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The High Frequency Active Auroral Research Program

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E.J. Kennedy, P. Rodriguez, and C.A. Selcher
Information Technology Division

Introduction: Electromagnetic waves in certain frequency ranges are absorbed or refracted by the ionosphere, an electrically conductive region of the upper atmosphere beginning at an altitude of approximately 80 km. Radio waves of sufficient energy density are capable of temporarily modifying its electrical and physical properties within a small volume, enabling a new type of interactive research having application to a variety of Navy and DOD missions. The High Frequency Active Auroral Research Program, jointly sponsored by the Office of Naval Research, the Air Force Research Laboratory, and DARPA, is constructing a new interactive ionospheric research facility in Gakona, Alaska, to conduct both basic and applied research in this scientific discipline. We present a description of the major components of the HAARP Gakona Facility including technical detail of its current and planned performance capabilities. We also present some results from three research areas: extremely low and very low frequencies (ELF/VLF) generation, artificial optical emissions, and space research.

Facility Description: The HAARP Gakona Facility is located in a relatively remote region of south central Alaska where a variety of ionospheric conditions may occur, ranging from quiet to mid-latitude to auroral. The major feature of the facility is the high frequency (HF) phased array antenna, currently consisting of 48 elements. When completed in 2006, this array will consist of 180 elements with performance parameters as shown in Table 1.

Table 1 -- HF Phased Array Antenna Performance Parameters.

	Current	2006
Radiated power	960 kW	3,600 kW
Frequency coverage	2.8 to 8.2 MHz	2.8 to 10 MHz
Effective radiated power (ERP)	75 to 83 dBW	86 to 95 dBW
Antenna beam width	9° to 32°	4.5° to 15°
Beam slewing	30° from zenith @ all azimuths	
Beam reposition time	15 µs	

The facility also includes a suite of 17 on-site scientific and diagnostic instruments including magnetometers, riometers, a digisonde, and three upper atmospheric radars. Work has begun on an incoherent scatter radar. Since becoming operational in March 1999, the HAARP Gakona Facility has been used in 27 research campaigns. Figure 5 is an overhead photo of the facility.

FIGURE 5
Overhead photo of the HAARP Gakona Facility.

Generation of ELF/VLF Waves: Much of the research at the facility is focused on the generation of ELF/VLF because of the value of these frequencies to the Navy for undersea applications. Propagating radio waves in the ELF/VLF frequency range are generated at the lower edge of the ionosphere when high-power HF radio waves modulate the conductivity of the ionospheric D and E layers in the presence of a background or "electrojet" current. The practical utility of this technique for communication systems is dependent on improving the efficiency and reliability of this process. A recent experiment was performed at HAARP to study the scaling of the ionospherically generated

ELF signal with power transmitted from the HF array. Results were in excellent agreement with computer simulations confirming that the ELF power increases with the square of the incident HF power. Furthermore, no saturation effects were observed indicating that greater ELF generation efficiency is possible with greater incident power.

Optical Emissions: The interaction of high-power radio waves with the ionospheric can produce faint optical emissions at specific wavelengths. Recent experiments at the HAARP Gakona Facility investigated the role of the HF beam pointing direction on the production of artificial airglow. The exciting result was that by pointing the HF beam directly along a geomagnetic field line, artificial emissions of greater than 200 Rayleighs (R) at 630.0 nm and greater than 50 R at 557.7 nm could be produced. This intensity was nearly an order of magnitude larger than that produced by heating directly overhead. Weak emissions of approximately 10 R were observed with effective radiated power (ERP) levels as low as 2 MW. These measurements have been repeated in other research campaigns with observations over a wide range of ionospheric conditions.1 Figure 6 shows the artificially generated emission at 557.7 nm that was obtained using the NRL CCD imager during one of the experiments. (The imager used in this research uses a high resolution, cooled CCD. It was developed by NRL's Plasma Physics Division and on loan to HAARP for the experiment.)

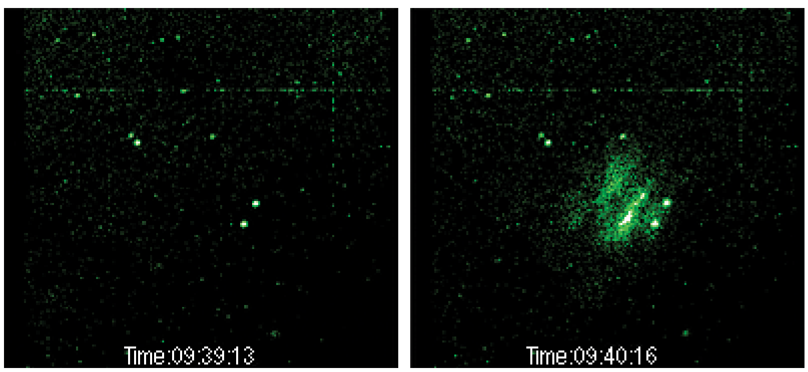

FIGURE 6
Two images of the sky over the HAARP Gakona Facility using the NRL-cooled CCD imager at 557.7 nm. The field of view is approximately 38°. The left-hand image shows the background star field with the HF transmitter off. The right-hand image was taken 63 s later with the HF transmitter on. Structure is evident in the emission region.

Lunar Radar Experiment: In another experiment, measurements were made of lunar radar cross-section by transmitting high-power radar pulses directly at the Moon from the HAARP facility and receiving the echo pulses with the WAVES radio receiver onboard the NASA/WIND spacecraft. This is the first time that such a lunar echo experiment has been done using a ground-based radar in combination with a spacecraft, a new approach to space research.2 During the two-hour experiment, the WIND satellite was about 40,000 km from the Moon's surface. Figure 7 is a 5-s interval of data showing the direct HAARP pulses (large peaks) and the lunar echo pulses (smaller peaks) received by the WAVES radio receiver. From the ratio of intensities of pairs of direct and echo pulses, we obtain an average lunar radar cross-section of about 15% relative to the geometric cross-section, with maximum values of about 50%. The HAARP transmissions were done at 8.075 MHz, a radio wavelength of 37 m; our measurements extend the spectrum of lunar radar cross-sections to the longest wavelength at which this experiment has been done.

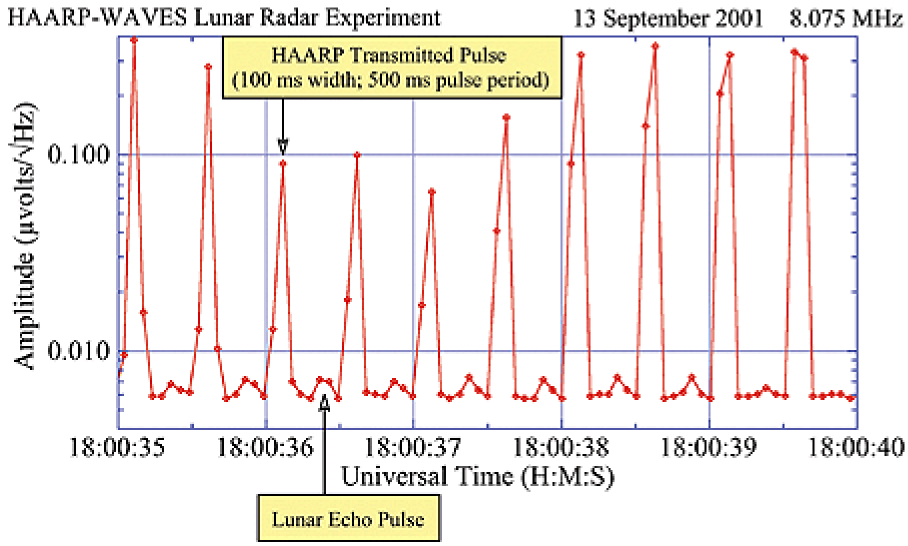

FIGURE 7
Direct and echo radar pulses measured by the WAVES radio receiver. The lunar radar cross-section is calculated from the ratio of direct and echo pulses.

The lunar radar experiment provided evidence of high reflectivity locations on the lunar surface that may be associated with topographical features. This new technique for lunar radar measurements is free of scintillation effects caused by the Earth's ionosphere and provides a relatively clean measurement of the echo. Thus, high power radars, such as HAARP, can bring an important new tool to lunar research, and future radar experiments with lunar-orbiting spacecraft can provide a new window on lunar topography.

Conclusion: Even though the HAARP facility is only partially complete, research results have already added new knowledge to the field of ionospheric interactions in basic and applied radio science. A primary focus area of the research program addresses communications and surveillance needs of the Navy with the potential to enable new capabilities for undersea applications.

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U.S. Naval Research Lab 4555 Overlook Ave., SW Washington, DC 20375