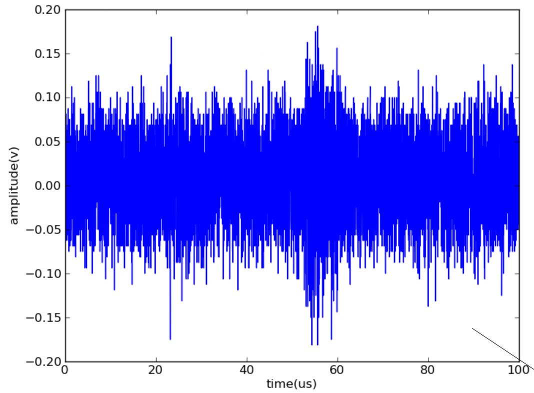


Band Pass Filter – Envelope Detector Output (100 Khz test)

Want to detect down converted beat signal.

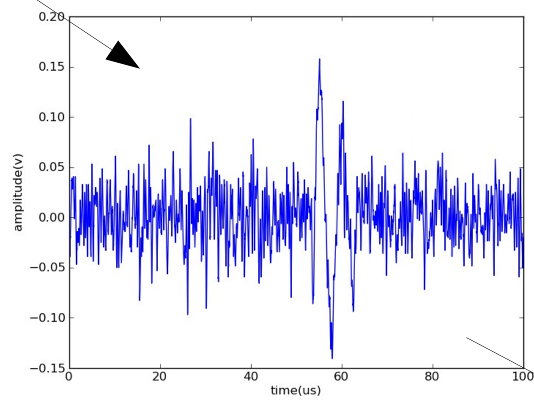
Signal Chain

Chirp Rate = 2 Mhz/us

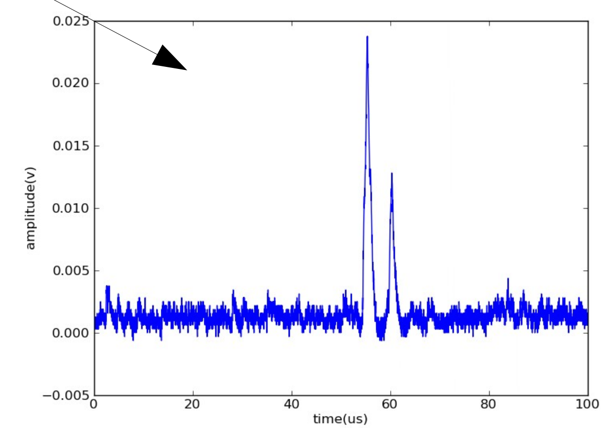


Down Convert Chirp

Delay = 100 ns



Pass Through Envelope Detector



Has been measured in lab down to -8 dB SNR

Conclusion

- Bi – Static Radar aims to achieve remote coverage over large portion of the Earth's Surface in search of UHE Cosmic Ray induced radio echoes.
- Transmitter and Receiver stations were completed in the late spring of 2013.
- A primarily analog – based chirp detection mechanism is being developed for the detection of chirp signals.

Remote Station Prototype

The TARA Project

M. Abu Bakr Othman, C. Allen, E. Barcikowski, J. Belz, D. Besson, B. Farhang-Boroujeny, W. Hanlon, D. Ikeda, J.Hanson, C.Jayanthmurthy, S. Kunwar, J.P. Lundquist, I. Kravchenko, S. Larson, I. Myers, T. Nakamura, J. S. Rankin, H. Sagawa, P. Sokolsky, H. Takai, T. Terasawa, G.B. Thomson, G.Vasiloff

(BNL, Kansas, Nebraska, NIPR, ICRR, Utah, Utah State) and the Telescope Array Collaboration

Thank You