DESCRIPTION OF THE HAARP GAKONA FACILITY WITH SOME RESULTS FROM RECENT RESEARCH

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ABSTRACT

The High Frequency Active Auroral Research Program has constructed a new interactive ionospheric research facility in Gakona, Alaska. We present a description of the major components of the facility including technical detail of its current and planned performance capabilities and recent measurements of its operating characteristics. The facility has been used during numerous research campaigns since reaching its current level of performance in 1998. We present some initial results from these research activities in the areas of ELF/VLF generation, artificial optical emissions, and trans-ionospheric measurements.

INTRODUCTION

The High Frequency Active Auroral Research Program (HAARP), jointly managed by the Office of Naval Research and the Air Force Research Laboratory, focuses on experimental research investigations of the ionosphere and space, especially as they relate to Radio Science applications. Research to be conducted at the HAARP Gakona Facility will study naturally occurring ionospheric processes as well as those that can be stimulated by interactions with high power radio waves. Among the possible interactions are: electron acceleration, including the production of optical and infrared (IR) emissions; the generation, maintenance and/or suppression of ionization structures aligned along the earth's magnetic field; the modulation of existing currents in the ionosphere, thereby generating new frequencies in the ELF/VLF frequency range; and the production of stimulated electromagnetic emissions (SEE). Other program objectives include experimental research to assess the potential for making use of this emerging ionospheric technology for new radio wave system applications, and the use of the facility to support collaborative research programs such as those associated with the study of global change and the US National Science Foundation's Space Weather Initiative. To provide the experimental research capabilities required to meet these objectives, the HAARP Gakona Facility includes a flexible, powerful high-frequency (HF) transmitter and an extensive complement of radio frequency and optical diagnostic instruments.

Fig. 1. Aerial view of a portion of the HAARP Research Facility in Gakona, Alaska.

HAARP FACILITY TECHNICAL DETAILS

The Gakona Facility is located in a relatively remote region of south central Alaska at a magnetic latitude of 63°. The facility can be used for research over a wide range of background ionospheric conditions ranging from quiet, nearly mid-latitude to auroral. The occurrence of the overhead auroral electrojet is frequent enough to permit reliable scheduling of ELF/VLF generation research. The lack of nearby industry is ideal for the installation of a large suite of sensitive electromagnetic diagnostic instruments.

The major feature of the facility is the 48 element, HF antenna array which, when completed, will consist of 180 antenna elements. This antenna system is configured as a phased array with distributed transmitters at each antenna element or node. Each element consists of a crossed, wire-cage dipole constructed to exhibit broadband performance in both impedance and pattern. The elements are positioned on a spacing of 24.4 m in a rectangular matrix of 6 columns by 8 rows. Each antenna is driven by a 10 kW transmitter (20 kW per antenna node) for a total array radiated power of 960 kW. The antenna spacing was determined by the need to cover the frequency range 2.8 – 10 MHz with one array while maintaining acceptable performance in feedpoint impedance, mutual coupling, beam pattern and beam slewing. The following table is a summary of important electrical parameters associated with the 48-element array and the performance predicted for the planned 180-element system.

	Current	**Completed**
Radiated Power	960 kW	3,600 kW
Frequency Coverage	2.8 - 8.2 MHz	2.8 - 10 MHz
Antenna Gain	13 - 23 dB	20 - 31 dB
ERP	75 - 83 dBW	86 - 95 dBW
Antenna Beamwidth	9° - 32°	4.5° - 15°
Beam Slewing	30° from Zenith @ All Azimuths	
Re-Position Time	--------- 15 µsec ---------	
Polarization	----- O-X / Linear -----	
Modulation Types	AM/FM/Pulse/Continuous Duty	
Modulation Frequency	---- 0 - 30 kHz Generally ----	

The individual transmitters used in the array are designed to stringent standards for signal purity in order to meet spectrum management requirements and to ensure the quality of scientific results. Each transmitter produces a power output of 10 kW, controllable over a 60 dB range. The design employs a 1 kW solid state low power amplifier driving a conventional push-pull, vacuum tube final stage configured to operate in Class AB to achieve a high degree of linearity. For low power operation, the tubes are bypassed and the antenna fed directly from the driver stage. Each transmitter input contains independent, digitally controlled amplitude and phase adjustment circuitry, permitting the synthesis of a wide variety of arbitrarily shaped antenna beams or even multiple beams. The array can be operated at two separate frequencies. With these capabilities it is possible, for example, to use a portion of the array as a heater and a portion as a probe or radar.

The antenna array is located approximately 1 km from a modern operations center where interactive ionospheric experiments are conducted. Computers within the operations center determine transmitter settings for each element in the array such that a specific frequency/beam pattern and modulation mode can be produced for a given experiment. The matrix of phase and amplitude information is passed between the operations center and antenna array over a high-speed fiber optic link to the transmitters which are configured as a local area network (LAN).

The Gakona Facility includes an extensive suite of diagnostic instruments, including a high performance drift mode digisonde; fluxgate and induction magnetometers; two riometers; an all sky camera; GPS and UHF Total Electron Content (TEC) receivers; an on-site VLF receiver; a 139 MHz VHF radar; and a real-time controllable ELF receiver located 12 km from the facility. Evaluation and installation of an incoherent scatter radar (ISR) will begin during 2002. A broadband, conical spiral HF receiving antenna is available for experimental use. Three outlying campaign shelters are provided and each is equipped with high-speed LAN access and time synchronization signals.

SURVEY OF EXPERIMENTAL RESULTS

Since reaching its current, 960 kW radiated power capability in March 1999, the HAARP HF array has been used in 18 research campaigns addressing a broad spectrum of basic and applied research in areas such as ELF/VLF wave generation in the ionosphere, stimulated electromagnetic emissions (SEE), radio wave scattering from field aligned irregularities (FAI), generation of artificial scintillation, and trans-ionospheric propagation.

Because the auroral electrojet is frequently accessible from the facility, one of the primary research areas has been the study of methods for generating frequencies in the ULF/ELF/VLF frequency ranges by using high power HF radio waves to modulate the conductivity of the ionospheric D and E layers. This research has concentrated on methods for improving the efficiency and reliability of the HF to ELF conversion process. In one of the early experiments, Lee et al showed that the conversion efficiency and harmonic content of ELF ionospherically generated ELF waves were a function of the HF modulation waveform [1]. In a recent experiment at the HAARP facility, Papadopoulos et al demonstrated that the well-known frequency dependence of ELF generation efficiency can be explained as a saturation effect, such that HF modulation duty cycle can be reduced significantly (in the ELF case) without decreasing the level of signal produced, thus enhancing the conversion efficiency [2]. Experiments by Wescott and Sentman were used to describe the equivalent ELF ionospheric source region through inversion of multiple measurements made on the ground at various ranges and azimuths from the HAARP facility [3]. Other active areas of ELF experimentation at the facility include the (1) the study of alternative techniques for low frequency generation that do not require an electrojet and (2) the study of the potential for injecting ELF waves into the magnetosphere.

The HF transmitter has also been used as an HF radar to study the occurrence of Polar Mesospheric Summer Echoes (PMSE) and their relationship with noctilucent clouds. In studies conducted during the summers of 2000 and 2001, Kelley et al have characterized the occurrence statistics for PMSE and have shown that there is some evidence for changes in the character of

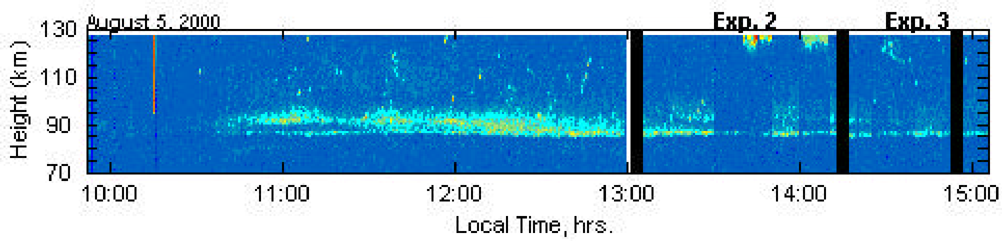

Fig. 2. Detection of Polar Mesospheric Summer Echoes using the HAARP HF transmitter in the radar mode.

the echoes due to interaction with the high power HF probe, even for the low duty cycle employed in these experiments [4]. An example of radar returns from the altitude where PMSE is commonly observed is shown in Fig. 2.

The facility has been used to study HF propagation through the ionosphere in conjunction with various spacecraft. In the first experiment, in 1996, Rodriguez et al demonstrated reception of trans-ionospherically propagated HF signals at several earth radii using the WIND spacecraft [5]. In another experiment, the dual beam capability of HAARP was exploited to heat a portion of the ionosphere along a path toward the WIND spacecraft while simultaneously transmitting a beacon signal to characterize any interactive effects. During the March 1999 campaign, Rodriguez used the beam steering capability of HAARP to investigate the dependence of propagation path loss on beam position. Fig. 3 shows the received HF signal at WIND as the beam is repositioned over a 2-hour experiment. In another experiment, Rodriguez et al studied interference effects produced in the ionosphere through the simultaneous operation of HAARP and HIPAS acting as an active interferometric array [6]. Recently, HAARP was used to study aspects of potential, future solar radars, by using the WIND spacecraft to receive a signal bounced off the moon from the HAARP HF transmitter operated in the pulsed radar mode.

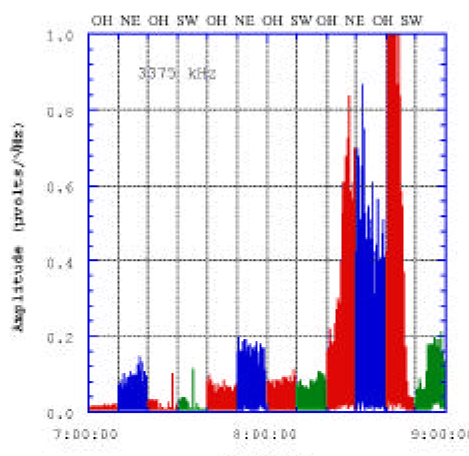

Fig. 3. Detection of the HAARP HF transmitter at 15 - 17 Re using the WIND spacecraft.

Optical emissions were first observed at HAARP during the March 1999 research campaign [7]. Although some of the subsequent experiments had suggested a spatial dependence for optimal optical generation, the first methodical experiment to define such a dependence was recently completed during the HAARP winter campaign of 2002. In an experiment by Pederson, it was demonstrated that the strongest emissions occur when the heater beam is aligned with the magnetic zenith. Under these conditions, strong emissions are readily detected at both 6300 Å and 5577 Å. During a short campaign in April 2002, weak emissions were also observed at 4278 Å. There is evidence that other lines may also produced. In Figure 4, before and after images from the high resolution, narrow field of view NRL CCD imager show a patch of sky approximately 15 degrees wide. When the HF transmitter is turned on in the second image, substantial structure is observed at 5577 Å.

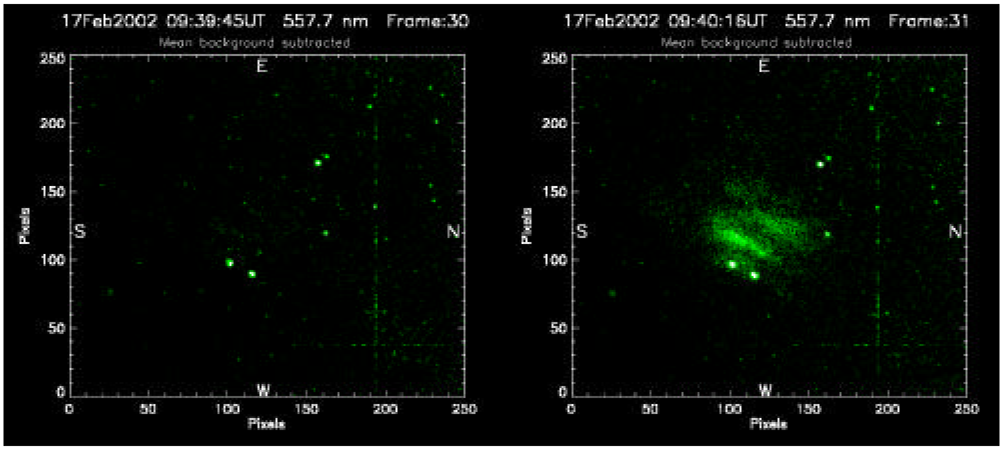

Fig. 4. Optical emission at 5577 Å produced at the HAARP Gakona Facility during the February optical campaign detected using the NRL imager.

CONCLUDING REMARKS

In this paper, we have presented a description of the HAARP Gakona Facility including technical details of its performance capability. In addition, we have presented only a brief description of some of the ongoing studies at the facility. Additional presentations at this conference provide more detailed discussion of other specific research efforts. The HAARP Gakona Facility is a new resource for the study of interactive and upper atmospheric research. During three years of intense research activity at the site, the facility has contributed new knowledge to the general fields of Radio Science and ionospheric physics and its contributions are expected to grow as the facility is completed.

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