4

Some Applications of High-Power High-Frequency Facilities

The High Frequency Active Auroral Research Program (HAARP) transmitter is primarily used for basic research into the interactions of high-power radio waves with the high-latitude ionosphere. As noted by many workshop participants, these interactions produce a wide range of effects that may be applied in practical applications. At the workshop, discussions focused on (1) improvement of the space environment, (2) establishment of reliable communications channels, (3) testing of radio propagation systems, (4) simulations of natural disturbances in the ionosphere for mitigation testing, and (5) testing of concepts for high-payoff strategies for removal of space debris.

Table 4.1 aggregates the practical applications of high-frequency (HF), high-power ionospheric heaters such as HAARP that were highlighted by one or more participants at the workshop, especially in a closing wrap-up session.

ENHANCED PRECIPITATION FROM THE RADIATION BELTS

Earth's radiation belts contain high-energy electrons and ions that can damage the electronics of satellites in low Earth orbit. The energetic electrons, spiraling around Earth's magnetic field lines, bounce between the hemispheres at mirror points. If the mirror altitude is below 100 km, the high-energy particles collide with the background neutral atmosphere and lose their energy in the form of optical emissions and enhanced ionization. This process, called precipitation, depletes the energetic population for the electrons that have orbital "pitch angles" that are nearly parallel to the magnetic field lines at their equatorial midpoints.

Using HAARP, researchers can launch ULF/ELF/VLF (ultralow-frequency/extremely low-frequency/very-low-frequency) waves into the magnetosphere to explore their effect on trapped high-energy electrons and protons. Some participants thought that data from these experiments would be important for the design of radiation belt remediation (RBR) systems that could be needed to protect commercial and military satellites if, for example, the radiation belts were "pumped" as a result of an accidental or deliberate high altitude nuclear explosion, or from a Carrington-type space weather event.[1]

IMPROVED TRANSMISSION THROUGH THE IONOSPHERE

At several points in the workshop, participants considered the potential role of heaters in general and HAARP in particular for experiments that would yield information that could be used to improve satellite communication. The plasma irregularities in the ionosphere have long been known to seriously degrade communications and navigation signals from satellites. These ionospheric structures distort and corrugate the phase fronts of very-high-frequency (VHF), ultrahigh-frequency (UHF), and L-band radio waves that propagate through them. A smooth phase front to a ground receiver produces a uniform amplitude pattern at the antenna and minimal signal distortion, but a corrugated wave becomes diffracted by mixing of individual wave components to produce a phase front with large amplitude and phase fluctuations. When this signal reaches a ground antenna, the navigation or communications information can be buried in the noise.

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[1] For a description of this event, see NASA (2008) and also NRC (2008).

TABLE 4.1 Practical Uses of High-Power, High-Frequency (HF) Facilities Noted by Individuals at the Workshop

Physical Quantity	HAARP/Arecibo HF Application	Potential Influence	Science
Radiation belt particles	Studies of induced loss with ULF/ELF/VLF wave injection in the radiation belts	Reduced satellite damage	Wave-particle interactions
Field aligned irregularities	Wide scale size generation	Enhanced radio scintillations Test timing/location algorithms	Instability and ionization
		HF radar spread doppler clutter	Propagation and mitigation
Artificial ionization	Local enhanced density production	Artificial radio mirror	Electron acceleration
Artificial aurora	Multiple optical wavelength generation	Space-based optical sensor testing	Electron acceleration and neutral excitation
Stimulated electromagnetic emissions	Electromagnetic noise source	Adjacent channel communications interference	Electrostatic wave diagnostic
HF radar echoes	Radar echoes from sun and meteors	Solar flare/coronal mass ejection detection Asteroid studies	Plasmasphere mapping
Enhanced neutral density	Artificial increase of neutral drag?	Satellite debris deorbit	Ion outflow and neutral drag

NOTE: ULF/ELF/VLF, ultralow-frequency/extremely low-frequency/very-low-frequency.

Research has shown that receiver algorithms that have been designed to work in a high-noise environment can be tested by transmissions of satellite signals through regions of the ionosphere disturbed by the HAARP HF transmissions. At other HF facilities, such as EISCAT (European Incoherent Scatter Scientific Association), Sura, and Arecibo, previous tests of ionospheric effects on UHF (250-MHz) radio signals from satellites have produced amplitude scintillations of 2 dB or less.

Recent observations at HAARP have shown three levels of UHF scintillations from the TACSat4 satellite radiating at 253 MHz.[2] The typical natural level of radio scintillation is 1 dB or less. When the HAARP transmitter is turned on to create field-aligned irregularities but not artificial ionization, the radio scintillation level goes up to about 2 dB. When artificial ionization clouds are made by HAARP, the amplitude fluctuations go up to 15 dB or more. Such strong scintillation levels are only seen naturally when there is a large auroral disturbance in the ionosphere. Real-world testing of satellite communications and navigation (i.e., Global Positioning System) receivers usually requires waiting for natural disturbances to be coordinated with the positions of in orbit. A workshop participant stated that by using HAARP, natural-looking plasma disturbances can be produced at the time that equipment is to be tested for radio scintillation mitigation.

IMPROVED REFLECTION FROM THE IONOSPHERE

HF communications and HF radar systems rely on the ionosphere to refract or scatter ground transmissions back to the ground. The distance between HF ground-to-ground points depends on the altitude of the ionosphere and on the electron density at the peak of the ionosphere layer: The altitude determines the maximum ground range between the HF transmitter and HF receiver, while the density determines the maximum frequency that can be used. Altitude and density fluctuations in the natural

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[2] From Paul Bernhardt, paper in preparation and results to be discussed at the December 2013 meeting of the American Geophysical Union. Dr. Bernhardt described these results to the workshop and reported that they were based on his observations during the March 2013 BRIOCHE campaign.

ionosphere limit the reliability and coverage range of HF systems. Some participants thought that HAARP could produce artificial ionization clouds that might provide reliable HF communications paths.

EXPLORING NONLINEAR TRANSMISSION

It is commonly assumed that an HF system with more effective radiated power will have an increased signal-to-noise ratio at the receiver. However, Paul Bernhardt noted that increasing the transmitter power and antenna gain may cause nonlinearities in the ionosphere that will produce self-modulation, self-absorption, and self-scattering. Thus, HF propagation conditions may become worse for transmissions above a certain power. The effect, called stimulated electromagnetic emission (SEE), which introduces additional noise onto the HF signal, is produced by conversion of the electromagnetic wave into electrostatic waves in the ionosphere. These waves can parametrically decay into low- and high-frequency waves that introduce sidebands on the received signals.

Bernhardt stated that the HAARP transmitter has been used to demonstrate that induced sideband distortions of transmitted HF waves can be found at frequencies as low as 7 Hz and as high as 110 kHz for magnetic stimulated Brillouin scatter, stimulated ion Bernstein decay, lower- and upper-hybrid parametric decay, ion-acoustic and electron plasma wave parametric decay, and other modes. He further noted that for transmissions near the harmonics of the electron cyclotron wave, the sideband generation can be very pronounced. Self-absorption occurs when the nonlinear interactions convert part of the electromagnetic signal into dissipative plasma modes such as electrostatic waves and electron heating and acceleration. Self-scatter is caused by high-power HF waves that produce irregularities and density enhancements that deflect the original signal away from the intended receiver. All of these self-interaction processes, says Bernhardt, are coupled by the nonlinearities in the ionospheric plasma. High-power transmissions are used to investigate the practical signal-intensity limit of high-power signals for communications and radar applications.

DETECTING SOLAR EVENTS

See "Solar Radar" in Chapter 3.

ENHANCING SPACECRAFT DRAG

A major problem with old satellites is that they can become space debris. The atmosphere region above 700 km altitude is tenuous and orbiting material, therefore, has a long residence time. It was stated at the workshop that the HAARP facility has been known to produce ion outflow that drags oxygen atoms to an altitude of 800 km. Controlled experiments of this nature—induced ion/neutral species outflow— can improve quantitative modeling of chemical/collisional cross-sections and improve the ability to model processes that can perturb neutral densities or enhance satellite drag. Dennis Papadopoulos believes that HAARP operations, in conjunction with the Canadian CASSIOPE satellite and the Russian Resonance mission, could provide experimental observations of this and other HAARP induced processes. While actual enhancement of satellite drag is at this point only speculation, he and participants, including Elizabeth Kendall, thought the potentially high payoff merited further investigation.

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