MONITORING LOW FREQUENCY PROPAGATION WITH A SOFTWARE DEFINED RADIO RECEIVER
I. PROPAGATION CONCEPTS
II. OBSERVATIONS

Whitham D. Reeve
Anchorage, Alaska USA

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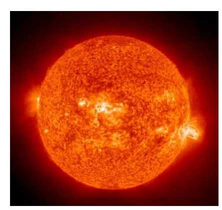

Introduction

Part I ~ Propagation Concepts
- Earth-Ionosphere Waveguide Mode
- Solar Flare Effects on Low Frequency Propagation

Part II ~ Observations
- Receiver Instrumentation
- Low Frequency Transmitter Stations
- Signal Measurements
- Spectrum Analyses
- Received Power and Signal-to-Noise Ratio
- Discussion

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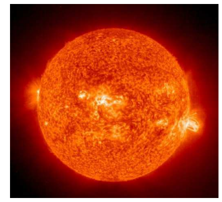
INTRODUCTION



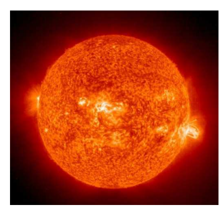
Describe applications of a software define radio (SDR) receiver to

- Monitor low frequency signals
- Detect Sudden Ionospheric Disturbances (SID)

First, briefly review Earth-Ionosphere Waveguide and low frequency propagation

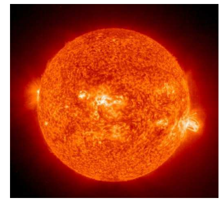
Then, look at low frequency observations

INTRODUCTION



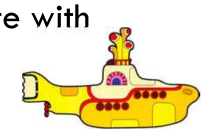
Solar flare effects on terrestrial radio propagation and thus the flare itself may be detected by monitoring variations in the signals received from a low frequency transmitter

The variations caused by a flare are called a *Sudden Ionospheric Disturbance* or SID



INTRODUCTION

Low frequencies are used to communicate with submarines



- Penetrate sea water
- Require very powerful transmitters and very large antenna/counterpoise systems

No SIDs were detected during the measurement period

- No surprise
- Low point in sunsport cycle

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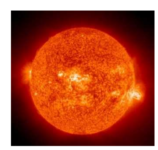
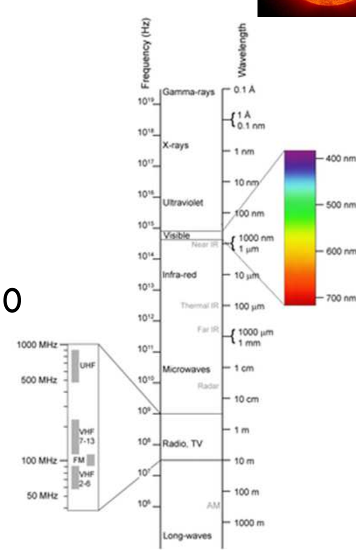


INTRODUCTION

For our purposes,
low frequencies refer to frequencies in

- VLF band (3 to 30 kHz)
- Lower part of the LF band (30 to 300 kHz) up to approximately 50 kHz



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EARTH-IONOSPHERE WAVEGUIDE

Low Frequency Propagation Modes

- Ground Wave
  - Radio wave skirts Earth's surface
  - Eventually dissipates due to ground losses
- Sky Wave
  - Radio wave refracted by Earth's ionosphere
  - Eventually dissipates due to absorption losses in ionosphere

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EARTH-IONOSPHERE WAVEGUIDE

Possible Low Frequency Propagation Modes

- Space Wave
  - Combination of Ground Wave and Sky Wave
  - Earth-Ionosphere Waveguide Mode
  - Very low losses at low frequencies: 1.5 ~ 3 dB/1000 km

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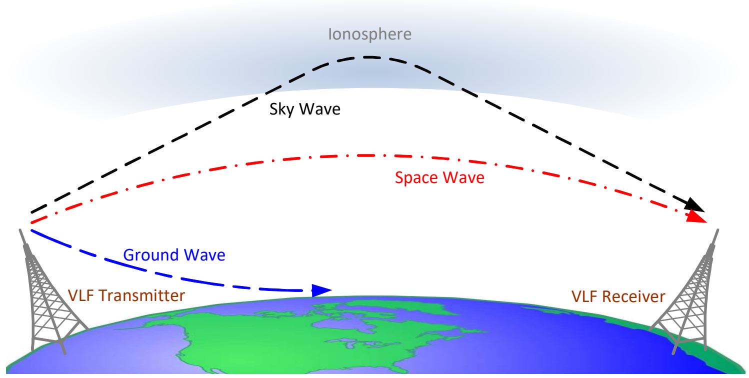
EARTH-IONOSPHERE WAVEGUIDE

Low Frequency Propagation Modes



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EARTH-IONOSPHERE WAVEGUIDE

Earth's surface and ionosphere form a spherical waveguide

- Lower wall of waveguide formed by the high conductivity of the ground or water surface
- Daytime: Upper wall by the sharp change in refractive index in the ionosphere's D-region
- Nighttime: Upper wall by ionosphere's E- and F-regions
- No sidewalls

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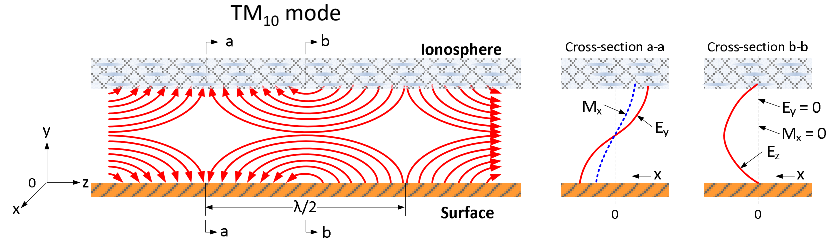
EARTH-IONOSPHERE WAVEGUIDE

Waveguide Modes

- TM mode ~ Transverse Magnetic
- TE mode ~ Transverse Electric

TM_{10} mode



LOW FREQUENCY PROPAGATION

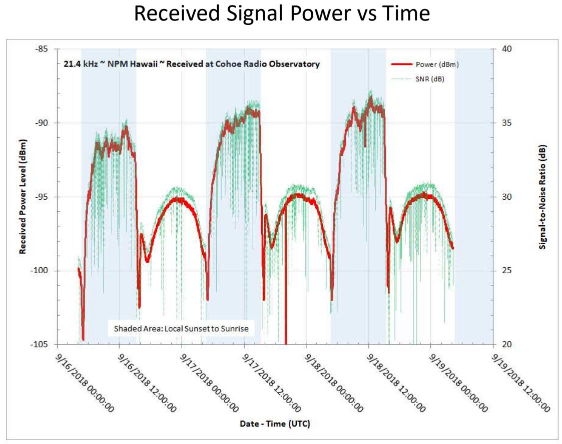
Night

- Less absorption loss
- Signal increase
- Variable

Day

- More absorption loss
- Signal decrease
- Steady

Received Signal Power vs Time

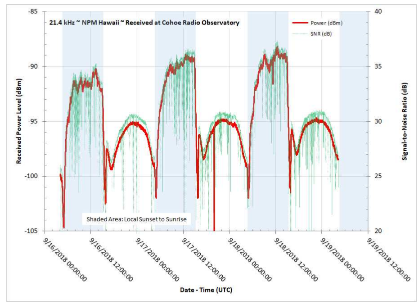


LOW FREQUENCY PROPAGATION

Received signal level dips at sunrise and sunset

- Ionosphere moves up at sunset
- Moves down at sunrise
- Refraction altitude changes on order of 1 wavelength at low frequencies (~15 km)

Received Signal Power vs Time



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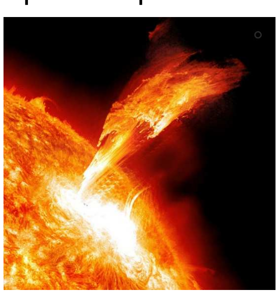
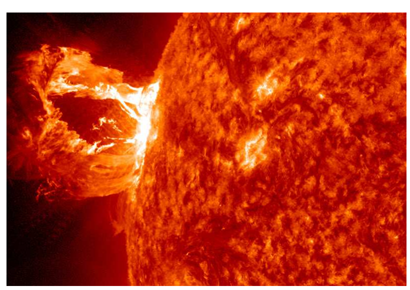
LOW FREQUENCY PROPAGATION

Flare radiation

- Suddenly increases electron density in ionosphere
  - Ionization increases
- Suddenly increases temperature
  - Ionosphere expands and moves





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LOW FREQUENCY PROPAGATION

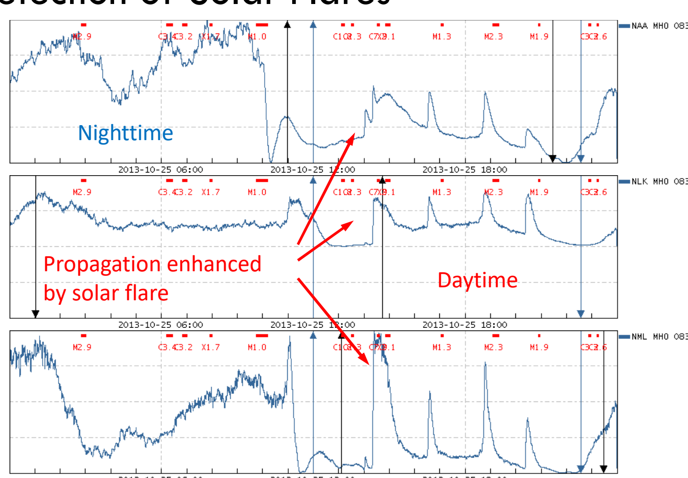
On day side of Earth:

D-region suddenly becomes a better reflector at low angles

- Enhances low frequency propagation
  - Received signal strength increases
- Sudden change of received signal level with respect to time infers the occurrence of solar flare
- Plot of signal strength indicates "shark fin" shape

LOW FREQUENCY PROPAGATION

Detection of Solar Flares



Source: Stanford Solar Center, Station MHO in Michigan

LOW FREQUENCY PROPAGATION

Transmitter and Receiver Antennas are Small Probes in the Waveguide

- Transmitter power ~ Hundreds of kilowatts to megawatts
- Transmitter antenna ~ Very large and efficient
- Receiver antenna ~ Very small and inefficient by comparison

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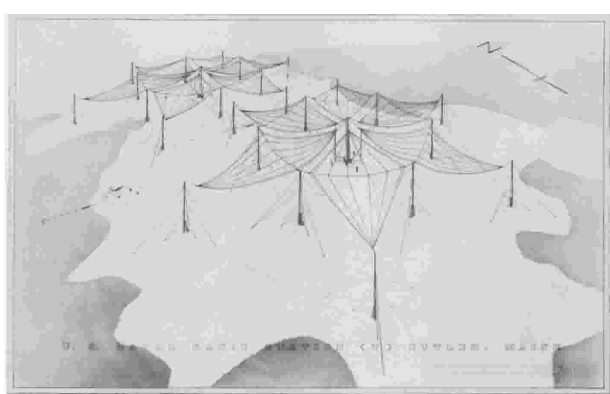
LOW FREQUENCY PROPAGATION

Transmitter Antenna

- Maine USA
- ~2 x 4 km
- Station NAA
- 24.0 kHz



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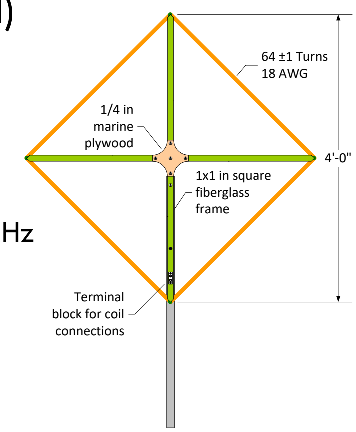
LOW FREQUENCY PROPAGATION

Receiver Antenna (typical)

- Square Loop
  - 1.2 m side length
  - 0.7 m^2 area
  - 3.4 m above ground
  - 2.7 cm effective height at 24 kHz

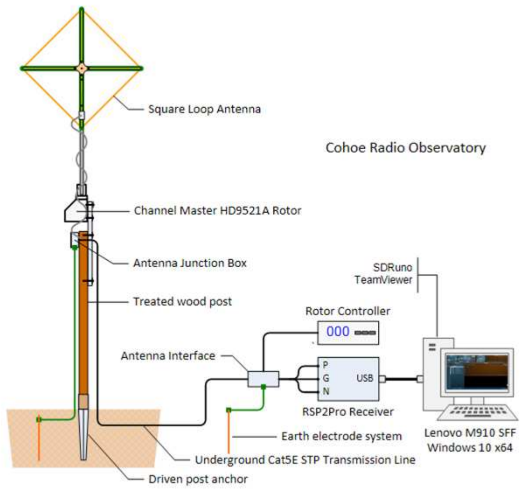


RECEIVER INSTRUMENTATION

Cohoe Radio Observatory

- Southcentral Alaska
  - Kenai Peninsula
  - Near Kasilof River
  - 120 km SSW Anchorage
- Geographic coordinates:
  - Latitude: 60.37 N
  - Longitude: 151.32 W
- Elevation: 22 m AMSL

RECEIVER INSTRUMENTATION



Installation completed
29 June 2018

Transmission Line:
Shielded Twisted Pair
(STP) CAT5E Cable

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RECEIVER INSTRUMENTATION

Receiver Hardware

- SDRPlay RSP2Pro
  - 9 kHz ~ 1.8 GHz frequency range
  - Balanced (HI Z) and Unbalanced (50 ohm) antenna inputs
    - Balanced input used for low frequency measurements
  - USB 2.0 Interface, power & signal

Power requirements:
170 mA at 5 Vdc

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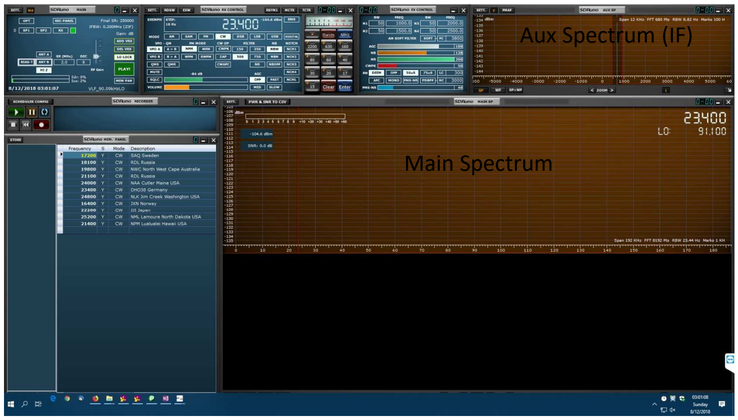
RECEIVER INSTRUMENTATION

Receiver Software

- SDRPlay SDRuno



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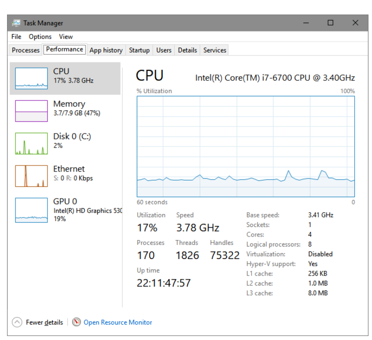
RECEIVER INSTRUMENTATION

Computer

- Lenovo ThinkCentre M910 SFF (Small Form Factor)
- Intel Core i7-6700, 3.4 GHz, 4-core processor
- 12 GB memory
- Windows 10 Pro x64



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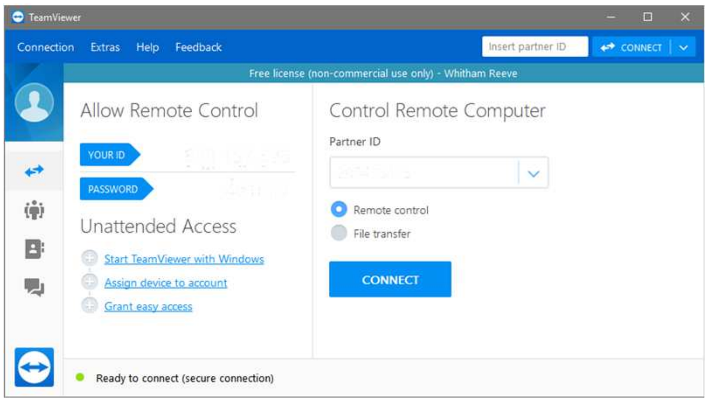
RECEIVER INSTRUMENTATION

TeamViewer software

- Allows remote software and data administration



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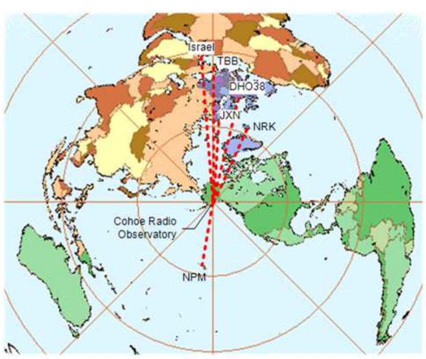
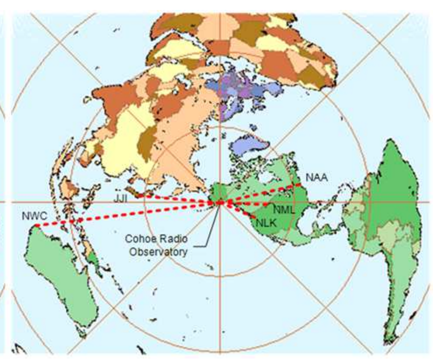
RECEIVER INSTRUMENTATION

Station Directions ~ Cohoe Reference



Antenna Oriented North-South



Antenna Oriented East-West

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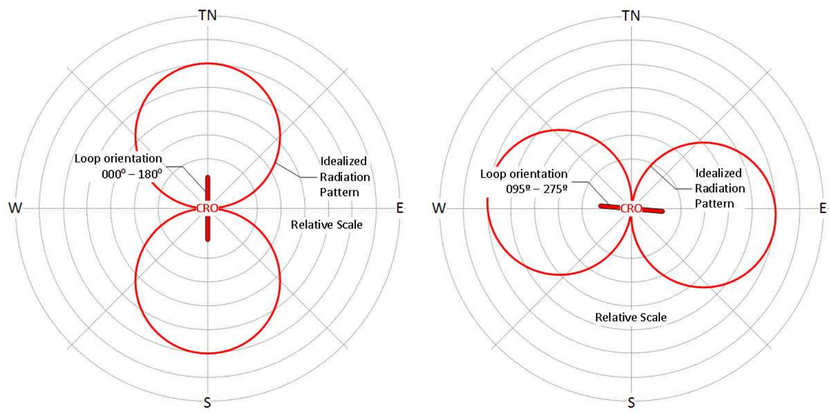
RECEIVER INSTRUMENTATION

Loop Orientation for Measurements



RECEIVER INSTRUMENTATION

Transmitter Stations ~ 13 received at Cohoe

Station	Location	Frequency (kHz)	Distance (km)	Direction (° TN)	Antenna Azimuth	Remarks
JXN	Gildeskål Norway	16.4	5773	007	N-S	Polar
RDL	Russia	18.1				No data
NWC	North West Cape Australia	19.8	12386	263	E-W	Near antipodal
RDL	Russia	21.1				No data
NPM	Hawaii USA	21.4	4390	190	N-S	
JJI	Miyazaki Japan	22.2	6297	277	E-W	
DHO38	Saterland Germany	23.4	7224	014	N-S	Polar
NAA	Maine USA	24.0	5464	068	E-W	
NLK	Washington USA	24.8	2272	113	E-W	
NML	North Dakota USA	25.2	3661	090	E-W	
TBB	Denizköy-Bafa Turkey	26.7	8756	360	N-S	Polar, noise
Unknown	Negev Desert Israel	29.7	9727	355	N-S	Polar, no data
NRK	Grindavik Iceland	37.5	3356	027	N-S	Polar

RECEIVER INSTRUMENTATION

Measurement Schedule ~ 10 Stations

Station	Start Date, Time (UTC)	End Date, Time (UTC)	Antenna
NPM, 21.4 kHz	16 September, 0405	19 September, 0414	N-S
JJI, 22.2 kHz	21 September, 1735	24 September, 1822	E-W
NML, 25.2 kHz	24 September, 1835	27 September, 1955	E-W
NLK, 24.8 kHz	27 September, 1959	30 September, 2007	E-W
NAA, 24.0 kHz	30 September, 2017	03 October, 2343	E-W
NWC, 19.8 kHz	03 October, 2350	07 October, 0001	E-W
JXN, 16.4 kHz	07 October, 0034	11 October, 0035	N-S
TBB, 26.7 kHz	11 October, 0038	13 October, 0337	N-S
NRK, 37.5 kHz	13 October, 0518	16 October, 0533	N-S
DHO38, 23.4 kHz	16 October, 0539	19 October, 1441	N-S

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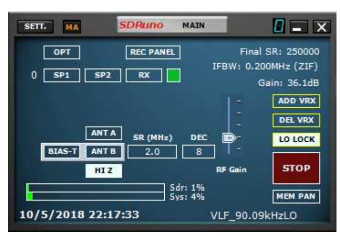
RECEIVER INSTRUMENTATION

Receiver Setup

- RSP2Pro SDR Receiver
- SDRuno Software



Receiver Frequency

Once setup, only need to change receiver frequency and data filename

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RECEIVER INSTRUMENTATION

Basic Receiver Settings

- Sample rate: 2 MHz/8 Decimation = 250 kHz
- Antenna Input: HI Z (1000 ohms balanced)
- RF Gain: 36.1 dB
- Mode: CW, 250 Hz BW
- AGC: OFF
- Noise Blanker: Wide, threshold set experimentally
- Displayed Span: 10 ~ 40 kHz
- Frequency: As required

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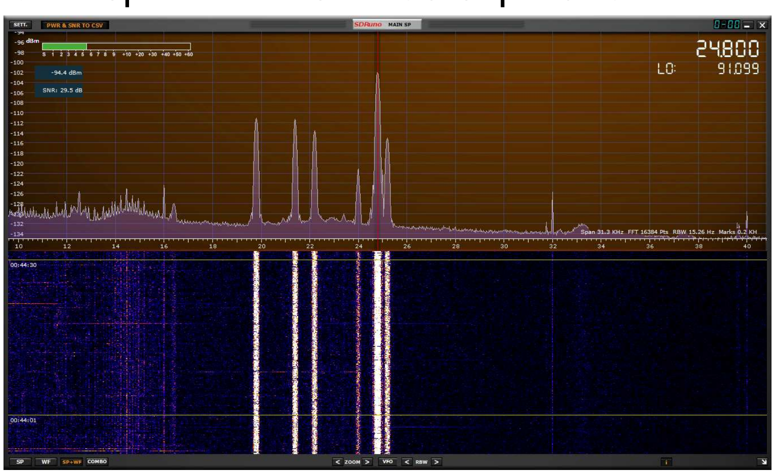
SPECTRUM ANALYSES

Main Spectrum ~ SP1: 30 Sep 2018



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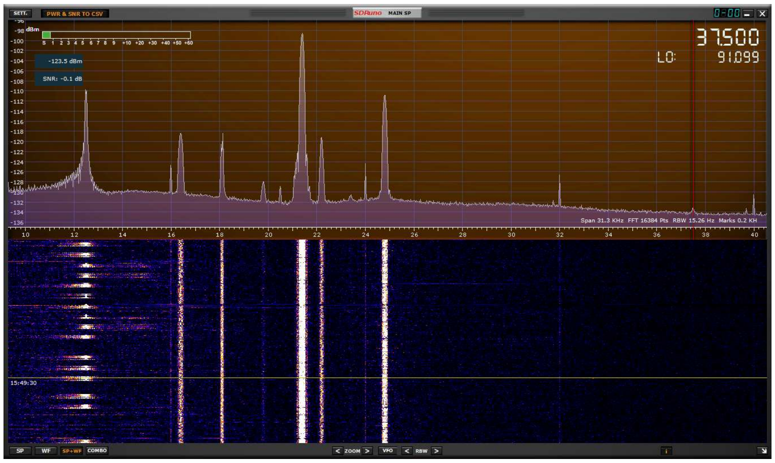
SPECTRUM ANALYSES

Main Spectrum ~ SP1: 15 Oct 2018



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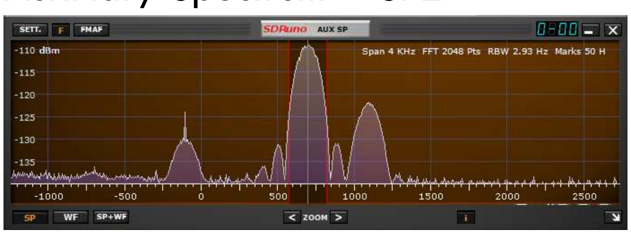
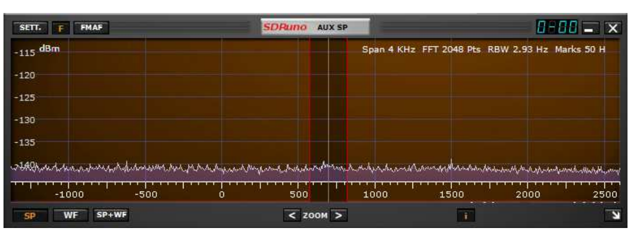
SPECTRUM ANALYSES

Auxiliary Spectrum ~ SP2



Station: NLK
24.8 kHz
Washington



Station: NRK
37.5 kHz
Iceland

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RECEIVED POWER & SNR

Data collected by SDRuno *PWR & SNR TO CSV* function

- Comma Separated Variable, .csv file
  - Each station data file 72 h duration
  - File size ~ 350 kB: 4.9 kB/h
  - 8640+ data points
- Import to Excel
- Plot as X-Y chart type
- Save as .xlsx file

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RECEIVED POWER & SNR

Data collected by SDRuno *PWR & SNR TO CSV* feature

- Date-Time stamp (PC time, UTC)
  - Data interval user selectable
  - Set to 30 s
  - Minimum 1 s
- Frequency (Hz)
- Power (dBm)
- SNR (dB)

Random Data sample from 27 September

Date Stamp	VFO Freq (Hz)	Power (dBm)	SNR (dB)
9/27/2018 19:59	24800	-122.4	0.7
9/27/2018 20:00	24800	-121.2	1.2
9/27/2018 20:00	24800	-122	0.6
9/27/2018 20:01	24800	-122.6	5.4
9/27/2018 20:01	24800	-121.6	2.1
9/27/2018 20:02	24800	-117.2	1.8
9/27/2018 20:02	24800	-123.5	3.2

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RECEIVED POWER & SNR

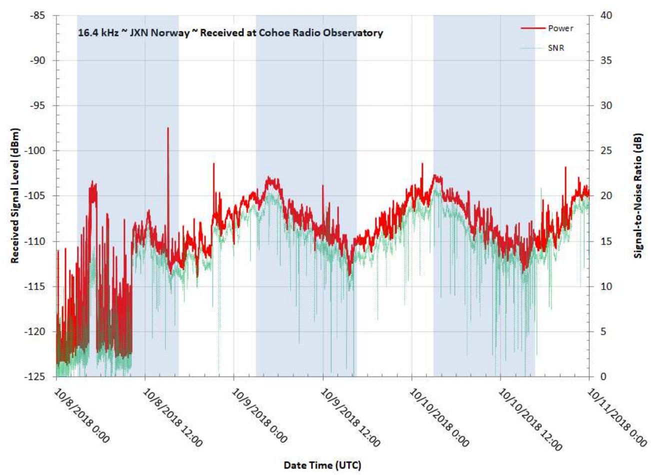
JXN

Norway

16.4 kHz

N-S

5773 km



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RECEIVED POWER & SNR

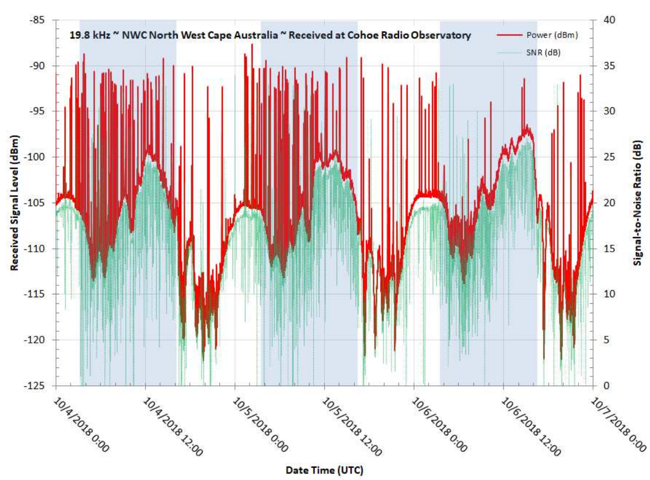
NWC

Australia

19.8 kHz

E-W

12386 km



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RECEIVED POWER & SNR

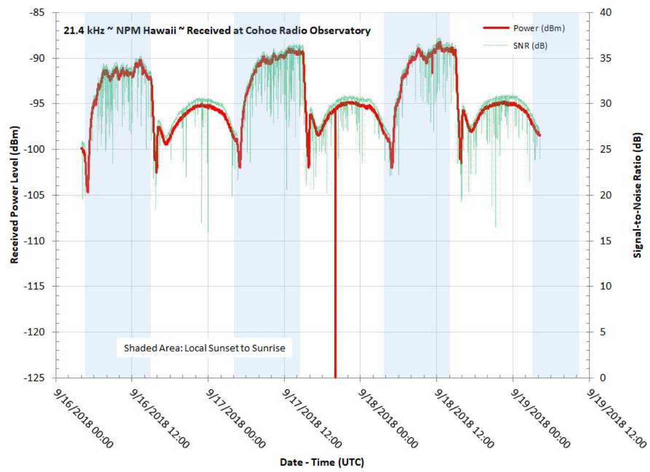
NPM

Hawaii
USA

21.4 kHz

N-S

4390 km



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RECEIVED POWER & SNR

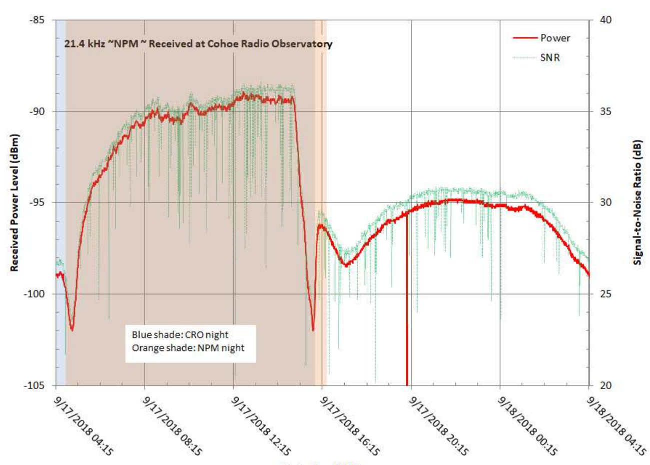
NPM

Hawaii
USA

21.4 kHz

N-S

1 Day



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RECEIVED POWER & SNR

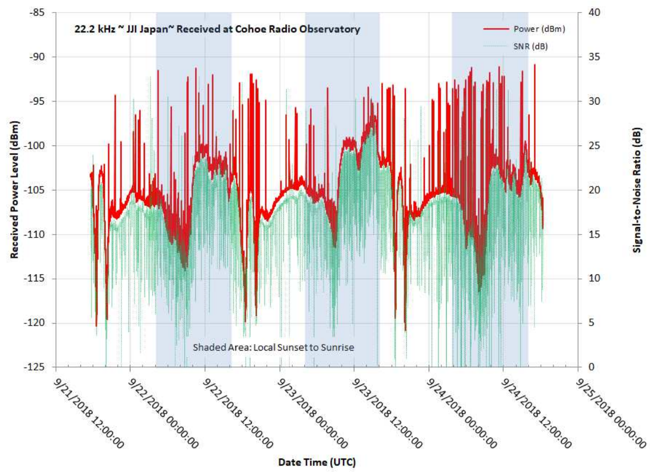
JJI

Japan

22.2 kHz

E-W

6297 km



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RECEIVED POWER & SNR

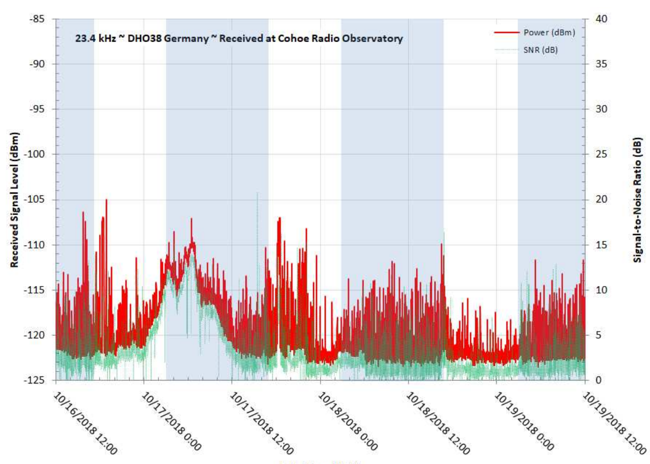
DHO38

Germany

23.4 kHz

N-S

7224 km



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RECEIVED POWER & SNR

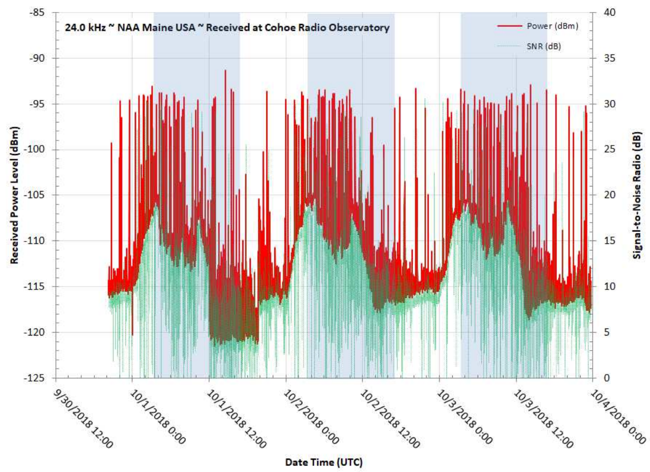
NAA

Maine USA

24.0 kHz

E-W

5464 km



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RECEIVED POWER & SNR

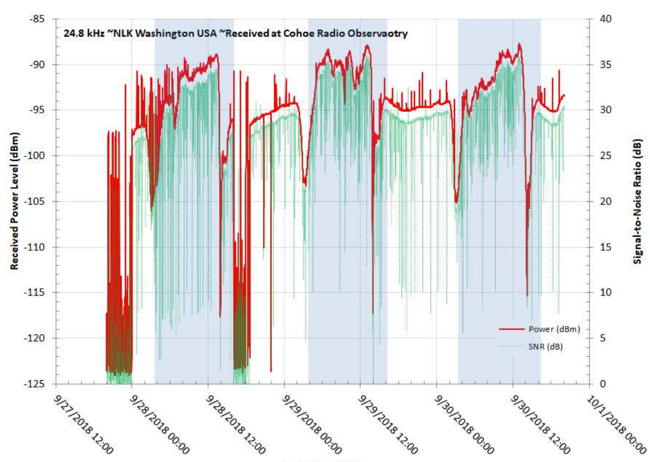
NLK

Washing-ton USA

24.8 kHz

E-W

2272 km



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RECEIVED POWER & SNR

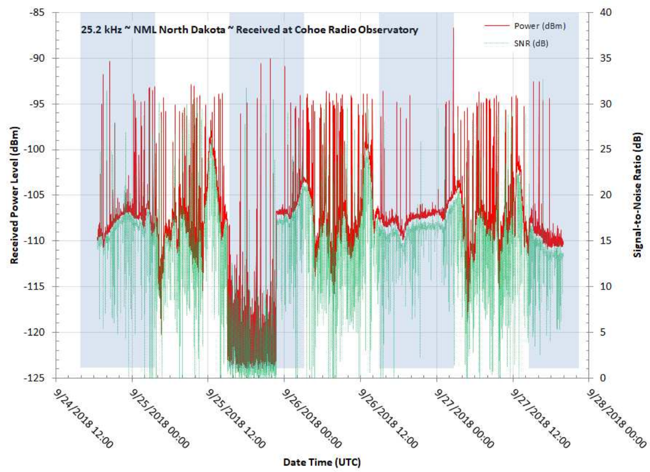
NML

North Dakota USA

25.2 kHz

E-W

3661 km



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RECEIVED POWER & SNR

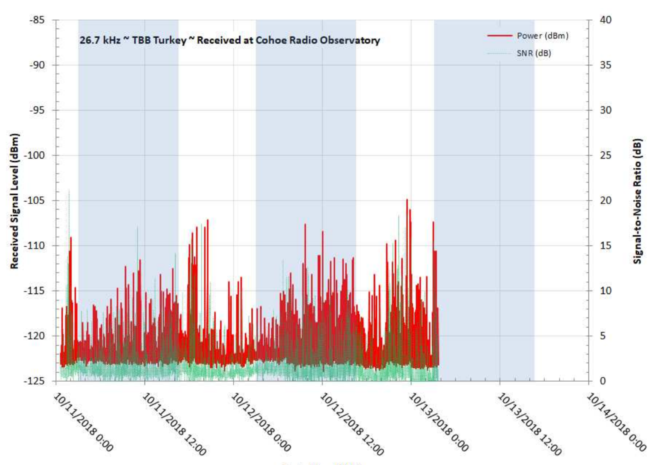
TBB

Turkey

26.7 kHz

N-S

8756 km



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RECEIVED POWER & SNR

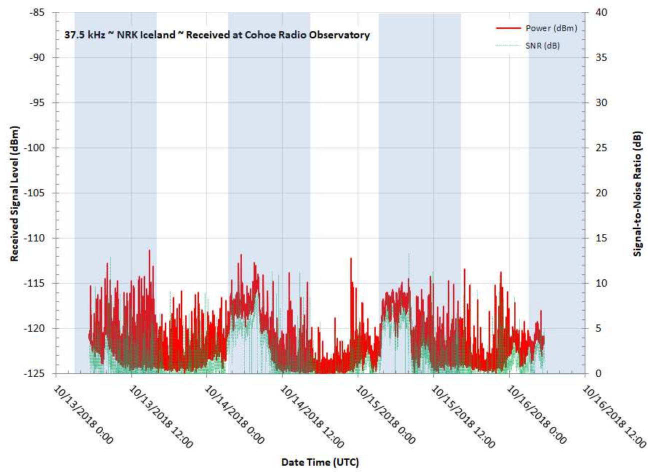
NRK

Iceland

37.5 kHz

N-S

3356 km



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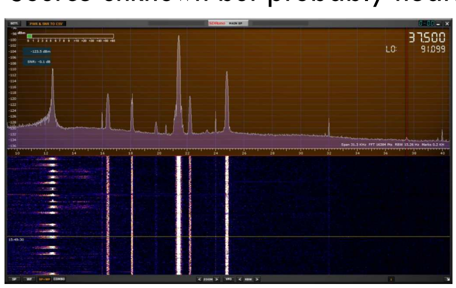
DISCUSSION

Noise

- Background noise about –123 dBm
  - Slightly higher at low end of frequency range
- Impulse noise much higher
  - Source unknown but probably nearby powerlines



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DISCUSSION

Noise

- Minimum Signal-to-Noise Ratio (SNR) for smooth daily plot
  - +30 dB
- Minimum Received Power Level for smooth daily plot
  - –90 dBm Nighttime
  - –95 dBm Daytime
  - Note difference between night and day only 5 dB

DISCUSSION

Improve SNR and Received Power Level

- Loop antenna with larger dimensional area
- Loop antenna with more windings
  - Keep self-resonant frequency above top of desired frequency range
- Change receiver setup
  - Software settings
  - Hardware configuration
    - Antenna
    - Feedline
    - Receiver

DISCUSSION

Improve SNR and Received Power Level

- Lowpass filter between antenna and receiver
- Post-process the .csv data
  - Remove signal samples that exceed a certain threshold
  - Data averaging, running average

DISCUSSION

Environmental Considerations

- Apparent background noise increase of 1 or 2 dB during rain
  - Possibly due to precipitation static
- All loop components and outdoor interfaces rated for outdoor service except antenna windings
- Loop antenna windings exposed to Sun and weather
  - Rain increases distributed capacitance of loop windings (lowers self-resonant frequency)
  - Ultraviolet resistance of coated magnet wire not known

CONCLUSIONS

SDR receiver with loop antenna suitable for low frequency observations

- SDRPlay RSP2Pro hardware
- SDRPlay SDRuno software

Rotatable loop provides most flexibility

Smooth plots achievable with +30 dB SNR

Impulse noise limits recognition of flare signature

PRESENTER

Whitham Reeve is a contributing editor for the SARA journal, Radio Astronomy. He obtained B.S. and M.S. degrees in Electrical Engineering at University of Alaska Fairbanks, USA. He worked as a professional engineer and engineering firm owner/operator in the airline and telecommunications industries for more than 40 years and now manufactures electronic equipment used in radio astronomy. He has lived in Anchorage, Alaska his entire life.

Email contact: whitreeve@gmail.com