An Introduction to Radar and the Super Dual Auroral Radar Network*

(with an emphasis on the Kodiak SuperDARN)

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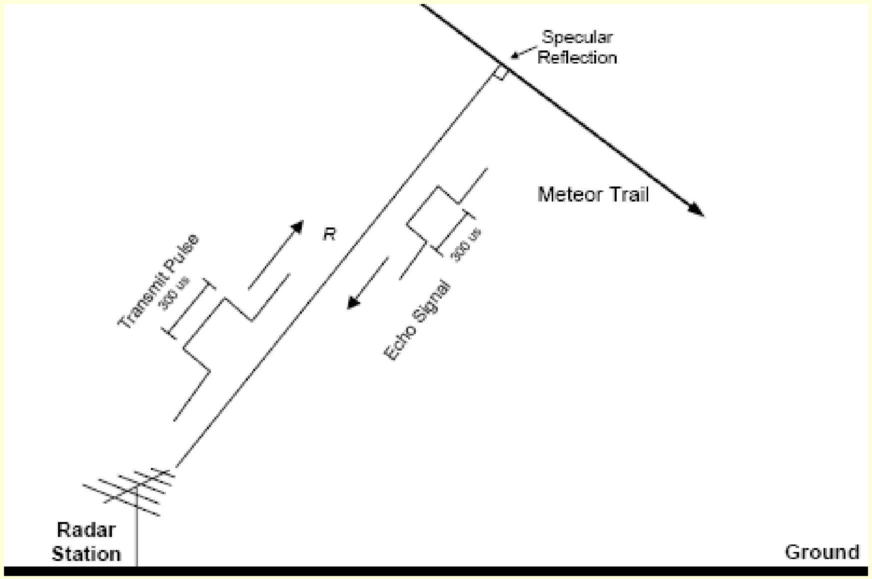
*The intention of this collection of slides is to provide the novice with a self-guided introduction to the Super Dual Auroral Radar Network – what it is and why it is. For those of you who are overwhelmed by any or all of the contents, don't fear. For those of you who find it too basic…too bad! ☺

What is radar?

- RAdio Detection And Ranging
- Radiation of electromagnetic signals for the detection and location of a target
- Three primary parameters are obtained from radar:
  - Range
  - Echo power
  - Doppler shift and spectral width (velocity)

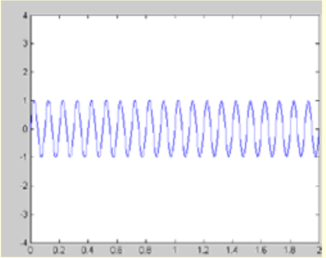
How does radar work?

- Range is determined by measuring the time delay between transmission of an electromagnetic signal and reception of the echo
- Echo power is the power of the received signal at the time of an echo
- Doppler shift is the difference in frequency between the transmitted signal and the received signal

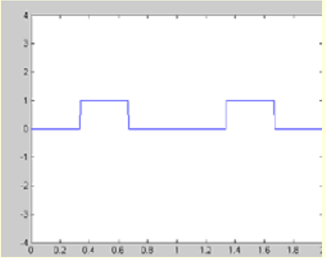


Types of Radar

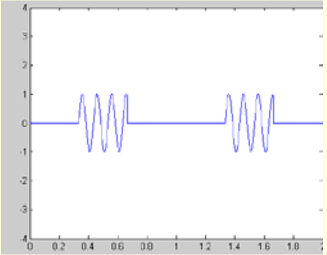
- Pulsed Radar
  - Transmits electromagnetic signals in pulses by amplitude modulating an RF signal with a rectangular function



Continuous Wave.
Frequency f.



Rectangular Modulating Signal.
Pulse width τ. Pulse separation ψ.



Total Pulsed Radar Signal

- Continuous Wave Radar
  - Transmits continuous electromagnetic signals

Types of Scatter

- Coherent Scatter
  - Scatter from a target with some degree of spatial and temporal coherence (correlation over distance and time)
- Incoherent Scatter
  - Scatter from a target with a minimal amount of spatial coherence

Exercise 1

- What is radar?
- What is pulsed radar?
- Name two types of radar scatter.

A Bit about SuperDARN

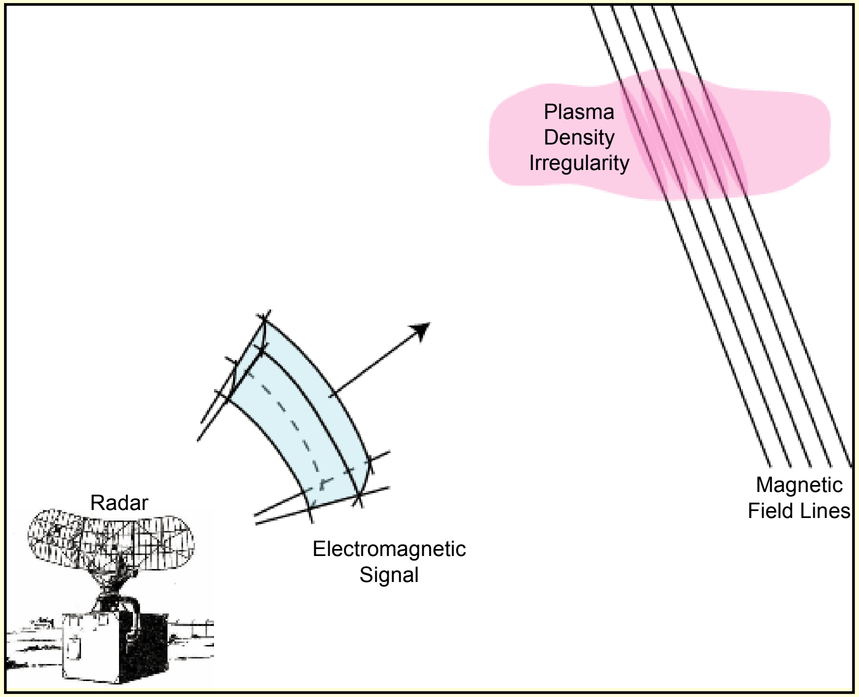
- SuperDARN stands for Super Dual Auroral Radar Network
- Designed primarily for the measurement and study of plasma convection in the ionosphere
- Each radar in the network is of similar design and uses the same operating software
  - 12 radars in the northern hemisphere
  - 7 radars in the southern hemisphere
- The fields-of-view of the radars combine to cover extensive regions of both the northern and southern hemisphere polar ionospheres
- Operate in the HF band, 8-20 MHz
- Pulsed radar
- Transmit a peak power of 9600 W

SuperDARN Fields of View

Northern Hemisphere

Southern Hemisphere

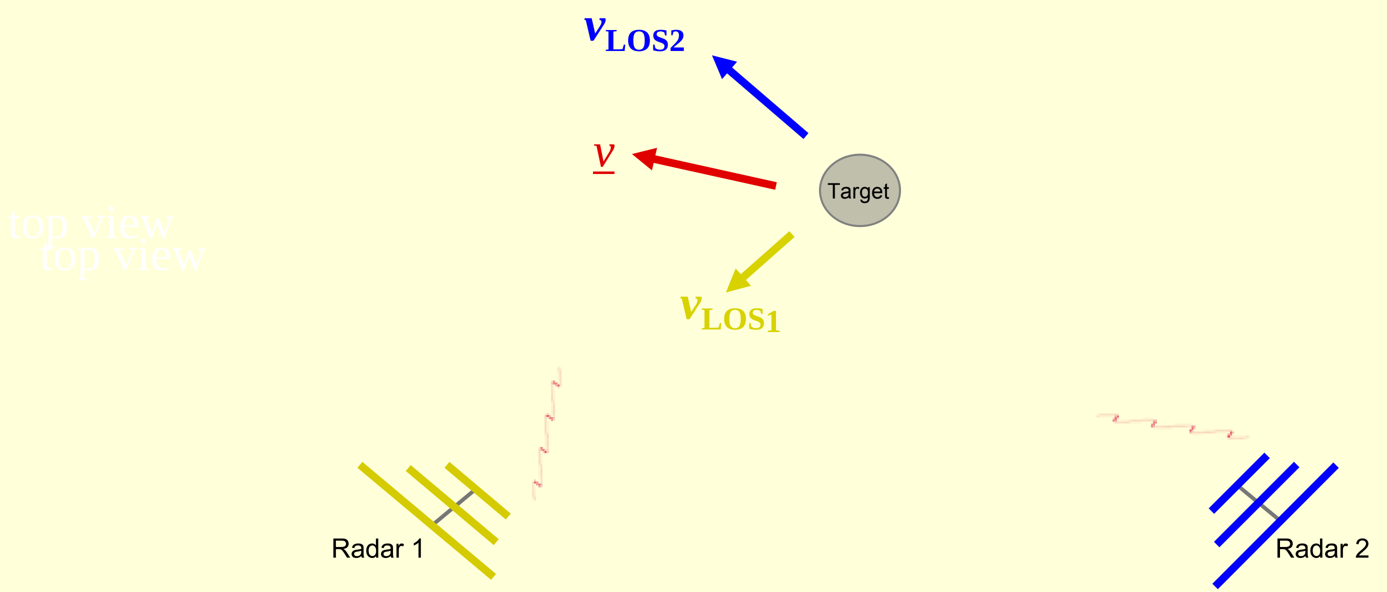
SuperDARN Targets



- The primary target for SuperDARN radars are field-aligned plasma density irregularities in the E and F-regions of the ionosphere
- Plasma density irregularities tend to diffuse along magnetic field lines
- There is some spatial coherence to the irregularities

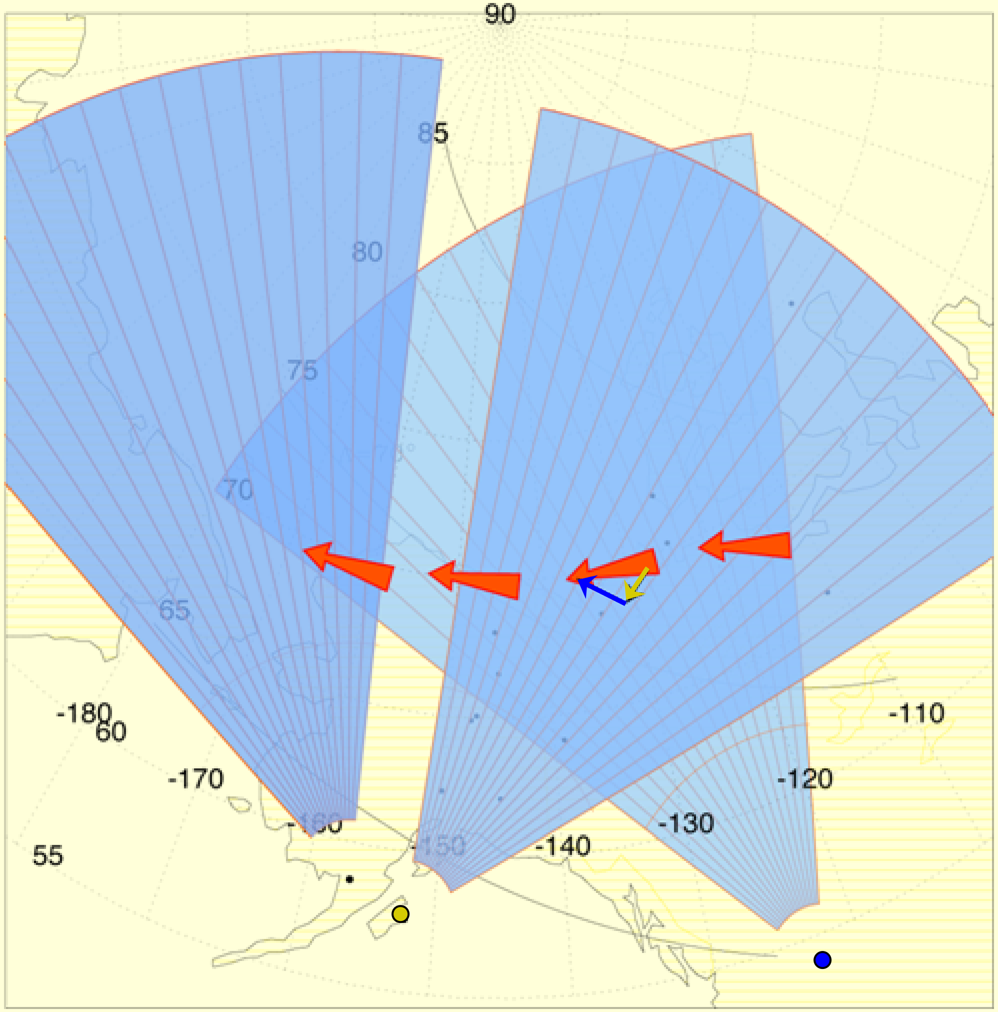
Why do SuperDARN fields of view overlap?

- A single radar gives line-of-sight velocity, v_{LOS}, which is the velocity of a target in the direction towards or away from a radar
- To determine the actual direction that a target is moving, a pair of linearly independent line-of-sight velocities are combined to form the vector velocity, $\underline{v}$, of a target



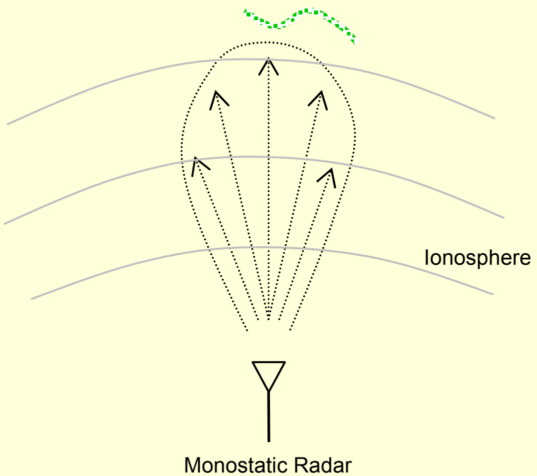
Mapping Convection

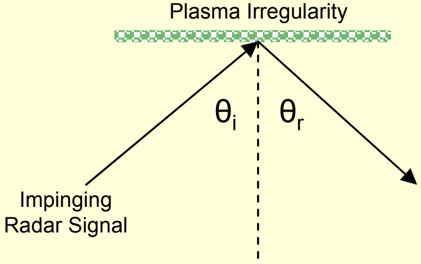
- Radars measure Doppler shifts
- The measurement is the projection of the velocity along a line of sight
- Combining velocity measurements of plasma density irregularities detected by two radars (i.e. yellow and blue arrows) results in a vector velocity (i.e. red arrow)
- Mapping multiple vector velocities displays the movement of the bulk plasma flow in the E and F-regions of the ionosphere



Specular Reflection

- Specular reflection is the reflection of a wave from a surface where the angle of incidence equals the angle of reflection
- Reflection from plasma density irregularities is specular in nature
- A plasma irregularity will only be detected if it is perpendicular to the radial component of the impinging signal





$$\theta_i = \theta r$$

Why High Frequency?

- At high latitudes magnetic field lines are nearly vertical (Figure 1)
- VHF and higher frequencies signals propagate through the ionosphere and out into space (Figure 2)
- At HF frequencies ionospheric refraction causes the signals to become orthogonal to the magnetic field lines and echoes (if any) are directed back to the radar.
- The amount of ionospheric refraction is dependent upon the plasma electron density which varies diurnally, annually, and with geomagnetic activity, therefore, the SuperDARN radars must be capable of operating over an extended HF frequency range

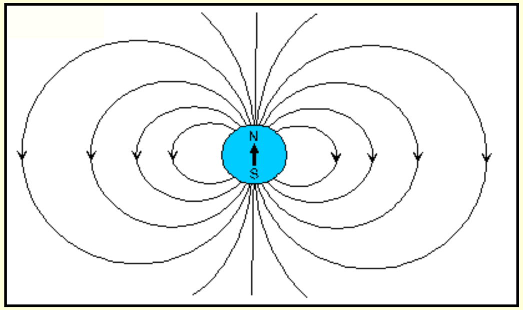


Figure 1. Nearly vertical magentic field lines at high latitudes.

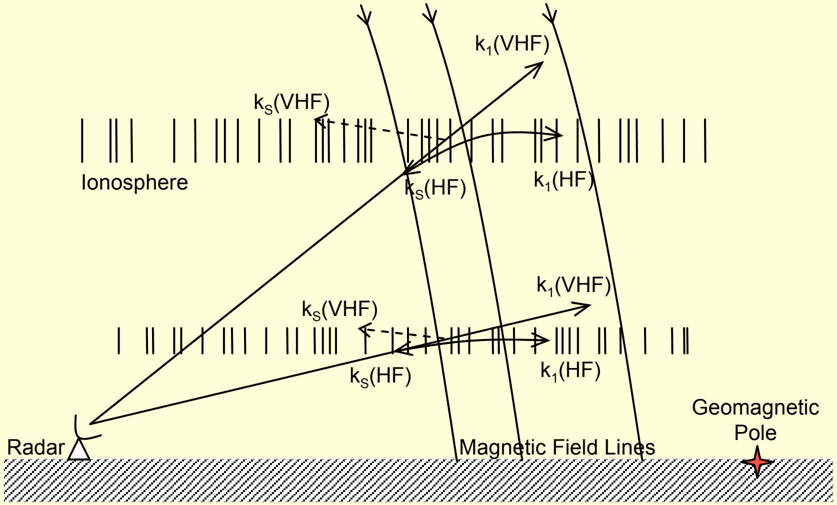


Figure 2. Illustration of ionospheric scattering of VHF and HF frequencies.

Exercise 2

- What does the acronym SuperDARN stand for?
- What is the primary target of SuperDARN radars?
- Is SuperDARN a pulsed radar or a continuous signal radar?
- What is the primary purpose of SuperDARN?

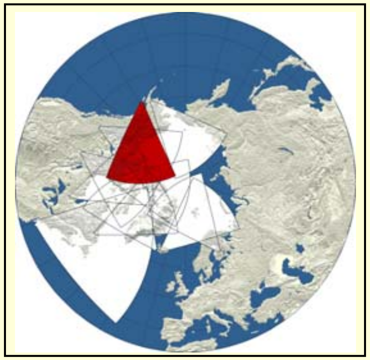
The Kodiak SuperDARN Radar

Operating Institution: Geophysical Institute, University of Alaska Fairbanks
Principal Investigator: Dr. William Bristow

Geomagnetic Coordinates: 57.17˚ N, 96.28˚ W
Geographic Coordinates: 57.60˚ N, 152.2˚ W

The Kodiak SuperDARN Site

Radar Location
Kodiak Island, Alaska



Interferometry (Back) Array

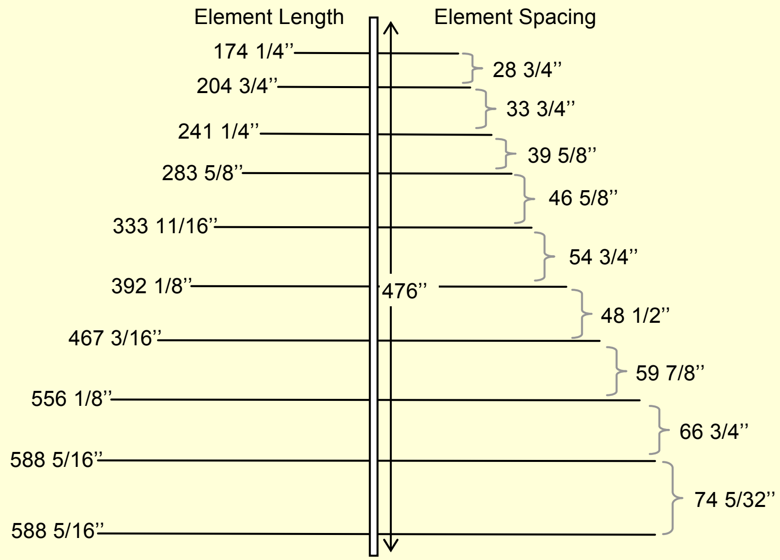
Control Shelter

Main (Front) Array

Inside the Control Shelter

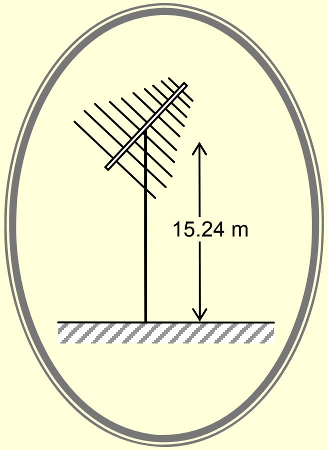
Kodiak SuperDARN Antennas

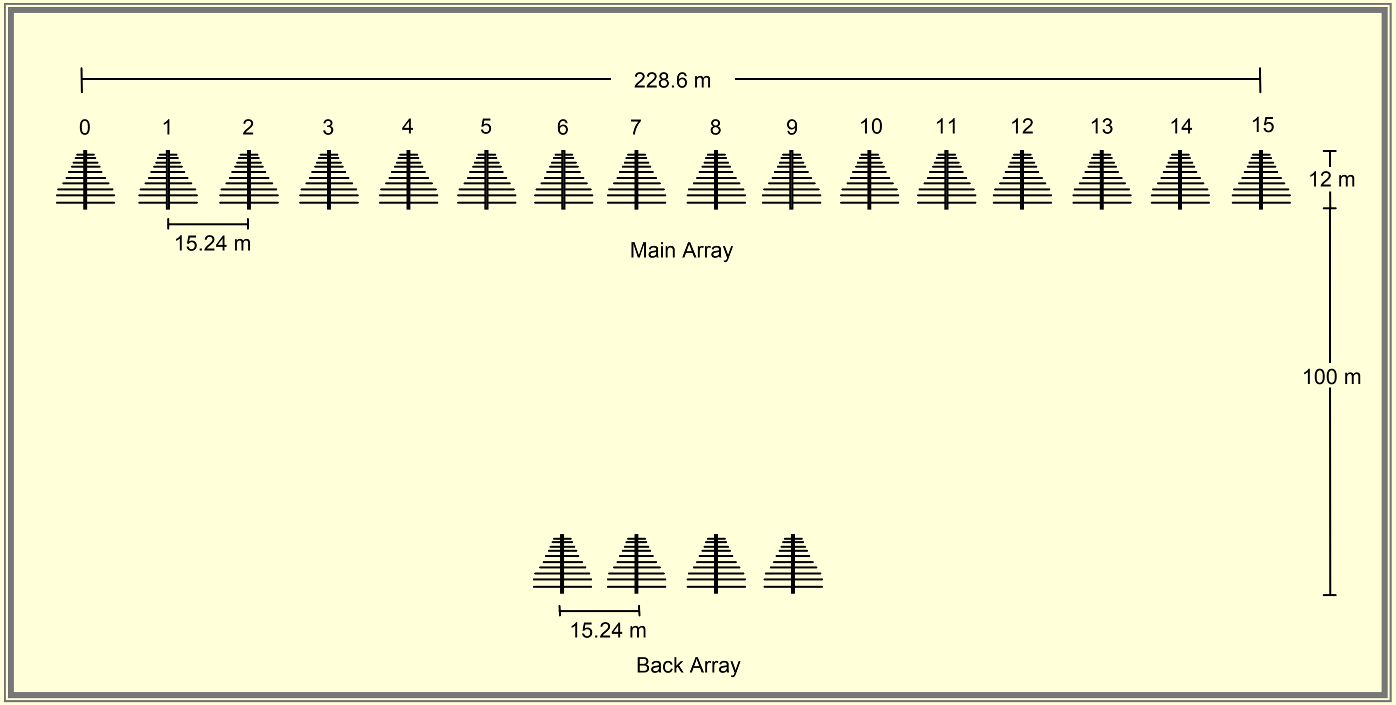
The antennas in both the main and back array are Model 608 log-periodic antennas manufactured by Sabre Communications Corporation



Kodiak SuperDARN Antenna Array

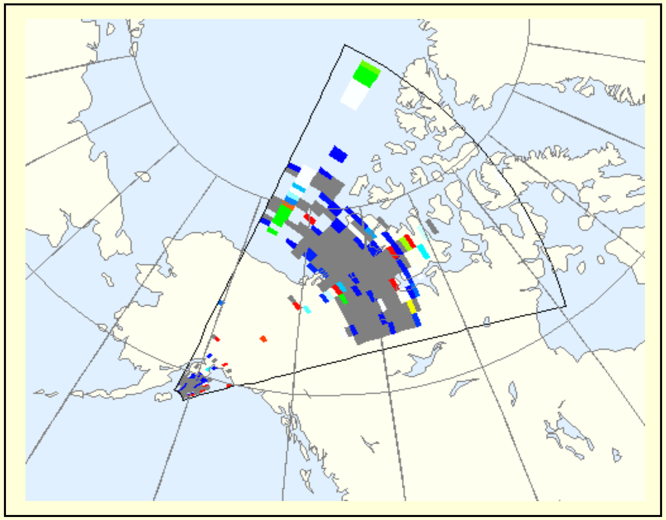
- There are 16 log-periodic antennas in the main array
- The secondary array is 4 log-periodic antennas
- The main array transmits and receives, while the back array is used for receive only
- Antennas stand 15.24 m apart and 15.24 m above ground





Kodiak Array Orientation

- The antenna array is directed approximately poleward
- The beam pattern is narrow in the horizontal direction (~6˚) and broad in the vertical direction (~30˚)
- 52˚ azimuth scan
- Typically 180 – 3555 km range
- Typically 75 range gates of 45 km each



Kodiak Radar Field of View

Kodiak SuperDARN Computers

Master QNX

Hosts operating and data processing software

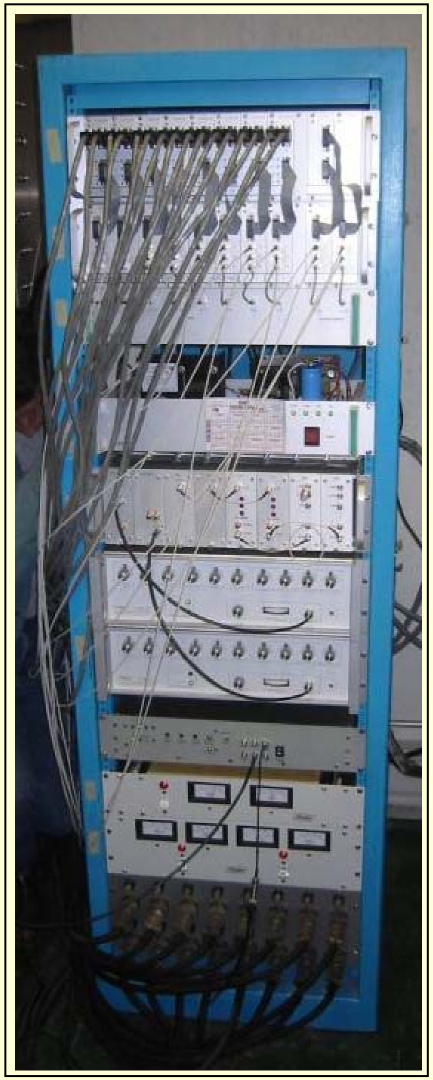
Timing QNX

Controls radar timing signals

Linux Box

Data storage and archiving

The Rack



Distribution of control signals to transmitters

Phasing Matrix

Power Supply

Receiver

Signal Generator

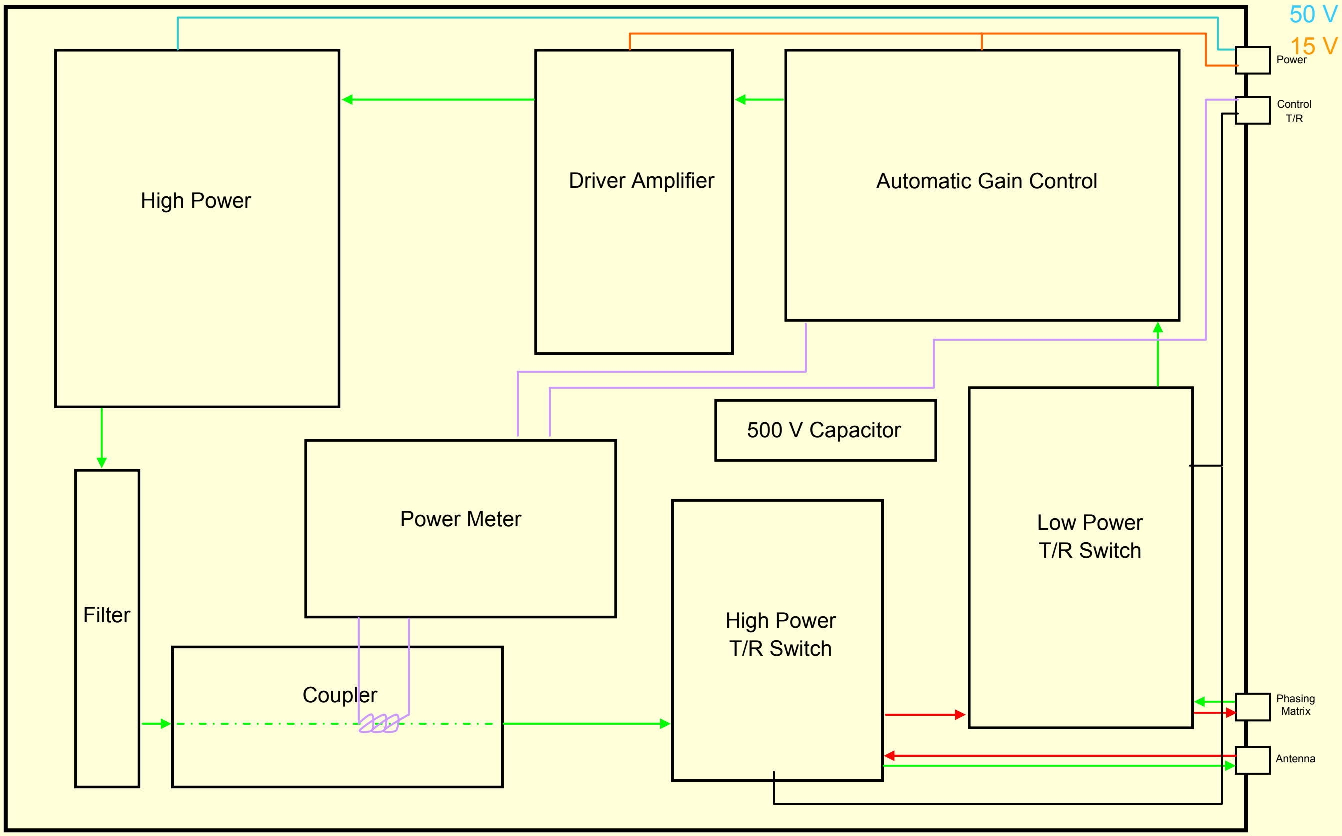
BAS Box

Power Supply

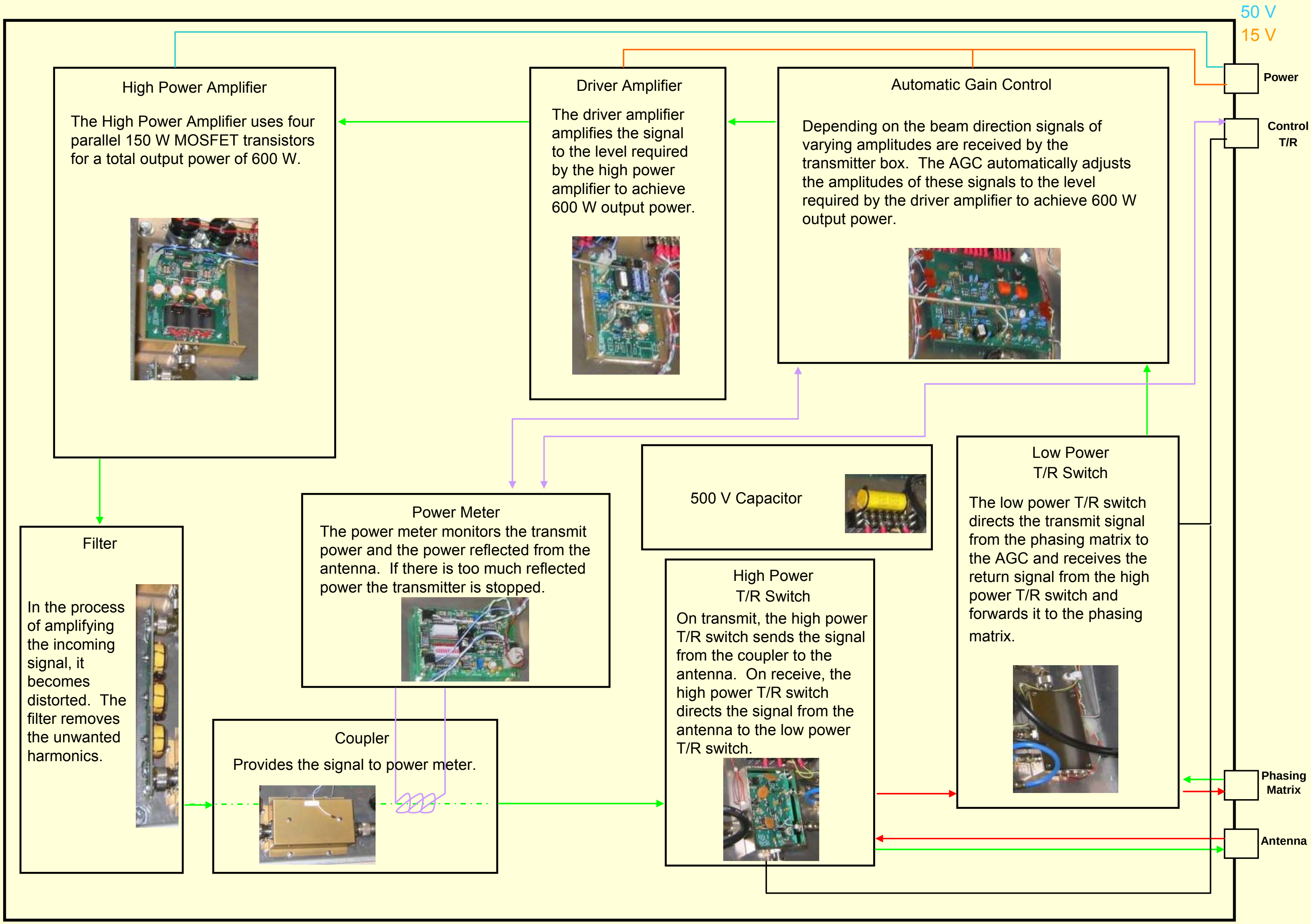
Connector Box

Transmitter Boxes

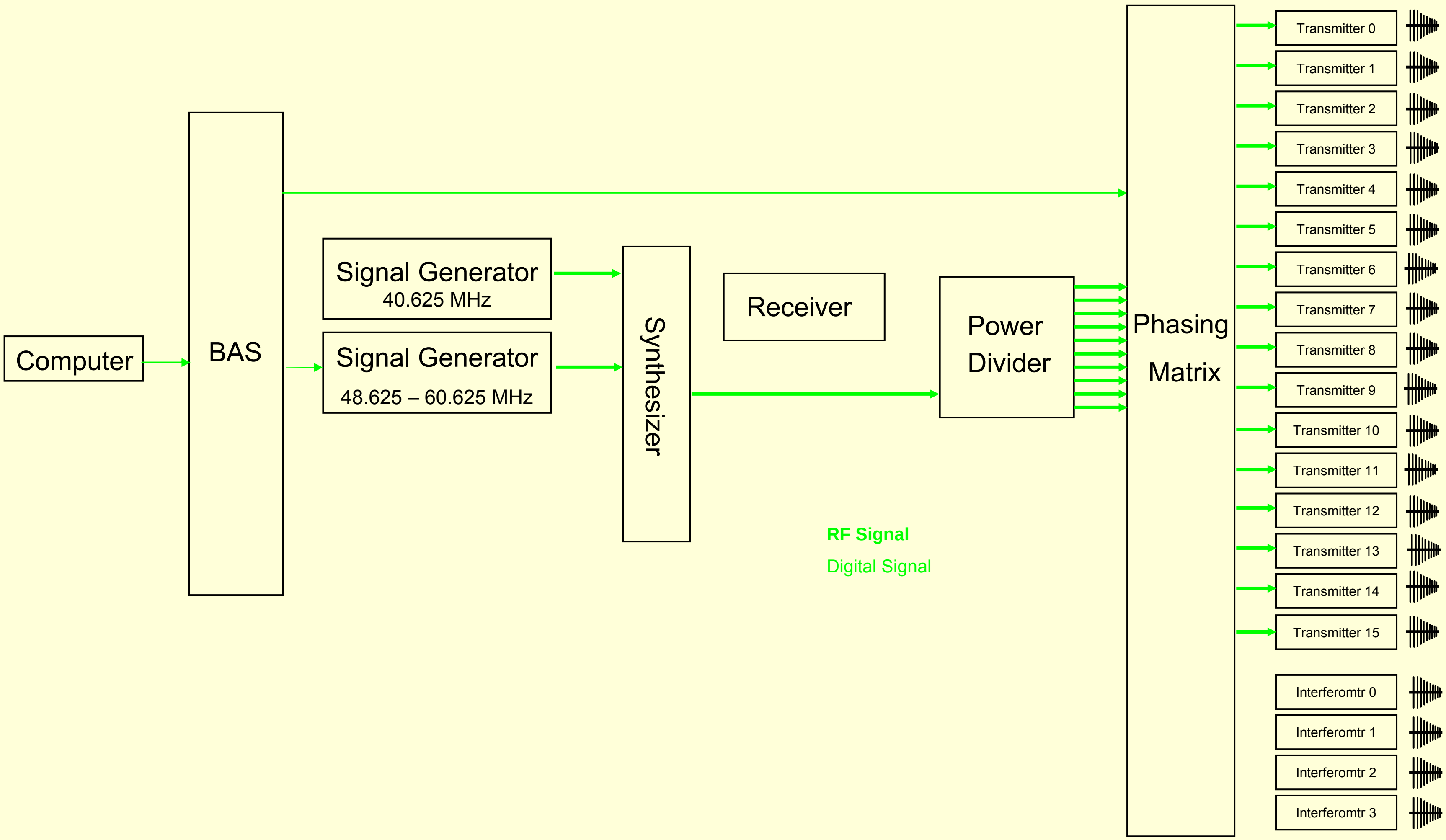
- There are 16 transmitter boxes located at the base of each antenna in the main array.
- Each transmitter is rated for a peak transmit power of 600 W, however the average transmit power is 14.4 W due to the pulse sequence implemented



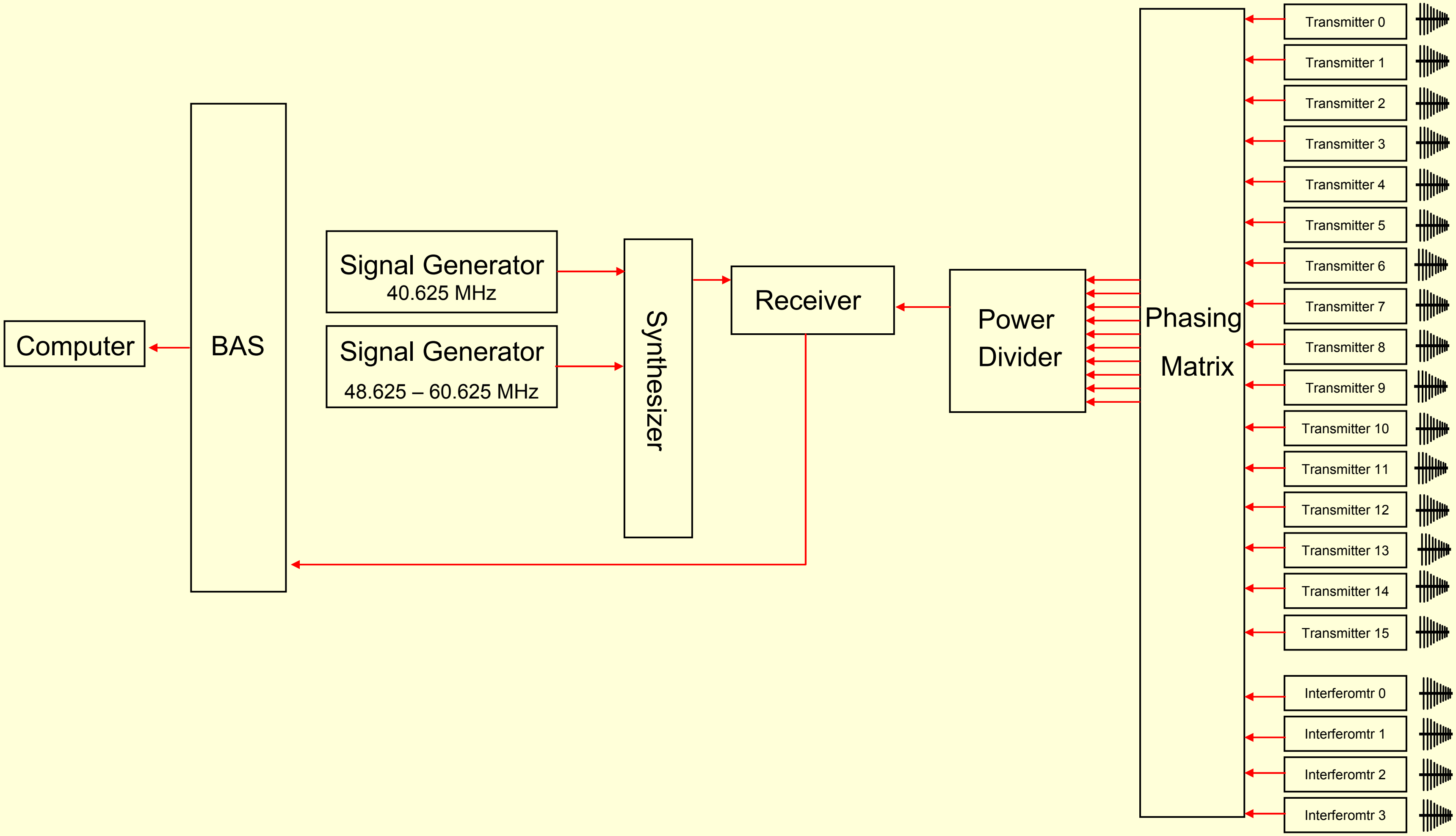
A closer look at the workings of a transmitter box…



Transmit Signal Propagation



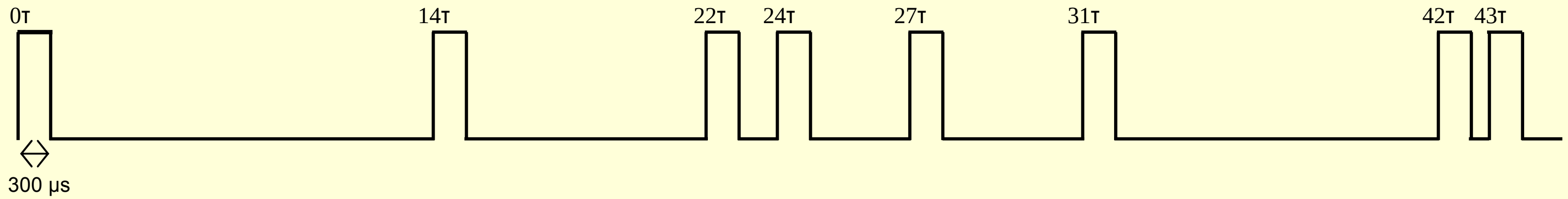
Receive Signal Propagation



Exercise 3

- How many antennas are in the main array of SuperDARN radars? in the back array?
- Do both the main and back array transmit and receive signals?
- What is the maximum range of SuperDARN radars?
- What is the maximum peak transmit power achievable by a SuperDARN antenna array?

SuperDARN Pulse Sequence



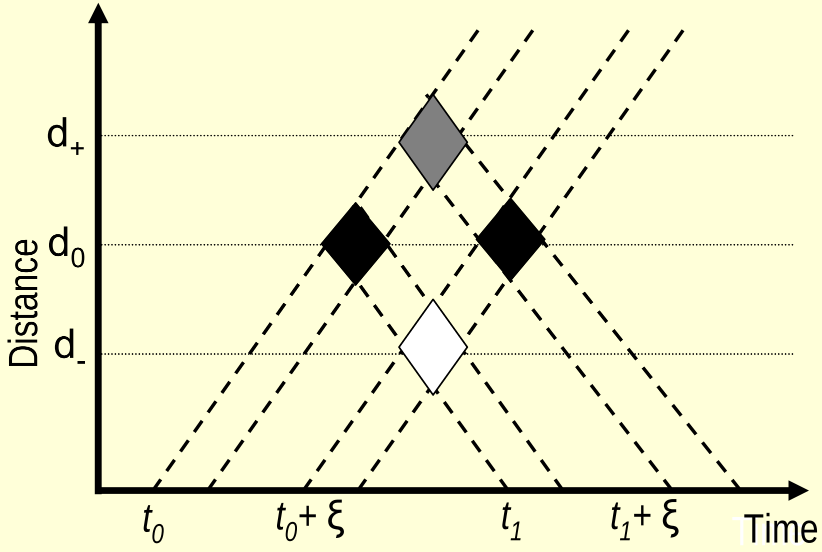
- Each SuperDARN radar transmits a multipulse sequence of unequally spaced pulses, which allows for the discrimination of returns from different pulses at different distances
- The pulses are separated by a multiple of a fundamental spacing τ, which is on the order of 1-2 ms
- Pulse lengths usually range from ~100 - 300 μs providing a range resolution of 15 - 45 km

Autocorrelation and Crosscorrelation Formation

- The goal of most radars is to obtain Doppler shift and spectral width from a received signal and derive range, velocity, and altitude information for a given target
- The autocorrelation function is used to determine line-of-sight velocity of a target
- The crosscorrelation function is used to determine the vertical angle of arrival information of a target

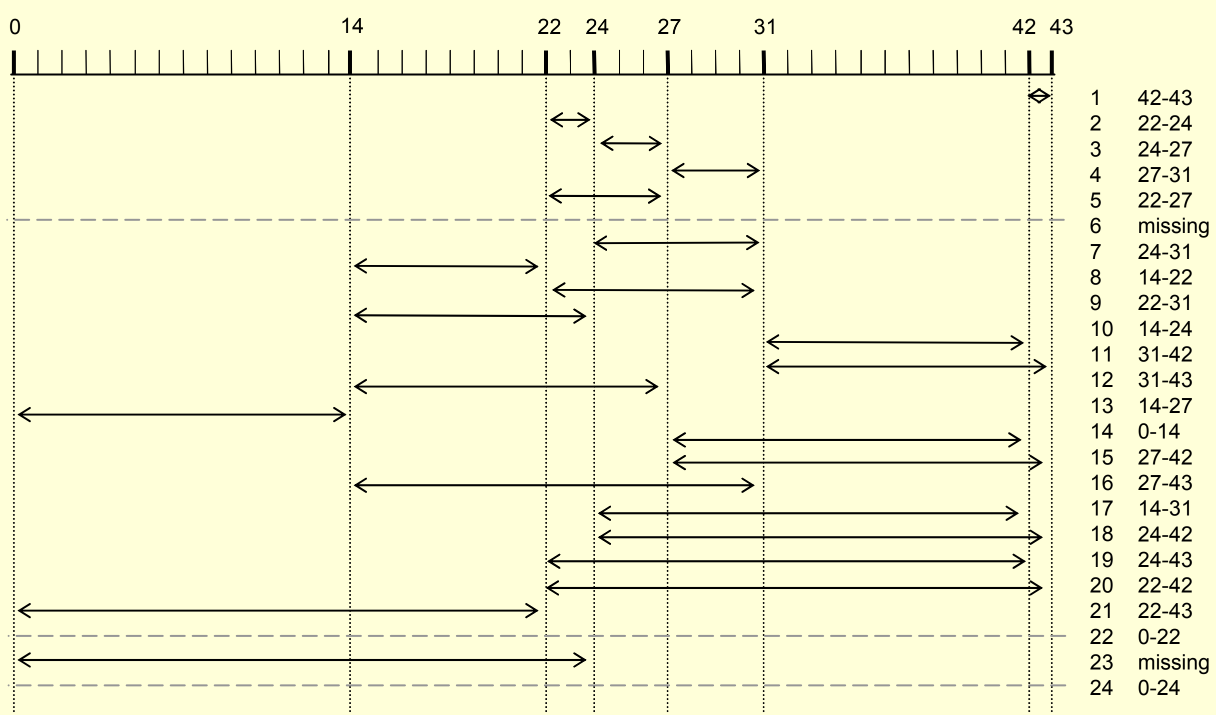
How it works…

- We want to know how much the plasma at distance d_0 has moved in time ξ
  - Transmit pulses:
    - P1 at time t_0
    - P2 at time $t_0+\xi$
  - Receive pulses:
    - P1 from d_0 at time t_1
    - P1 from d_+ at time $t_1+\xi$
    - P2 from d_- at time t_1
    - P2 from d_0 at time $t_1+\xi$
- Amplitude measured at t_1:
  $A(t_1) = A_1(d_0)+A_2(d_-)$
- Amplitude measured at $t_1+\xi$:
  $A(t_1+\xi)=A_1(d_+)+A_2(d_0)$
- ACF at lag ξ :
  $A(t_1)\,A(t_1+\xi) = (A_1(d_0)+A_2(d_-)).(A_1(d_+)+A_2(d_0))$



SuperDARN Lag Chart

- While typically only seven or eight unequally spaced pulses are transmitted per sequence, combining the received signals appropriately produces an ACF with nearly uniform lag spacing
- The example sequence shown below transmits 8 pulses at 0τ, 14τ, 22τ, 24τ, 27τ, 31τ, 42τ, 43τ, and it results in the ability to derive a 24 lag ACF, missing only lag 6 and 23

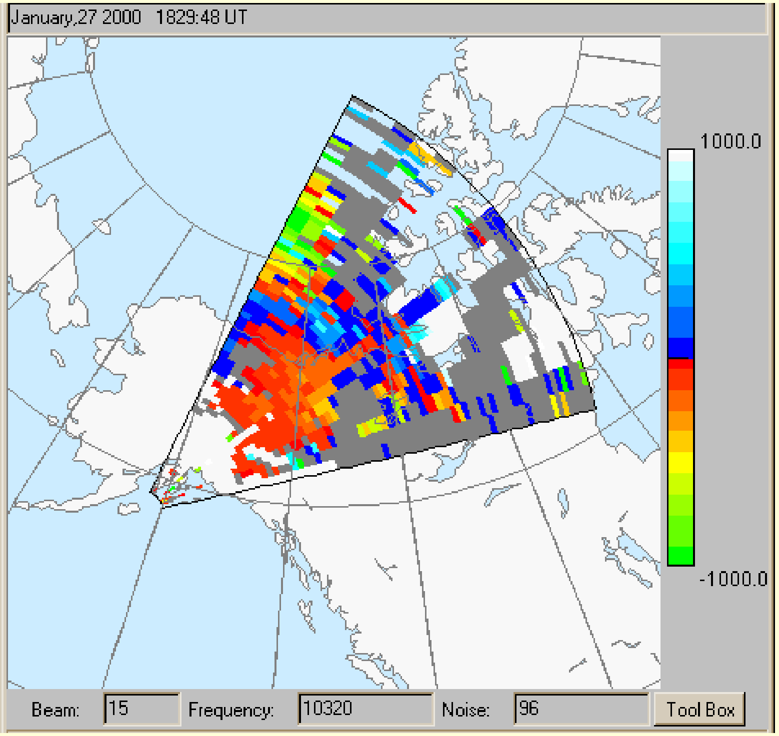


Exercise 4

- Why does SuperDARN use a multipulse sequence?
- What information is derived from an autocorrelation function?
- What information is derived from a crosscorrelation function?

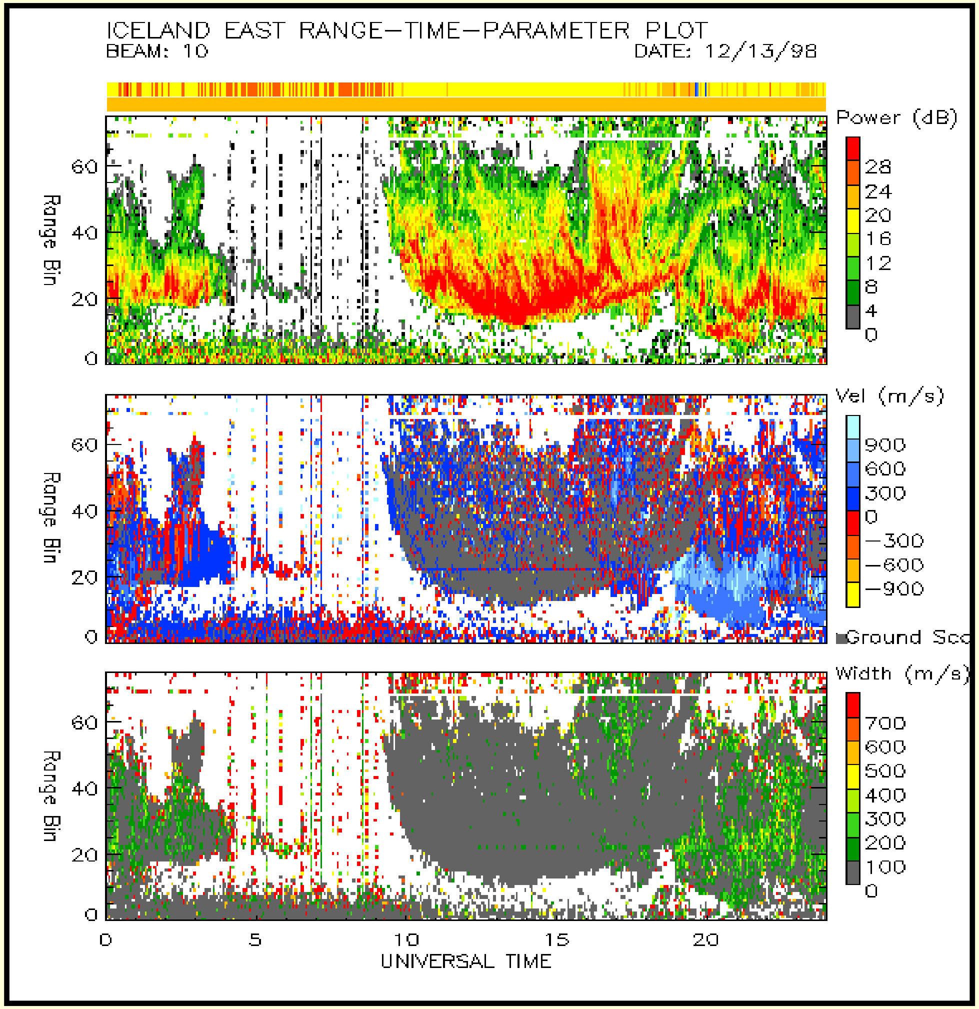
What SuperDARN Radars Observe

- This is geographic plot of scatter as seen by the Kodiak SuperDARN on January 27, 2000 at 1829:48 UT
- The gray region represents ground scatter
- The colored regions depict F-region irregularities moving with the bulk plasma velocity
  - Red and yellow depict velocities moving away from the radar
  - Blue and teal represent velocities moving toward the radar
- Real Time Radar Displays of this sort may be viewed at http://superdarn.jhuapl.edu/java/index.html



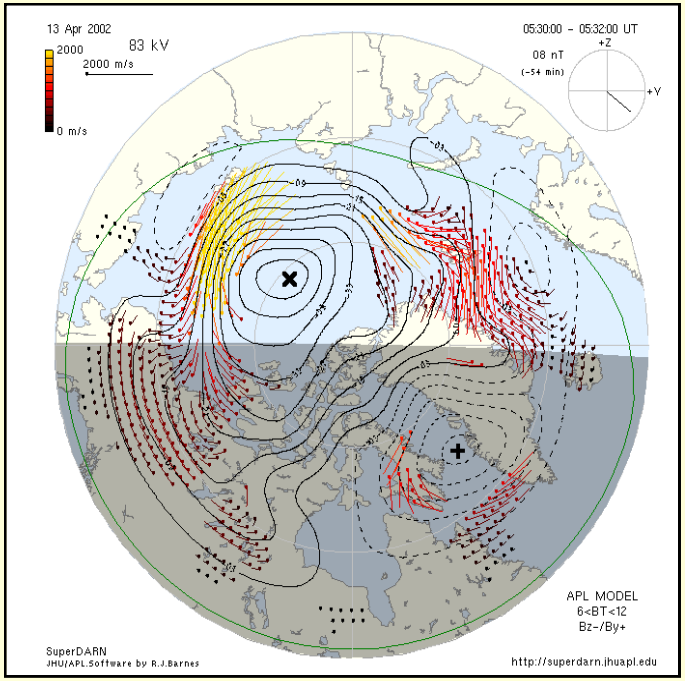
What SuperDARN Radars Observe

- Range-Time-Intensity (RTI) plots show a time series of the scatter observed along a single beam direction
- This capture includes plots on signal power, target velocity, and spectral width over a 24 hour period on beam 10 at the Iceland East radar



Understanding Convection Plots

- Combining multiple vector velocities of plasma irregularities observed by SuperDARN results in the formation of convection plots
- Referring to the plot at right
  - The dayside and nightside of the globe are depicted by the absence of shading and grey shading, respectively
  - The origin of a plasma irregularity detected by SuperDARN radars is depicted by the dots ( ) and the 'tails' point in the direction that the bulk velocity is moving
  - The black lines are equipotential contours that are formed by combining a statistical pattern with raw SuperDARN data and ionospheric data from other sources
  - The green line is called the Heppner-Maynard Line and characterizes the size of the convection zone
  - The 'x' and '+' represent the locations of the extreme potential values and the difference between these two extremes gives the total cross polar cap potential

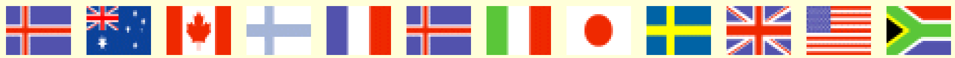


SuperDARN Convection Plot

A Few SuperDARN Research Topics

- Convection dynamics
- Remote Sensing of magnetic reconnection
- Substorms
- Magnetohydrodynamic waves
- Gravity waves
- Planetary waves
- Meteor scatter and Mesospheric winds

Conclusion

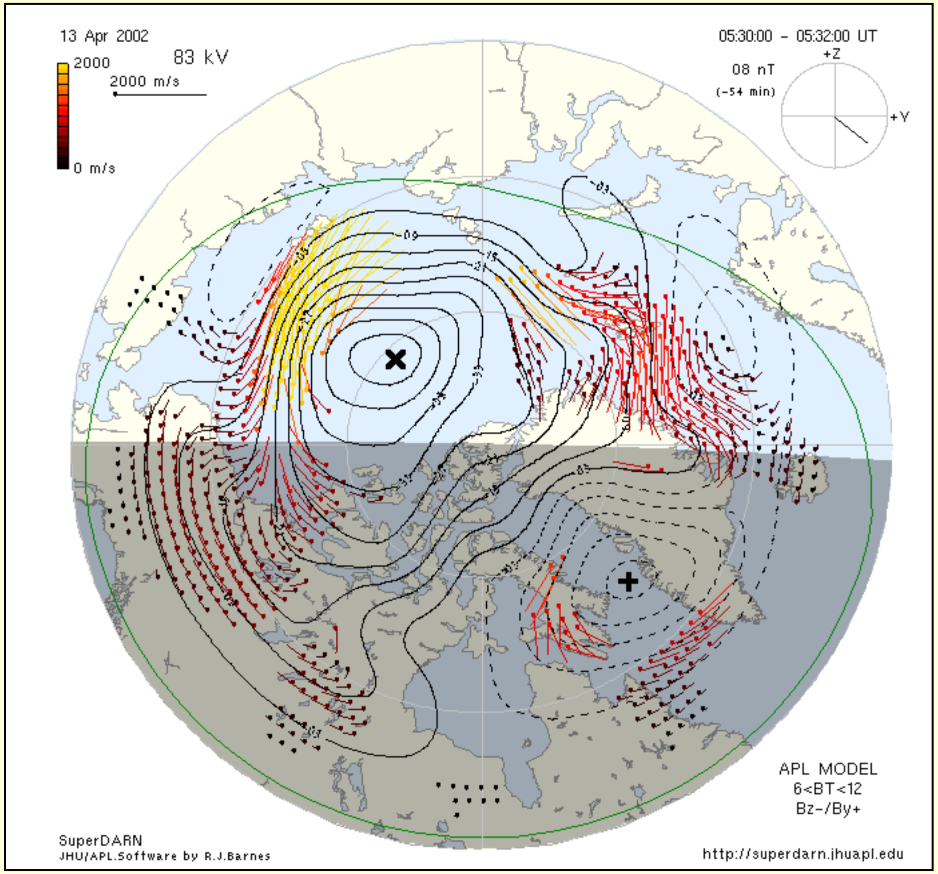


- SuperDARN stands for Super Dual Auroral Radar Network
- It is a collaboration among multiple nations. (see the main SuperDARN website for a listing of the participating institutions. http://superdarn.jhuapl.edu)
- The network was designed primarily for the measurement and study of plasma convection in the ionosphere but its impact on the scientific community has far surpassed the original intent with contributions to studies in the magnetosphere, ionosphere, thermosphere, mesosphere, and general plasma physics
- The fields-of-view of the radars combine to cover extensive regions of both the northern and southern hemisphere high-latitude ionospheres

Exercise 5

Using the convection pattern at right answer the following questions:

- Locate the region in which the bulk plasma velocity was highest.
- What is the cross polar cap potential?
- What is the strength of the Interplanetary Magnetic Field (IMF)?
- What is the orientation of the IMF?



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Exercise Solutions

- Exercise 1
  - *What is radar?* It is an electronic system used to radiate electromagnetic signals for the purpose of detecting and locating a target.
  - *What is pulsed radar?* A radar that amplitude modulates an RF signal with a rectangular function for transmission
  - *Name two types of scatter.* Coherent scatter and Incoherent scatter.
- Exercise 2
  - *What does the acronym SuperDARN stand for?* Super Dual Auroral Radar Network.
  - *What is the primary target of SuperDARN radars?* Field aligned plasma density irregularities.
  - *Is SuperDARN a pulsed radar or a continuous signal radar?* Pulsed radar.
  - *What is the primary purpose of SuperDARN?* To provide a global scale view of the configuration and dynamics of plasma convection in the high-latitude ionosphere.
- Exercise 3
  - *How many antennas are in the main array of SuperDARN radars? in the back array?* 16. 4.
  - *Do both the main and back array transmit and receive signals?* No. The main array transmits and receives, the back array receives only.
  - *What is the maximum range of SuperDARN radars?* 3555 km.
  - *What is the maximum peak transmit power achievable by a SuperDARN antenna array?* 9600 W.
- Exercise 4
  - *Why does SuperDARN use a multipulse sequence?* To prevent range aliasing.
  - *What information is derived from an autocorrelation function?* Doppler frequency and spectral width of received signal, which in turn provides line-of-sight velocity of a given target.
  - *What information is derived from a crosscorrelation function?* Vertical angle of arrival of a target.

Exercise Solutions

Exercise 5

Using the convection pattern at right answer the following questions:

•*Locate the region in which the bulk plasma velocity was highest.* See blue circle.

•*What is the cross polar cap potential?* 83 kV

•*What is the strength of the Interplanetary Magnetic Field (IMF)?* 8 nT

•*What is the orientation of the IMF?* Bz-/By+