

CHAPTER 2

Experimental Setup

2.1 Experimental Facilities

All of the ionospheric heating facilities have high-gain antenna arrays operating at frequencies between 3 and 10 MHz with approximately 50 to 100 MW effective radiated power (ERP). The experimental results discussed in this document are from research conducted in Alaska, specifically at the University of California, Los Angeles's (UCLA's) - High Power Auroral Stimulation (UCLA-HIPAS) Observatory near Fairbanks, Alaska, and at the High Frequency Active Auroral Research Program (HAARP) facility at Gakona, Alaska, 285 km south of HIPAS. Figure 2.1 shows the two heating facilities together with other nearby research sites in Alaska.

The HIPAS Observatory is located at Two Rivers, Alaska, 25 miles east of Fairbanks. It has geographic coordinates of $64^{\circ}52'N$ and $146^{\circ}50'W$. It lies within the auroral oval. The local magnetic field has a dip angle of $76^{\circ}30'$ ($13^{\circ}30'$ from vertical) and a declination of $28^{\circ}02'E$. The magnetic field strength of approximately 0.515 Gauss giving in an electron cyclotron frequency (f_{ce}) of 1.44 MHz at 250 km.

HIPAS has a total output power of 800 kW. The antenna array (Figure 2.2), which consists of eight crossed dipoles 14 m (47') above the ground, is tuned to radiate at either 2.85 MHz or 4.53 MHz. The antennas together have a gain

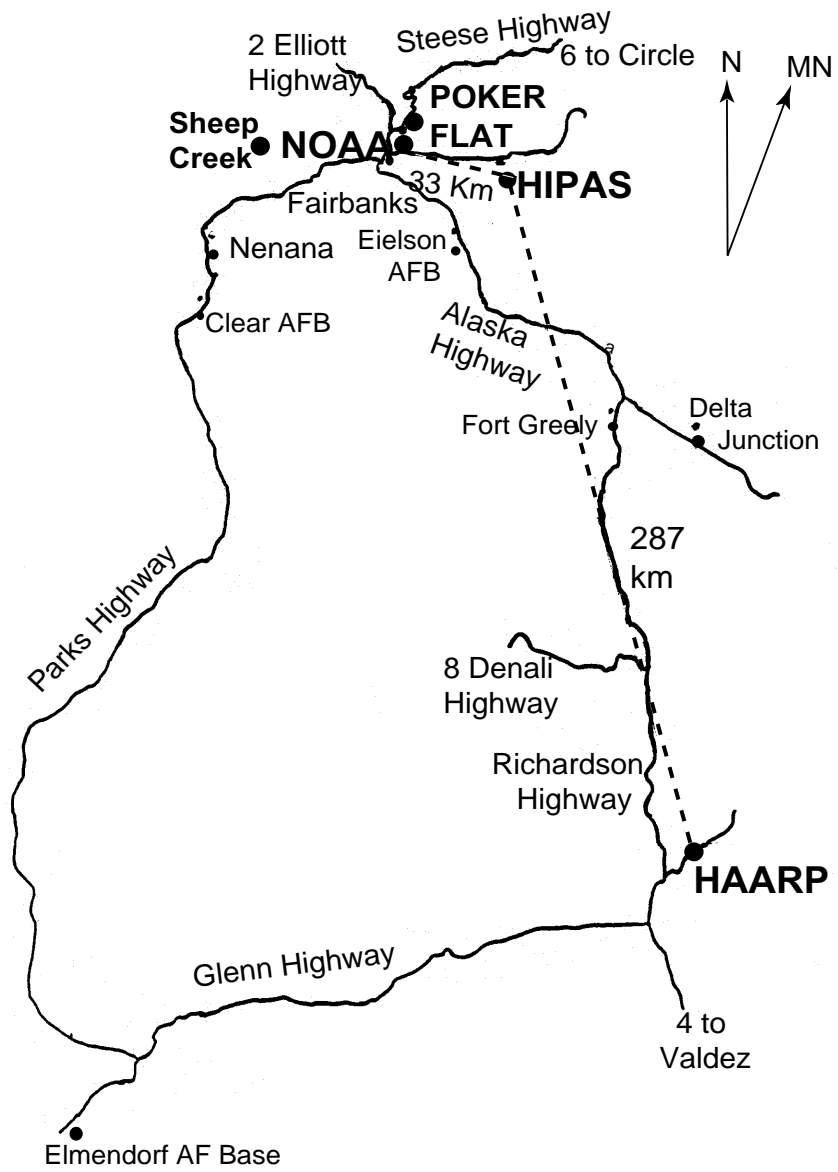


Figure 2.1: Ionospheric Research Site Map.

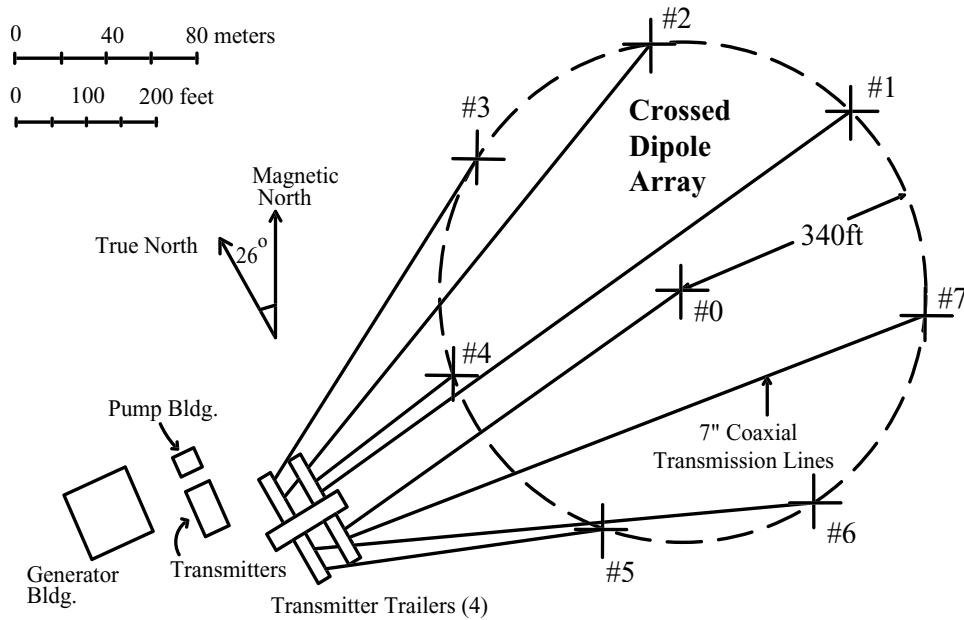


Figure 2.2: (Top) The layout of the HIPAS array with eight crossed dipole antennas field. Each antenna is connected to a transmitter with a total maximum output power of 800 kW.

approximately 18.4 dB intensity (dBi) (17.5 dBi) for frequency at 2.85 MHz (4.53 MHz), corresponding to a full beam width at half power angle of 22° . The characteristics of the transmitter are listed in table 2.1.

Each dipole antenna is connected to its own transmitter, originated from the Platteville facility, which consists of one 4CV100,000 (class C) final and one 3-1000Z (class B) intermediate amplifiers. This transmitter system allows control of the phase of each radiating antenna at the low-level (milliwatt) input to each transmitter. By adjusting the phases of the antennas relative to one another, the EM wave can be pointed towards any desired direction (Figure 2.3). All eight

	Full Power		1 Tx
	2.85	4.53	both
Frequency (MHz)			
Antenna Gain (dB)	18.4	17.5	3
Power (kW)	800	800	45
Effective radiated power (MW)	55.3	40	0.09
Electric field strength at 250 km altitude (V/m)	0.24	0.2	$9.5e^{-3}$
Energy flux at 250 km altitude (mW/m^2)	0.07	0.05	0.0001

Table 2.1: HIPAS operating parameters (Absorption is neglected).

transmitters and their water cooling systems are powered by two 1500 horsepower (1.2 MVA each), 4800-volt 3-phase diesel electric generators. The polarization of the antenna can also be independently configured to radiate in either O-mode (right-circular) or X-mode (left-circular) by reversing the leads on one antenna. Detailed information on the HIPAS facility is available [102].

The reflected HF signals from HIPAS were monitored by a receiver at the National Oceanic and Atmospheric Administration (NOAA) Tracking Facility at Gilmore Creek, 33 km northwest of HIPAS as shown in Figure 2.1. This receiver site is shielded from the transmitted ground wave by mountains. The calculated diameter of the heated region in the F-layer is about 100 km, which is large enough to consider the receiver as lying beneath the heated ionosphere.

The other Alaska heating facility, the High Frequency Active Auroral Research Program (HAARP) (Figure 2.1), is located at Gakona. It has the geographic coordinates $62^{\circ}23.5'N$ and $145^{\circ}3.3'W$. HAARP is managed jointly by the Air Force Research Laboratory and the Office of Naval Research. It is devoted to

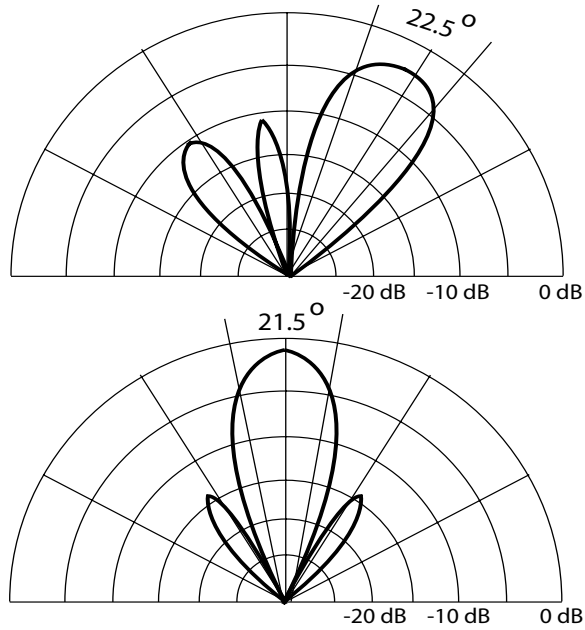


Figure 2.3: (Top) Beam pattern with antennas phased 30 deg off vertical. (Bottom) Beam pattern with all 8 antennas in phase.

the study of upper atmospheric physics and potential applications [74, 63]. The magnetic field strength is approximately 0.504 Gauss at an altitude of 250 km, which would produce an electron gyro frequency of 1.41 MHz. Currently, this array consists of 48 antenna elements, arranged as a rectangular array of 8 columns by 6 rows. Each antenna element is driven by a separate transmitter and has a combined radiated power of 960 kW. All the transmitters are powered by one diesel generator which is rated at 3,600 horsepower and can produce 2,500 kW of electrical power. The HAARP transmitter system with the antenna matching unit can radiate over a frequency band from 2.8 MHz to 10 MHz with antenna gain as a function of operating frequency (see Table 2.2). The antenna beam can

antenna array	6 x 8	
transmitting frequency (MHz)	2.8 – 8.1	
Pointing angle	Within 30 degrees of vertical	
Reposition time	15 degree within 15 microseconds	
Polarization	Left/right Hand circular, Linear	
Frequency (MHz)	2.8	8.1
Net radiated power (kW)	720.0	936.0
Antenna gain (dB)	11.8	22.8
Half power beam widths (N-S plane)	31.9 degrees	11.0 degrees
Half power beam widths (E-W plane)	44.6 degrees	15.4 degrees
Effective radiated power at the center	70.5 dBW	82.5 dBW
Energy flux at 250 km altitude ($\mu W/cm^2$)	0.0014	0.023

Table 2.2: Parameters of the HAARP antenna array.

be pointed at any direction within $\pm 30^\circ$ from the zenith in either circular or linear polarization. In addition, it has the capability of simultaneous transmission at two different operating frequencies.

The HAARP antenna system consists of multiple independently driven horizontal cross dipole elements. Each antenna consists of two upper and two lower cross dipole antennas for operation at the low frequency (2.8 – 7 MHz) and the high frequency (7 – 10 MHz), respectively. The dipoles are mounted to an aluminum tower 72 feet high which is supported at the base by a thermopile for reliable and long-lasting stability. A wire mesh ground screen is attached mechanically and electrically to the tower at a height of 15 feet above the ground.

2.2 Diagnostics Techniques

2.2.1 HF Receiver

Two types of HF receivers were used at different stages in this project, a narrow band (8 kHz) HF receiver (Figure 2.4) for monitoring the skywave and a wide band (125 kHz) HF receiver (Figure 2.5) for monitoring the SEE. The receiver was set up at the NOAA Tracking Station at Gilmore Creek, Alaska, approximately 34 km northwest of the HIPAS Observatory (see Figure 2.1). The receiving antenna was an efficient T-shaped broadband double Bazooka antenna (Figure 2.4b) built along the hillside and did not require a balun. This antenna consists of a coax (RG58) cable with its shield removed at the center. The feedline was attached directly to the two open ends and acted as a half-wave dipole along with the open wire end sections. Since the antenna had no exposed metal wire, static charges could not accumulate. Noise is reduced by ~ 6 dB in comparison to antennas constructed of exposed wire.

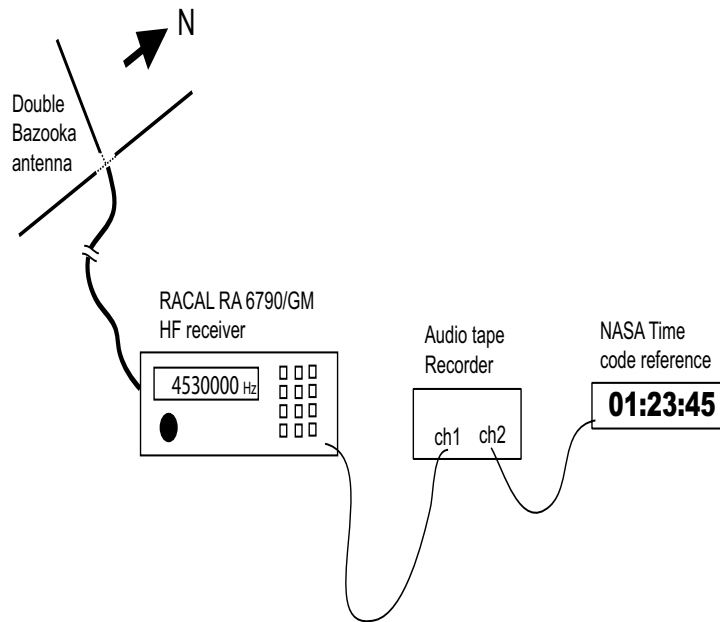


Figure 2.4: Setup of the narrow band (8 kHz) HF receiver for monitoring the skywave.

The double Bazooka antenna was connected to an indoor receiver via an RG-8 cable to minimize loss. The input was then connected directly to a RACAL HF radio receiver, model RA6790/GM, a solid-state receiver fully synthesized, microcomputer-based, tunable, and designed for a frequency range of 0.5 MHz to 30 MHz. It was capable of either automatic RF gain control (AGC) or manual control of the AGC threshold within the range of 0 to 110 dB above the preset. Manual mode was chosen for our work to detect the amplitude fluctuation of the reflected skywave with a frequency tuning resolution of 1 Hz. The receiver had seven built-in IF filters; we used an 8 kHz bandwidth filter to eliminate aliasing signals. The audio output was recorded on a digital audio tape through a phone

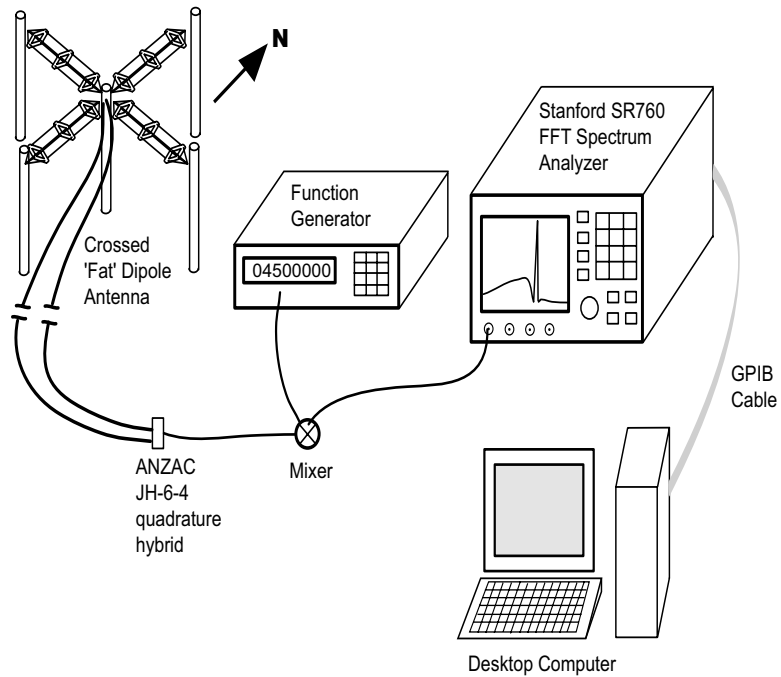


Figure 2.5: SEE receiver setup.

jack connector. An external 1 MHz reference signal was fed into the RACAL for timing accuracy. The second channel simultaneously recorded the NASA time code reference.

2.2.2 SEE Receiver

A wideband (125 kHz) receiver was used to monitor the SEE signals from the heated region. The whole receiver system (Figure 2.5) included a cross “fat” dipole antenna (see Figure 2.6), a frequency generator, a Stanford SR760 FFT spectrum analyzer, and a Pentium II desktop computer. The “fat” dipole antenna

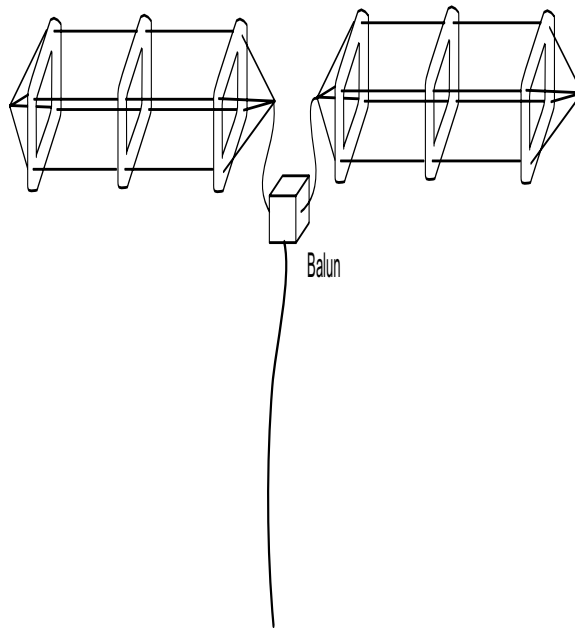


Figure 2.6: Fat dipole antenna.

was 19 m long and consisted of a ‘bundle’ of 4 wires, spaced approximately 30 cm apart, was easy to assemble and thus portable. The center of each dipole was fed to a 4:1 impedance ratio voltage balun. The cross dipole was aligned along the magnetic north-south and east-west directions. Signals from the two baluns were combined through an Anzac JH-6-4 quadrature hybrid and then mixed with an IF signal from the HP3253A function generator. At a frequency either 50 kHz or 60 kHz below the pump frequency and an amplitude of -10 dBm. The mixer output was connected to the SR760 spectrum analyzer.

For our work, the SR760 spectrum analyzer was set to have a frequency span of 100 kHz with a resolution of 250 Hz. The SR760 has a dynamic range of 90 dB and a digitizing rate of 256 kHz for its 16 bits A/D. The analyzer has a

built-in digital filter which filters and heterodynes the input in real time. The SR760 offers four types of windowing functions. The Hanning window which is the most commonly used window with amplitude variation of about 1.5 dB was used throughout the project. The SEE spectra shown in the following chapters are averages over 10 spectra with equal weighting in RMS to reduce fluctuations. The SR760 was automated by a personal computer via GPIB. The processed data was saved in the same computer.

2.2.3 Background Diagnostics

An ionosonde is a basic device used to measure the ionospheric electron density distribution. A series of short pulses are transmitted upward to the ionosphere, and then reflected from a layer whose local plasma frequency, $\omega_p = (4\pi n_e e^2 / m_e)^{1/2}$, equals the incident wave frequency. The reflected pulse is recorded by a receiver after a time delay equal to the total time of flight of the pulse, t . Giving the pulse propagation at the speed of light, the virtual height, h' , can be obtained by $h'(f) = 1/2ct$. Since the pulse is traveling in a plasma media, the speed of the pulse is smaller than the speed of light. The value of the virtual height obtained from the above equation is thus greater than the true height. A plot of the virtual heights versus the corresponding frequencies is called an ionogram [49].

A vertical-incidence ionosonde, the Lowell Digital Ionospheric Sounding System (DISS), operated by the Air Force Space Forecast Center at Sheep Creek, about 50 km west of HIPAS is available through a 1200/2400 baud modem connection. It has a fixed probing time interval and frequency range, which provide the general information on the density profile and the peak frequencies of the ionospheric F1, F2, and E layers every 30 min. Another digital sounder, the Lowell Digisonde model DPS-4, located at the HAARP facility, is accessible via

internet connection. The ionogram at the HAARP facility is updated every 15 min.

A Stanford Research Institute (SRI) digital ionosonde located at the NOAA facility can be accessed and initialized through an internet connection. When performing experiments at the HIPAS facility, the SRI ionosonde is set to sound every 10 minutes to provide the ionospheric background condition at the receiving site.

The critical frequencies of the ionospheric E and F layers are influenced by the solar activities. When sunspots appear on the surface of the sun, strong magnetic fields may be detected on earth. During a magnetic disturbance, additional currents circulate in the ionosphere, especially at high latitudes, and concentrate along the auroral field lines. Enhanced ionization in the ionosphere causes stronger absorption in the E and D-regions. Both sunspots and solar flares can greatly enhance ionospheric ionization [16]. Hence, both magnetic and solar information is needed to predict the ionospheric conditions and to determine the parameters in the experiments.

A magnetometer is an instrument for measuring the strength and direction of magnetic fields on or near the Earth surface and in space. Using magnetometer data, one can track the current state of the geomagnetic conditions including the magnetic fluctuations due to auroral substorms and magnetospheric storms. A riometer is a device using cosmic radio noise to measure ionospheric absorption. This cosmic noise absorption has a sidereal variation from the changes in the ionization and the condition of the upper atmosphere. Thus by monitoring the background cosmic noise intensity on the ground, we can observe disturbances in the ionosphere, which often reflect auroral events at higher latitudes. The magnetometer and riometer data are collected at both the High Latitude Monitoring

Station (HLMS) at Elmendorf Air Force base near Anchorage and at the United States Geological Survey (USGS) College station as a part of the Space Environment Laboratory Data Acquisition and Display System (SELDADS) database. The daily summaries of ionosphere and solar geophysical activities are available on the internet (<http://www.sec.noaa.gov/forecast.html>). In addition, the HLMS has a 50 MHz single beam radar that measures reflections from the auroral structures in the E-region. It covers the distance from the Anchorage station to approximately 100 miles north of HIPAS, ~ 1200 km from the radar (Figure 2.7) .

The Super Dual Auroral Radar Network (SuperDARN) is an international collaborative program for scientific investigation of the upper atmosphere, ionosphere, and magnetosphere. It is a network of high-frequency radars for studying the Earth's ionosphere. The SuperDARN consists of HF radars in the northern and southern hemispheres. Three radars within this network observe the Alaska sector, Kodiak and King Salmon in Alaska, and Prince George in British Columbia. The HAARP facility is centered in the Kodiak field of view at about 650 km range. Each radar's azimuthal scan is done in 16 sequential beams within 1 to 2 minutes. There are several scan modes for different temporal and spatial resolutions. The primary product of the radars is line-of-sight plasma drift velocity in the F-region. Combining all the velocity data from the entire northern hemisphere network produces convection maps. The SuperDarn radars can also determine the evolution of density irregularities generated by the HF heating in the F-region.

HLMS VHF AURORAL RADAR

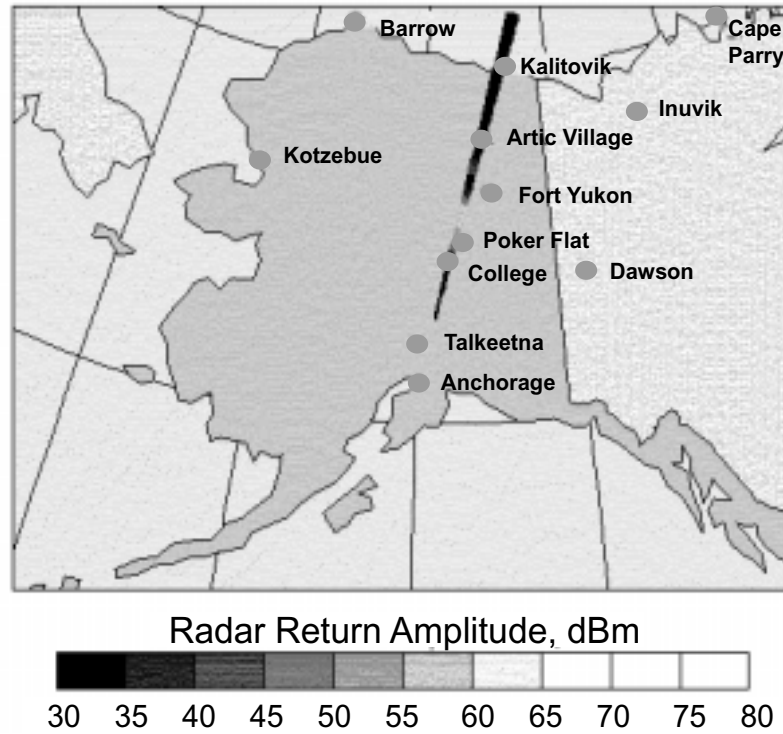


Figure 2.7: Radar coverage area of the HLMS auroral radar.

2.3 Conditions for the Experiment

The effect of matching at the peak frequency in the F layer is optimized under quiet ionospheric conditions. These quiet conditions allow an unambiguous determination of the peak ionospheric plasma frequency f_oF_2 , a better determination of the time window for the matching conditions, and reproducible experiments. Normal absorption in the collisional D-region (70 – 90 km) is a prerequisite to efficient coupling to the higher altitude. An ionosonde records the range of frequency for observable return pulses and thereby determines the absorption in the ionosphere. As a collisional absorption is inversely proportional to the HF frequency, clear echo returns at low frequencies indicate low absorption and no field-aligned precipitation. Magnetometer readings also help determine the conditions in the ionosphere. A magnetic fluctuation of more than 300 nT implies a very absorptive condition whereas a fluctuation of 100 to 200 nT suggests a high electron density in the E-layer. The latter will cause an EM wave reflection at a lower altitude. Thus, a minimal magnetic fluctuation is preferred for coupling the EM wave to the F-layer. The process of ultraviolet (UV) ionization and molecular recombination changes the ionospheric density profile. As a result, the electron density is higher and more variant during daytime and in summer at high latitude. For these reasons, the matching experiments are conducted between late September and early April either in the morning or late in the afternoon.