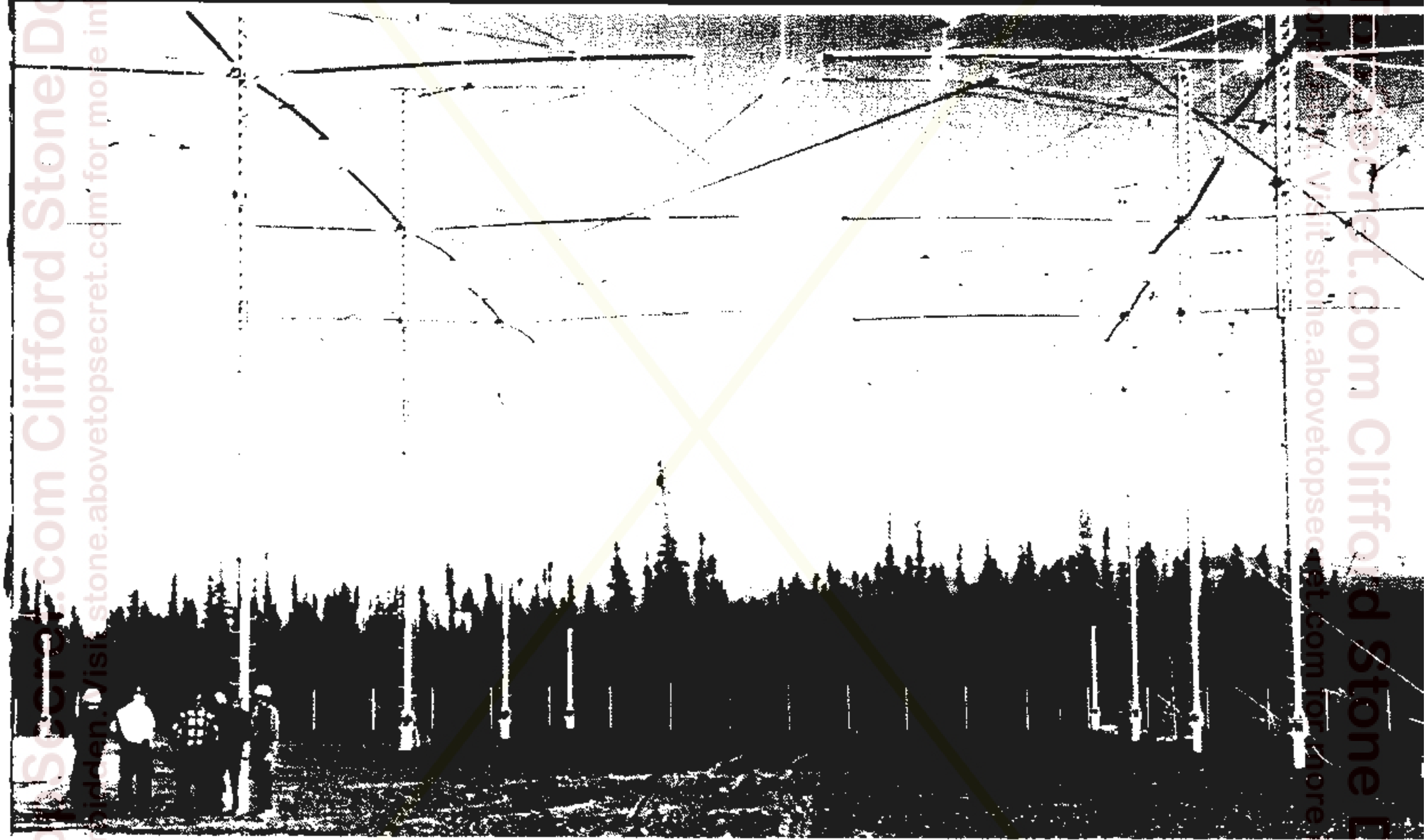
HAARP

RESEARCH AND APPLICATIONS



A JOINT PROGRAM OF THE
AIR FORCE RESEARCH LABORATORY
AND THE OFFICE OF NAVAL RESEARCH

19981105 002

HAARP High Frequency Transmitter

Cover:
The HAARP site, Gakona, Alaska

From the AboveTopSecret.com Clifford Stone Document Archive
Commercial use is forbidden. Visit stone.abovetopsecret.com for more information on usage.

This report describes and documents the scientific uses and the wide range of applications created by the HF Active Auroral Research Program (HAARP). The report is based on the deliberations of a scientific committee sponsored by the Air Force Research Laboratory and the Office of Naval Research and convened by the East-West Space Science Center of the University of Maryland. The committee was composed of the following members.

Dennis Papadopoulos, Committee Chairman;
Professor of Physics, University of Maryland

Paul A. Bernhardt
Active Experiments Project Leader,
Beam Physics Branch, Plasma Physics Division,
Naval Research Laboratory

Herbert C. Carlson Jr.
Chief Scientist,
Air Force Office of Scientific Research

William E. Gordon
Professor and former Dean, Rice University;
Member of the National Academy of Sciences

Alexander V. Gurevich
Head, Ionospheric Division, Lebedev Institute;
Corresponding Member of the Russian Academy of Sciences

Michael C. Kelley
Professor of Electrical Engineering,
Cornell University

Michael J. Keskinen
Head, Space Experiments Section,
Charged Particle Physics Branch,
Naval Research Laboratory

Roald Z. Sagdeev
Distinguished Professor of Physics,
University of Maryland;
Member of the Russian Academy of Sciences;
Foreign Member of the National Academy of Sciences

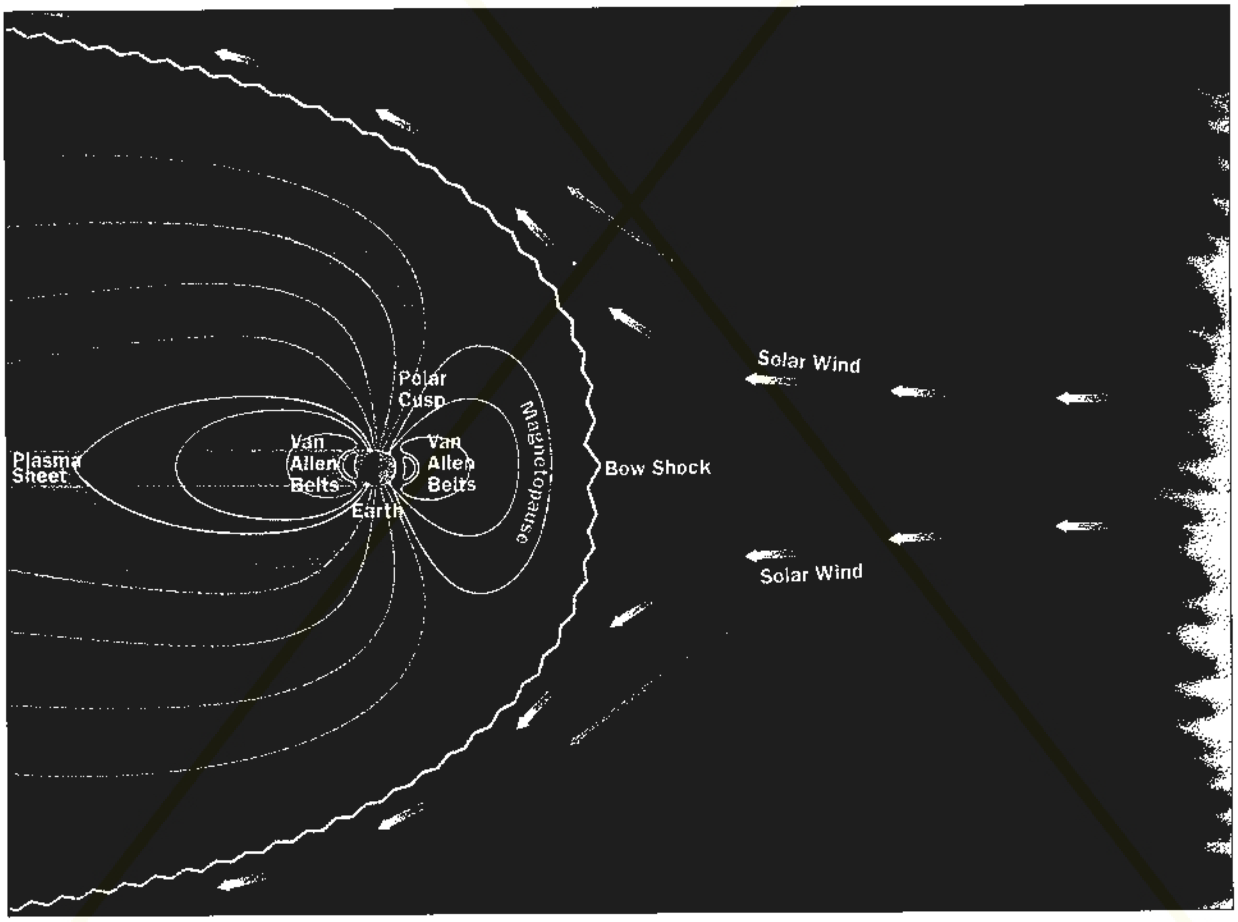
Gennady M. Milikh, Committee Secretary;
Research Associate, University of Maryland

CONTENTS

THE ISSUES

GEOSPACE GLOBAL CHANGE

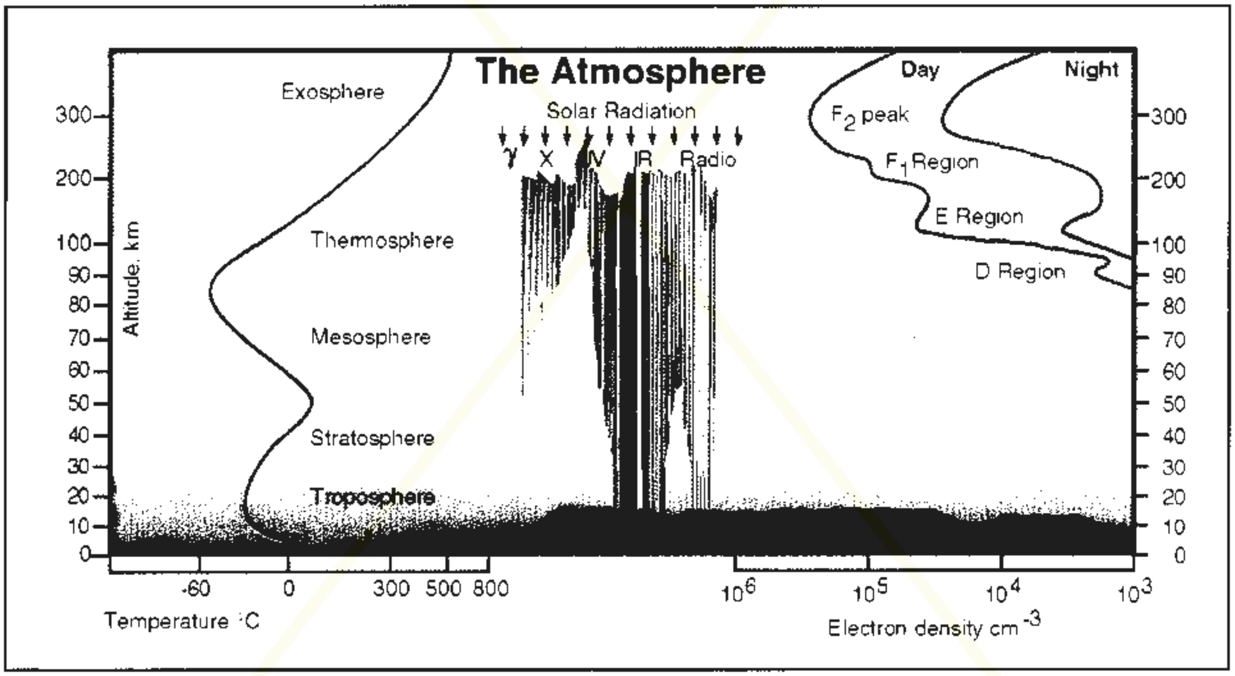
The Sun controls and shapes the three major regions of Geospace—the magnetosphere, the ionosphere, and the atmosphere. These regions, rather than being isolated, interact with each other and form a chain that connects the Earth to the Sun through the atmosphere and the solar terrestrial environment. Disturbances originating at the Sun spread through this chain via the solar wind and solar radiation. They ultimately influence our weather, our climate, and even our communications. The clouds and the Earth's surface play a critical role in this chain, which is finely tuned to be in a delicate equilibrium with life on Earth. The atmosphere and the ionosphere are the geospace



NASA graphic

The impact of the solar wind on the Earth's magnetosphere. The solar wind confines the Earth's magnetic field to a comet-shaped zone that has our planet as its nucleus. The magnetosphere is drawn out into a very long tail (not shown) that stretches away from the Sun.

regions closest to the surface of the Earth. The lowest regions of the neutral atmosphere—the troposphere, the stratosphere, and the mesosphere—are critical in controlling the global temperature of the Earth and in filtering the harmful effects of the solar radiation. The next layer—the ionosphere—starts at about 60 – 70 km altitude and contains a significant fraction of electrically charged particles. Because charged particles are subjected to electric and magnetic forces, the ionosphere has a uniquely important role within the overall solar-terrestrial system. It couples to the magnetosphere and heliosphere above by electric forces and to the stratosphere below by conventional atmospheric dynamic forces. It is a region that supports and controls electric currents and potentials ranging up to a million amperes and hundreds of kilovolts, respectively.

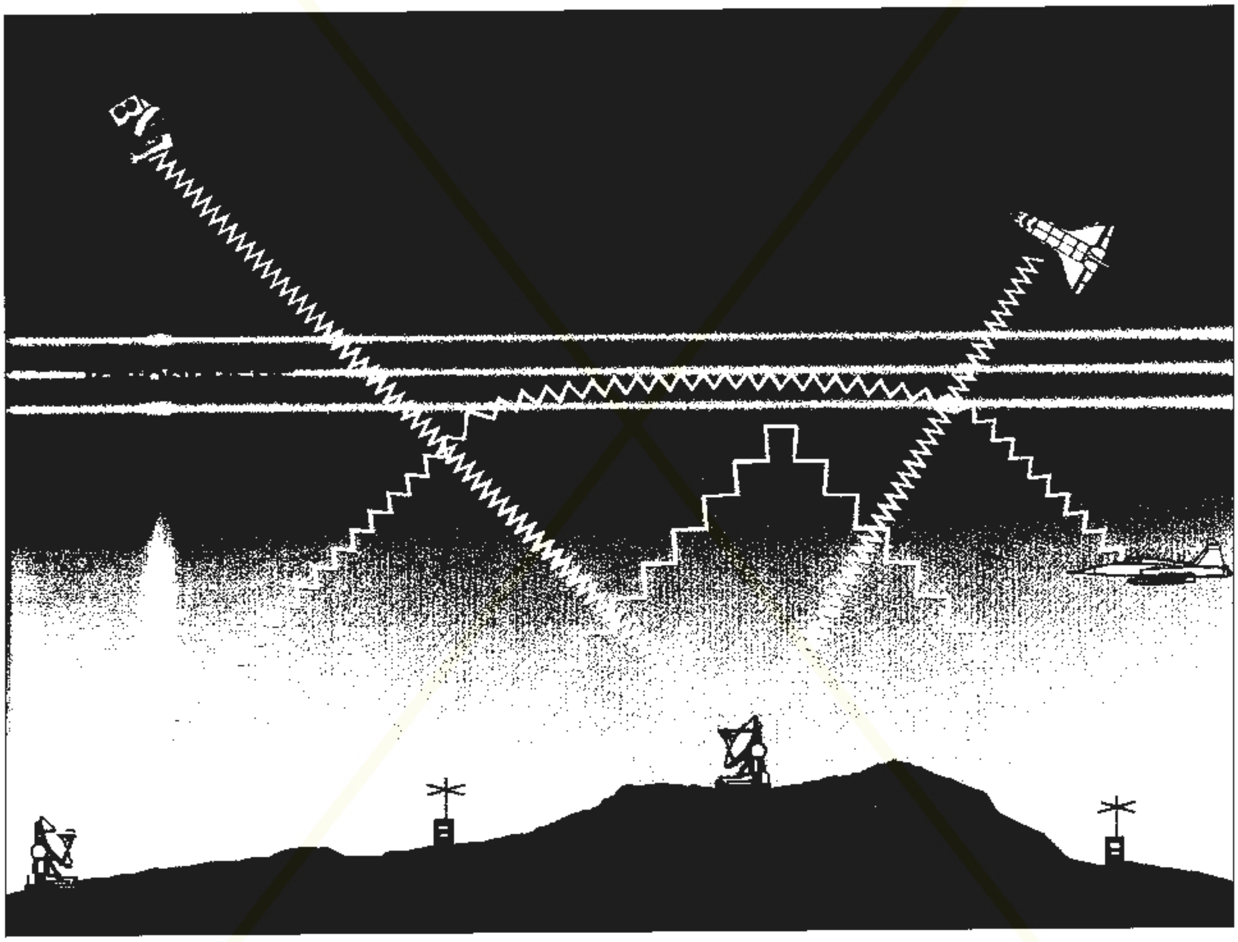


NASA graphic

Schematic representation of the atmosphere and the ionosphere. The altitude dependence of the temperature and electron density are shown on the left and right sides, respectively. The spectrum of solar radiation and its atmospheric absorption are shown in the middle. The ionosphere starts at about 70 km. Communication paths between the ground and satellites have to cross the ionosphere and the atmosphere.

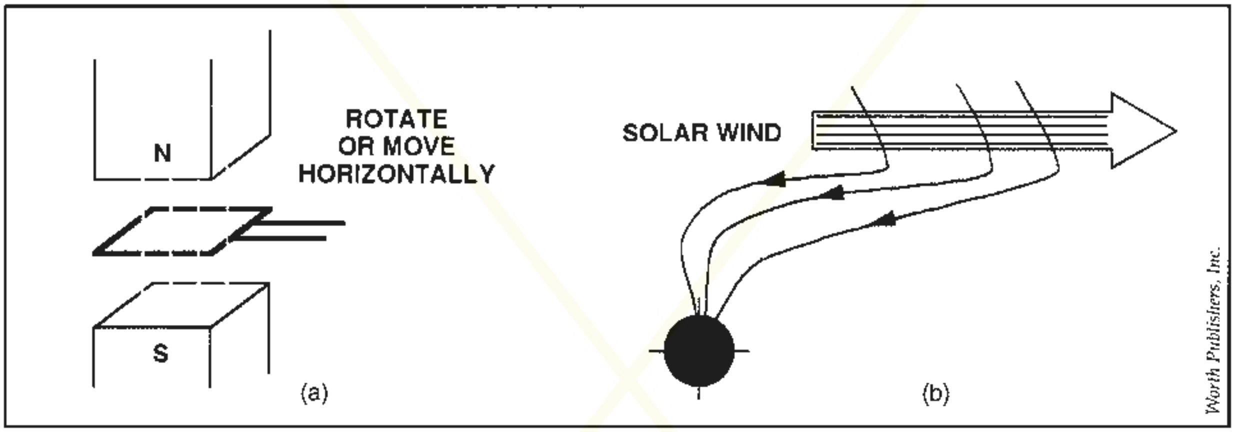
From the AboveTopSecret.com Clifford Stone Document Archive
Commercial use is forbidden. Visit stone.abovetopsecret.com for more information on usage.

The presence of charged particles in the ionosphere controls the performance of many military and civilian systems using electromagnetic waves. On the low frequency end (VLF/ULF/HF), reflection of radio waves by the ionosphere allows for worldwide communications and Over-the-Horizon (OTH) radar operation. On the higher frequency end (VHF/UHF) transionospheric propagation is a ubiquitous element of numerous civilian and military communication, surveillance, and remote sensing systems. Paths linking satellites to the ground cross the ionosphere, and the system performance is often critically dependent on the state and structure of the ionosphere in the vicinity of these paths.



HF links using ionospheric reflection and transionospheric communication paths

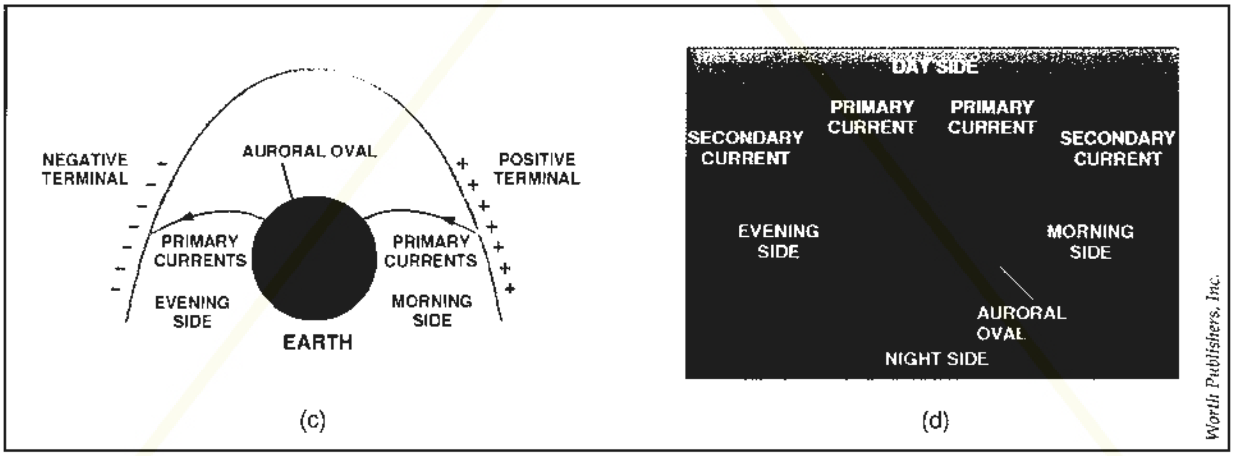
The polar ionosphere located above the Arctic is of particular significance. The magnetic field lines traversing this region connect directly to the solar wind—a stream of charged particles flowing outward from the Sun toward the magnetosphere, permitting direct access of solar wind particles into the ionosphere. Furthermore, the solar wind, functioning as a conductor, creates an electric generator. This is similar to the conventional generators that produce electric energy when a conductor moves or rotates across a magnetic field. The currents generated by the solar wind flow toward the Earth guided by the magnetic field and close the electric circuit by traversing the polar ionosphere. This is known as the auroral electrodynamic circuit and carries towards the Earth 0.1 to 1 million MW of power, equivalent to 100 to 1000 large power plants. The energy is dissipated in the polar ionosphere and transferred to the mesosphere, driving complex photochemical and plasma-physical processes. A fraction of this energy appears as a spectacular light display, known as the aurora borealis.



Worth Publishers, Inc.

(a) Conventional generator

(b) The interaction of the solar wind with the Earth's magnetic field creates a naturally occurring generator.



Worth Publishers, Inc.

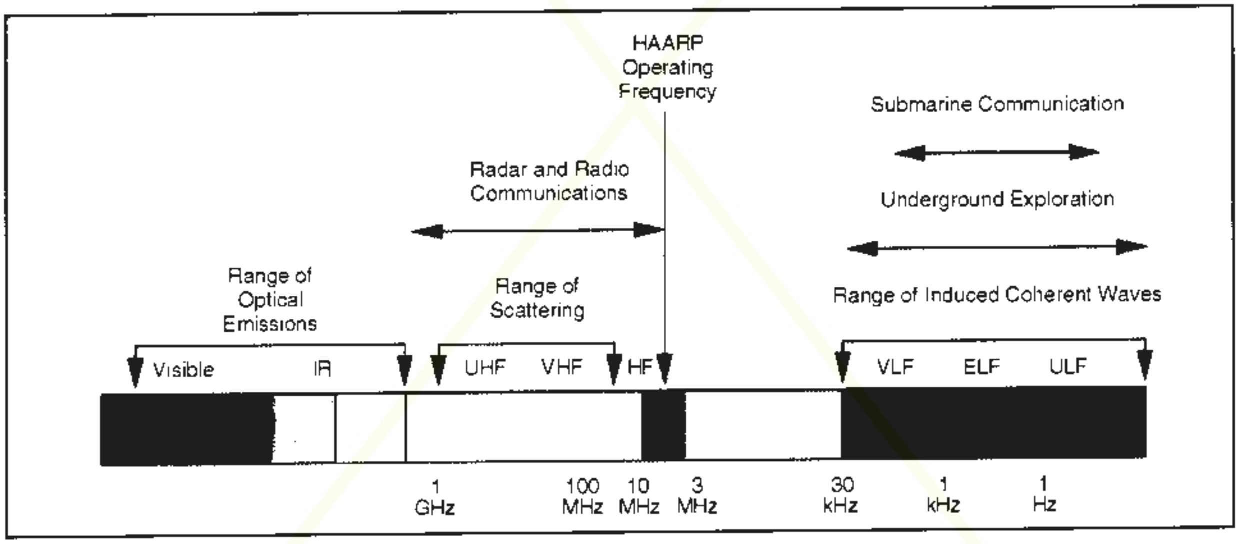
(c) The positive and negative terminals of the naturally occurring generator are shown together with the primary currents.

(d) The primary currents induce secondary upward currents in the outer edge of the auroral oval to close the electrical discharge circuits. The currents across the polar cap and along the auroral oval depend on the atmosphere's conductivity.

Remote sensing of the Arctic and monitoring of the state of the polar ionosphere is a prerequisite in understanding and modeling the global Earth system—a major goal of the U.S. Global Change Research Program (GCRP). Furthermore, increased reliance on space-based electromagnetic systems requires not only monitoring of the global ionospheric state but also an examination of the impact that controlled local modifications in the vicinity of transionospheric paths can have on these systems. The possibility that system performance can be influenced by controlled local modifications, using ground-based HF transmitters, could affect the planning and economics of space systems.

The HF Active Auroral Research Program (HAARP) is based on a HF transmitter and a complement of diagnostics located in Gakona, Alaska. The location of the HF transmitter underneath the auroral electrodynamic circuit and the power and flexibility of operation, based on use of today's most sophisticated technology, provide the HAARP with a novel and unique broadband remote sensing resource. By exploiting the properties of the auroral ionosphere as an active, nonlinear medium, the primary energy of the HF transmitter, which is confined in the frequency range from 2.8 to 10 MHz, can be down-converted in frequency to coherent low frequency waves spanning five decades, as well as up-converted to infrared and visible photons. It can, furthermore, structure the ionospheric density in a way that provides a controlled scatterer for HF/VHF/UHF frequencies. As a result, the HAARP HF transmitter can generate sources for remote sensing and communications spanning 16 decades in frequency.

This report describes and documents the importance of the HAARP in fulfilling the above requirements, in addition to advancing the scientific frontiers in ionospheric physics.



The HAARP transmitter radiates in a narrow frequency range of 2.8 to 10 MHz. However, using the ionosphere as an active medium, it can provide secondary radiation sources in the IR, visible, and ULF/ELF/VLF ranges. It can also develop new links in the HF/VHF/UHF ranges by rippling the electron density of the ionosphere, thereby producing controlled scatterers at these frequencies.

HAARP Unique Features—Current Plan

- 12x15 cross dipole array driven by 360 10 kW transmitters
- Very high effective radiated power: 86 to 96 dBW (2.8 to 10 MHz)
- Wide range of parametric control
  - Wide array operating band: 2.8 to 10 MHz (~two octaves)
  - Very wide scan: ±30° cone
  - Rapid beam scan: 10 µs
  - Arbitrary polarization: any cross or linear polarization
  - Beam shaping and radiation pattern control
- Modern fiber-optic control system
  - High-speed phase control (144 MB/s)
  - High-speed data communication
- Fast system computation: 1.28 GFLOPS
- Unique transportable and remotely operable graphic interface
- Integrated diagnostic support for control/coordination/expansion

HAARP Diagnostic Instrumentation

HAARP ACQUISITIONS	DIAGNOSTICS AVAILABLE TO HAARP
Magnetometer	University of Alaska, Geophysical Institute
ELF/VLF receivers	Magnetometer chain
Longwave wideband radiometer	Riometer chain
D region remote sensing receivers	Optical imager chain
HF vertical ionosounders	High latitude monitoring site (UA, Geophysical Institute)
HF stimulated EM emissions receiver	VHF (50 MHz) radar
HF (28 MHz) radar	Riometer
VHF (30 MHz) riometer	Magnetometer
VHF imaging riometer	Air weather service
VHF (50 MHz) radar	HF vertical ionosounder (College Station)
VHF (250 MHz) scintillation monitor	
UHF incoherent scatter radar*	
RF spectrum monitor	**DIAGNOSTICS UNDER CONSIDERATION**
Imaging photometer	Satellite-based diagnostics
SWIR photometer	
SWIR imager	
Rayleigh/ozone lidar	
Sodium resonance lidar	

* Planned

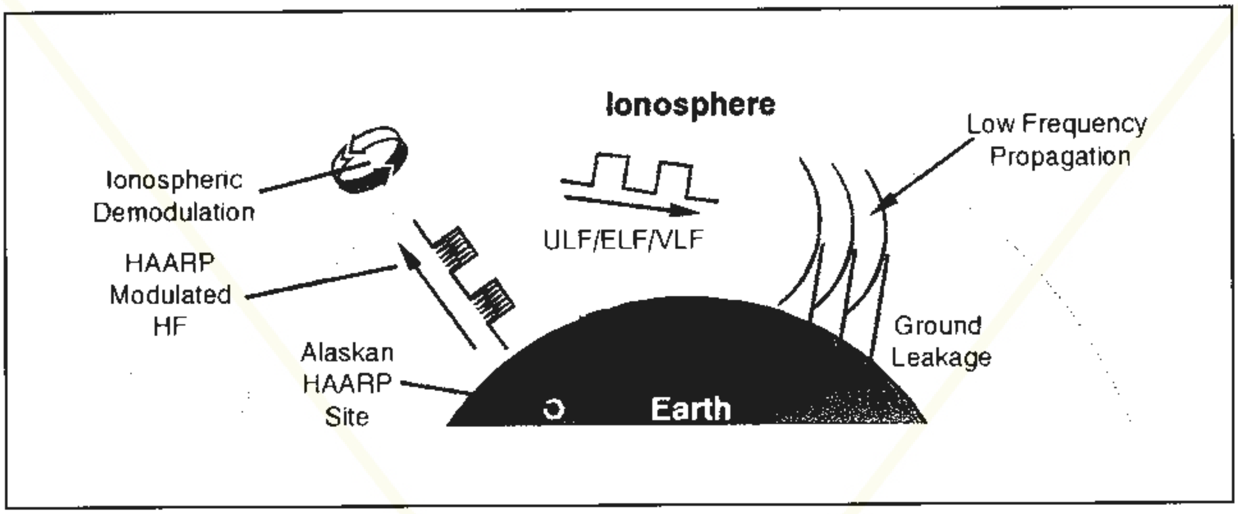
THE HF ACTIVE AURORAL RESEARCH PROGRAM

Local Ionospheric Modifications and Remote Sensing

The HAARP facility, currently under development in Alaska, is the outgrowth of more than 30 years of ionospheric heating research. A wealth of experimental studies conducted at ionospheric heating installations, such as the ones in Arecibo, Puerto Rico; Tromso, Norway; Fairbanks, Alaska; and several installations in the former USSR brought the understanding of the physics and the phenomenology of the HF-ionosphere interactions to a new plateau. The scientific field was ready to make the transition from pure research to applications in the civilian and military arenas. In February 1990, a major workshop sponsored by the Office of Naval Research and the Air Force Research Laboratory, and with representation from the National Science Foundation, took place in New London, Connecticut. The workshop, attended by more than 60 representatives from key science, technology, and application areas, defined the operational requirements of the next HF ionospheric transmitter and presented the rationale that led to the HAARP. It was concluded that an HF transmitter located in the auroral zone, with ground power three times larger than the one in Tromso and operationally enhanced with the flexibility provided by the most advanced phased array and software technology, would provide the Nation with unprecedented capability to locally control the state of the ionosphere. The workshop endorsed the HAARP transmitter as the cornerstone of the transition from ionospheric research to technology and applications.

The primary energy of the HAARP transmitter can be radiated at any selected frequency between 2.8 and 10 MHz. By matching the radiating frequency to the ionospheric density profile, the radiated energy can be deposited selectively at altitudes between 70 and 90 km (D/E Region) and between 200 and 300 km (F Region), or it can escape into space. A significant fraction of the absorbed HF energy is reradiated as optical energy. The ionosphere thus acts as a convertor of the HF energy into optical photons. This process is similar to those that create the natural airglow seen in the night sky by sensitive optical instruments. The heater-produced airglow spectrum depends on the heater beam intensity and the composition and density of the atmosphere in the energy deposition layer. The HAARP heater is the only one with sufficient beam intensity to induce re-radiation of the observed energy in the infrared. Furthermore, the monochromatic heater signal can be converted into a broad radio spectrum impacting communications and providing diagnostic utility. Both the optical and radio emission spectra provide powerful sources for remote sensing techniques with many dual-use applications.

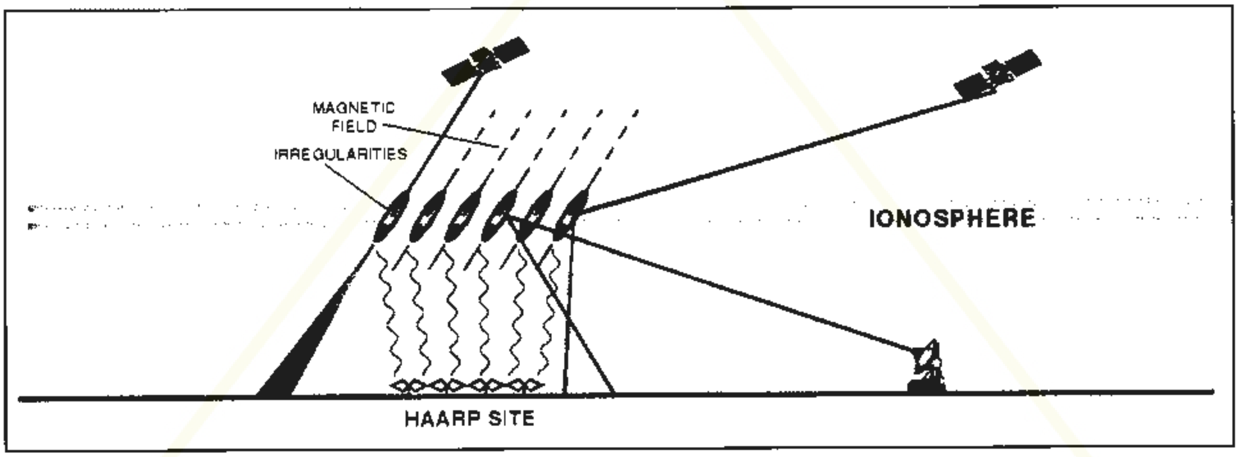
The presence of electric fields and currents in the auroral oval provides HAARP with unique capabilities. It can be used as a low-frequency transmitter or radio system that is tunable continuously over the range from 0.001 Hz to 40 kHz. This function is achieved by amplitude or frequency modulation of the transmitter signal at the desired low frequency. The ionosphere, acting as a high-frequency filter, demodulates the HF signal and returns an electromagnetic signal with frequency equal to the low modulation frequency. This wave can propagate with low attenuation over thousands of kilometers, guided by the waveguide



ULF/ELF/VLF waves created by ionospheric demodulation of amplitude or frequency modulated HF signals from the HAARP transmitter. The low-frequency waves are guided by the waveguide formed between the ground and the ionosphere. These waves propagate unattenuated over thousands of kilometers. Energy leakage through the sea and ground allows for communication with submarines and underground exploration.

formed by the ground and the ionosphere, in the manner that many low-frequency communication systems are used by the Navy.

When the energy is deposited in the F Region near the peak of the electron density, it creates striations in the local ionospheric electron density. The striations are rodlike and are aligned with the magnetic field. They can act as specular field aligned scatterers (FAS) that reflect frequencies from HF to UHF in a highly directional manner. The FAS could modify the signals traversing them as well as provide new communication links.



HF power from the HAARP transmitter incident on the ionosphere creates structures in the electron density. These structures, acting as Bragg scatterers, create new ground-to-ground and ground-to-space HF/VHF/UHF links. They can also affect the performance of conventional satellite-to-ground VHF/UHF links.

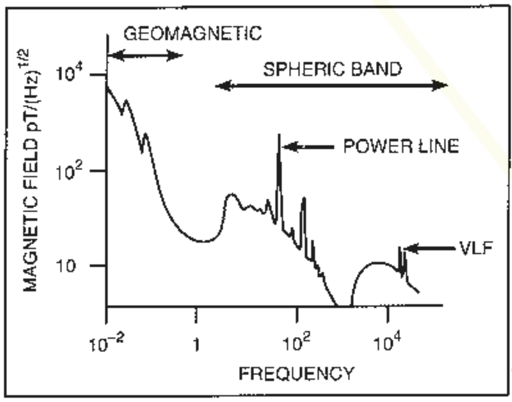
APPLICATIONS

Low Frequencies

Most communication systems and remote sensors use the short wavelength portion of the electromagnetic spectrum, operating from several megahertz to the visible and ultraviolet. These frequencies have inherent advantages in terms of bandwidth, resolution, and ease in the development and deployment of sources and detectors. However, their poor penetrating capability constitutes a major impediment when used for probing or communicating deep into the ground or the sea.

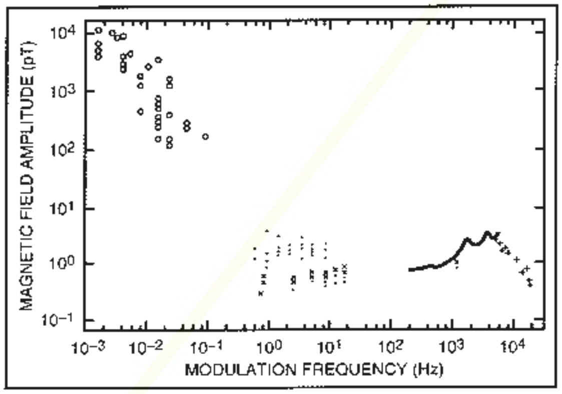
Low frequencies penetrate much deeper into the ground and the sea and have been used for submarine communications and geophysical exploration. However, problems in developing efficient broadband low-frequency sources make the use of low frequencies for subterranean applications difficult. As a result, low-frequency electromagnetic applications have often relied on natural sources, such as lightning and geomagnetic pulsations. But, while natural sources have logistic and interpretative advantages over small artificial sources, they suffer from their inherent unpredictability and the noiselike characteristics of their signal. Furthermore, natural signals are extremely weak in the 1 to 2 kHz and 0.1 to 10 Hz frequency bands. These bands are important in mineral and petroleum exploration.

The HAARP heater, operating in the low-frequency conversion mode, generates controlled, monochromatic, coherent waves between 0.001 Hz and 40 kHz. This source has all the advantages of the natural sources and none of their disadvantages. Thus HAARP fills a long-standing vacuum in controlled electromagnetic sources, with the potential to revolutionize low-frequency remote sensing and communications.



AGU

Magnetic field spectrum of low-frequency waves generated by random natural sources. In the absence of coherent, tunable, low-frequency sources, these waves have been used for underground exploration.



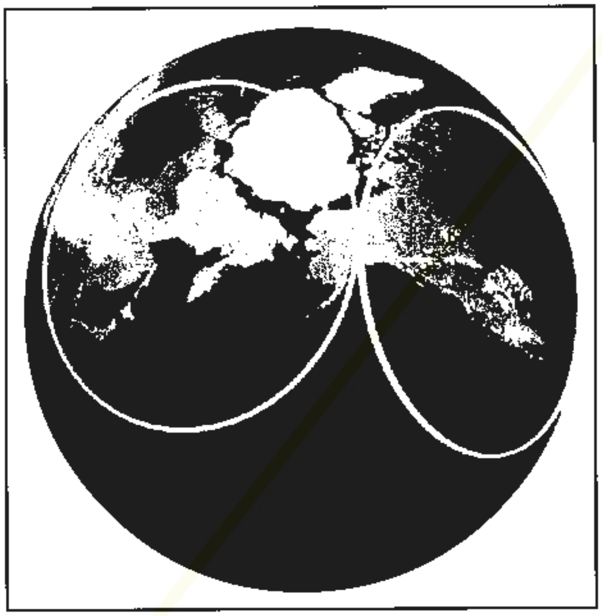
AGU

Magnetic field spectra produced by modulated HF interacting with the ionosphere, constituting a coherent, tunable source. It is expected that HAARP will produce at least one order of magnitude larger amplitudes.

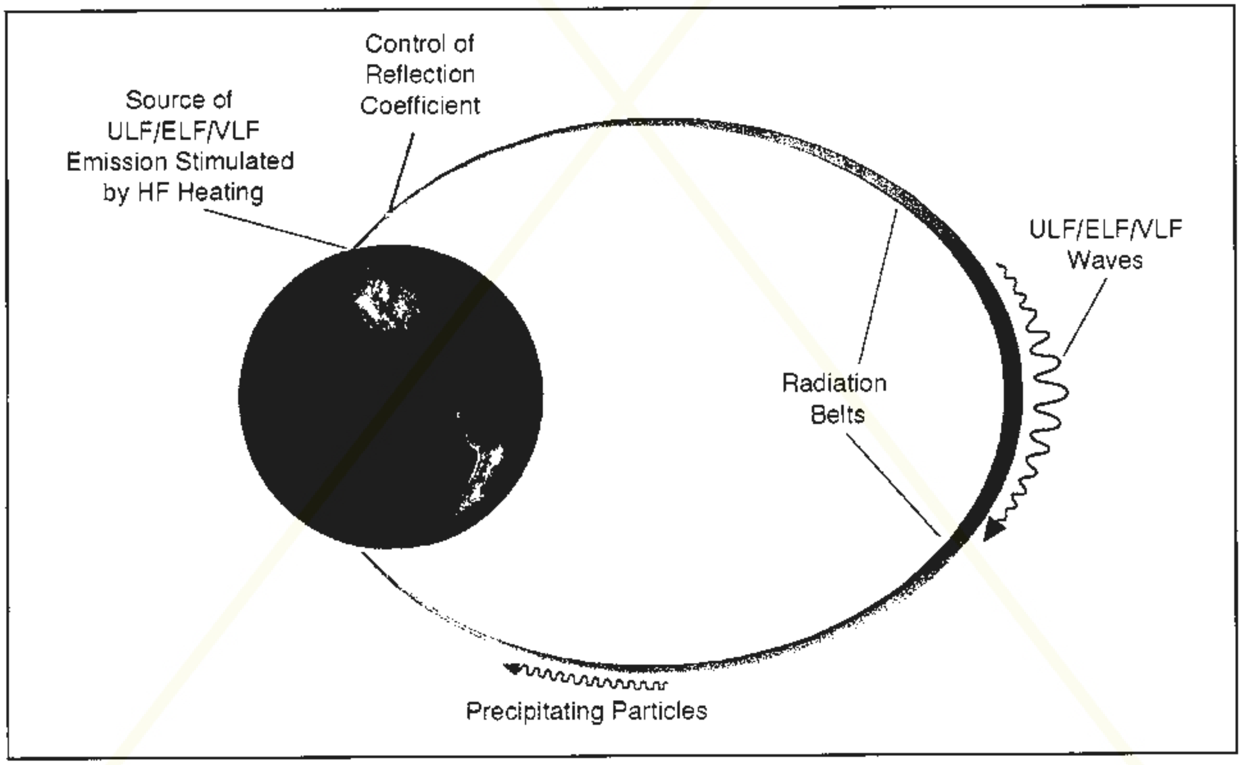
From the AboveTopSecret.com Clifford Stone Document Archive
Commercial use is forbidden. Visit stone.abovetopsecret.com for more information on usage.

Low frequencies propagate as guided waves in the waveguide formed between the conducting ground and the ionosphere, suffering weak attenuation. As a result, a significant fraction of the Earth can be covered from the HAARP site.

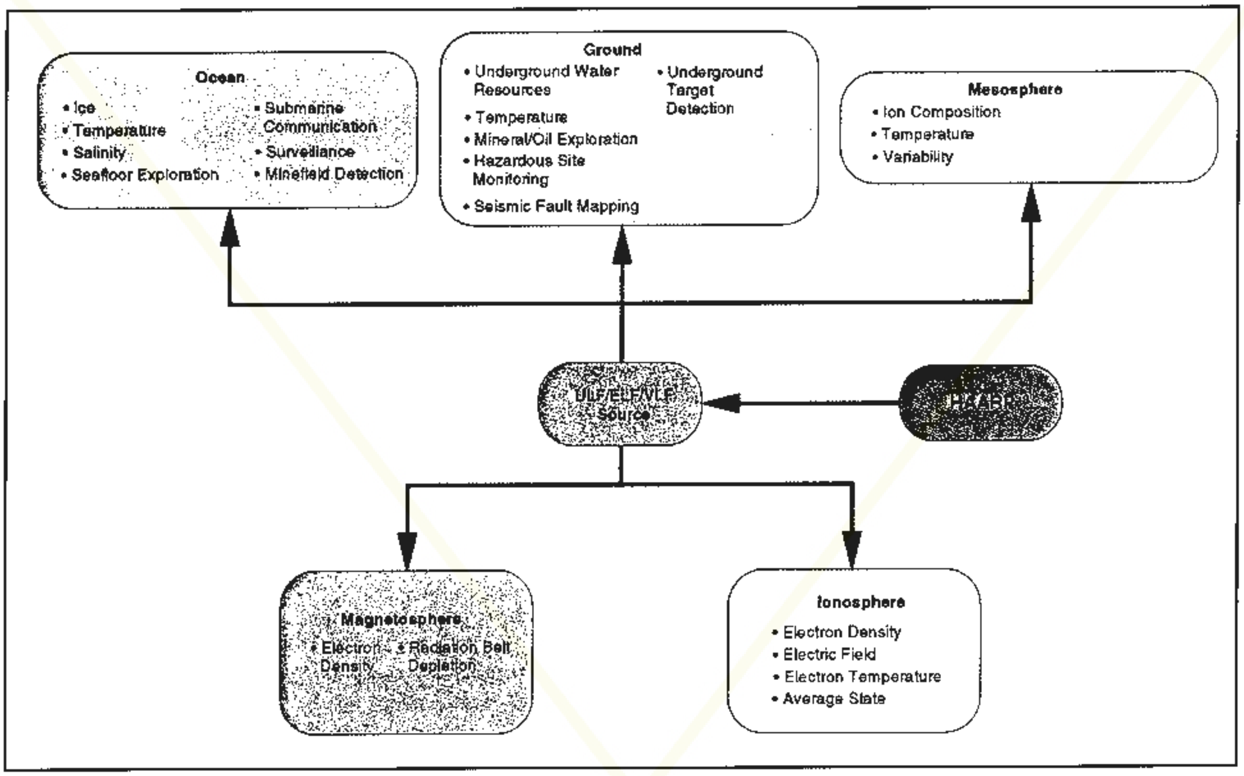
Low-frequency waves injected in the Earth's radiation belts can induce precipitation of the energetic particles trapped in this region of geospace. Harnessing this process could allow control of the flux of energetic particles in particular regions of the radiation belts and could impact the operation and lifetimes of satellites operating in this geospace region.



Expected coverage from HAARP at 100 Hz. The coverage increases faster than linearly with decreasing frequency.



Precipitation of radiation belts particles induced by injection of low-frequency waves



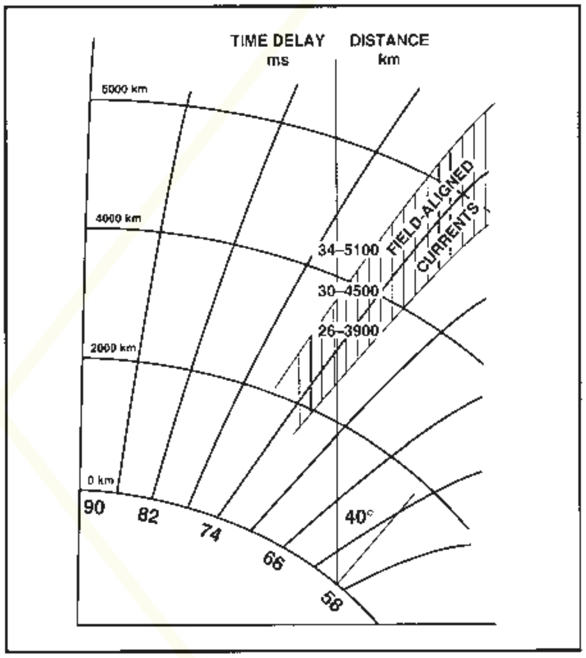
A summary of HAARP applications and parameters that can be probed when operating as a tunable, low-frequency transmitter

The unique features of the HAARP heater operating as a tunable, low-frequency transmitter allow for a wide range of applications, including probing of the underground, the mesosphere, the ionosphere, and the magnetosphere.

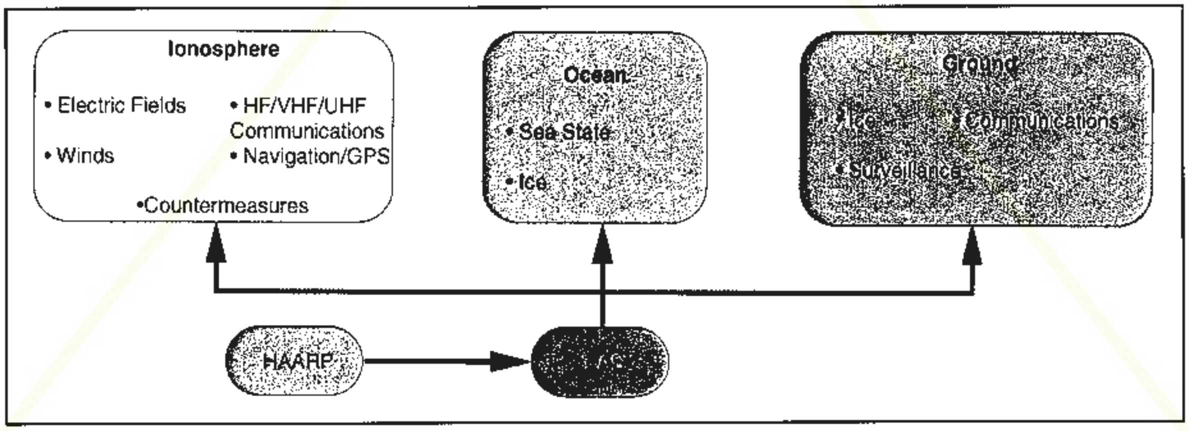
From the AboveTopSecret.com Clifford Stone Document Archive
Commercial use is forbidden. Visit stone.abovetopsecret.com for more information on usage.

HIGH FREQUENCIES

The HAARP transmitter can impact the use of certain HF/VHF/UHF ground-to-ground and ground-to-satellite links by modifying the ionospheric region through which they pass. Of major importance is use of the FAS concept to enhance ground-to-ground and ground-to-satellite links that would otherwise be marginal or absent. Establishment of over-the-horizon VHF/UHF paths will permit new communications, surveillance, and remote sensing systems using ground-based facilities. New ground-to-space paths could extend the coverage range of civilian and military communications and surveillance systems. On the military side, the ionospheric plasma can be artificially structured in the vicinity of transionospheric communication, surveillance, or navigation paths affecting the performance of these systems. In the HF range, the HAARP transmitter can also operate as a radar. When its frequency of operation exceeds the critical frequency of the F Region, it can be used both as an incoherent scatter radar to diagnose high-altitude plasma in the auroral ionosphere and as a coherent radar to probe turbulent processes occurring in the auroral magnetosphere. Similar techniques can be used to probe the solar wind, the solar corona, and planetary bodies and their ionospheres. Finally, novel concepts have been developed using the HAARP transmitter in a radar mode in conjunction with a subaudio acoustic source to probe the auroral stratosphere and mesosphere.



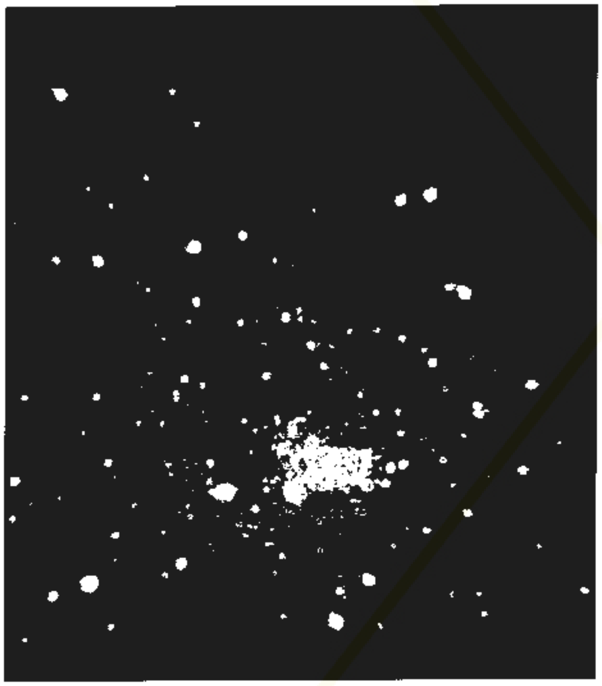
The HAARP as a radar to probe the auroral magnetosphere



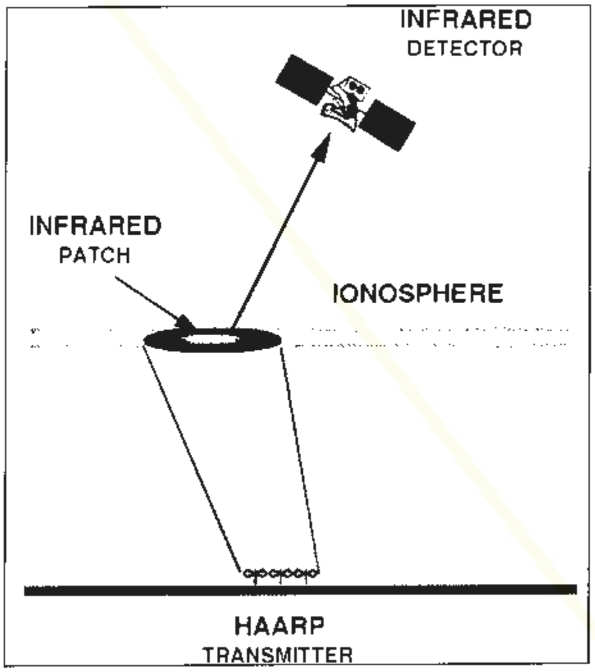
A summary of applications and parameters that can be probed by HAARP in the HF/VHF/UHF range

OPTICAL FREQUENCIES

Under steady-state conditions, a significant fraction of the HF power absorbed by the ionospheric electrons results in atomic and molecular excitation and reradiation in a wide range of optical frequencies. It is expected that, at its highest beam intensity, the HAARP heater will produce airglow with megawatt power mainly in the visible and IR region of the spectrum. The IR emissions are predominantly caused by the indirect excitation of CO_2 molecules and propagate undisturbed upwards, while they are absorbed downwards. They can be detected from properly instrumented satellites located within the line of sight of the modified region. Of particular importance is the proposed U.S.-Russia "RAMOS" satellite, whose orbit will fly over the HAARP site frequently. Measuring the IR and optical emissions with good spatial resolution provides a wealth of information about the state of the ionospheric region in which they were generated, including neutral density structure, wind dynamics, and relative abundance of the IR emitters. The IR emissions, including the potential for striating their source region, have significant military implications to IR detection and countermeasures.



Artificial airglow excited by high-power radio waves

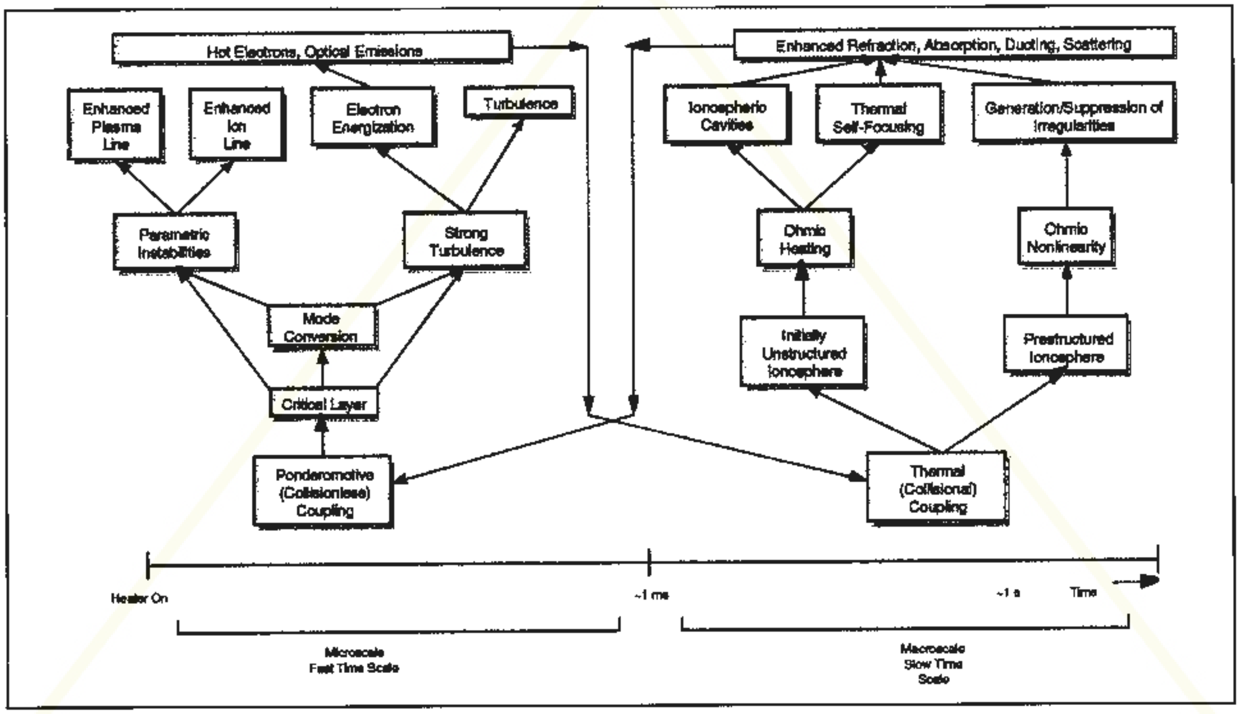


HAARP as an instrument of IR diagnostics of the atmosphere

HAARP – BASIC RESEARCH

GUIDING LIGHT TO THE FUTURE

The wide range of applications of HAARP as a remote sensing and communications instrument represents the fruition of many years of basic ionospheric research conducted in previous, much weaker and less sophisticated installations. In terms of both effective radiated power and flexibility of operation, HAARP constitutes a major advance in ionospheric transmitters. Its design requires that the combination of frequency and the radiated power density exceed the theoretical threshold in which new physical phenomena are expected. Such phenomena include strong nonlinearities associated with solitary waves, onset of turbulence, generation of energetic electron fluxes, IR emissions, and very short scale structures. Past lessons taught us that even more important than the theoretically predicted phenomena are the breakthroughs. New phenomena appear when technological progress allows exploration of the response of nonlinear physical systems under new dynamic conditions. The HAARP will be the guiding light to the future, in a similar fashion as past active ionospheric programs led to the unprecedented range of applications discussed in this publication.

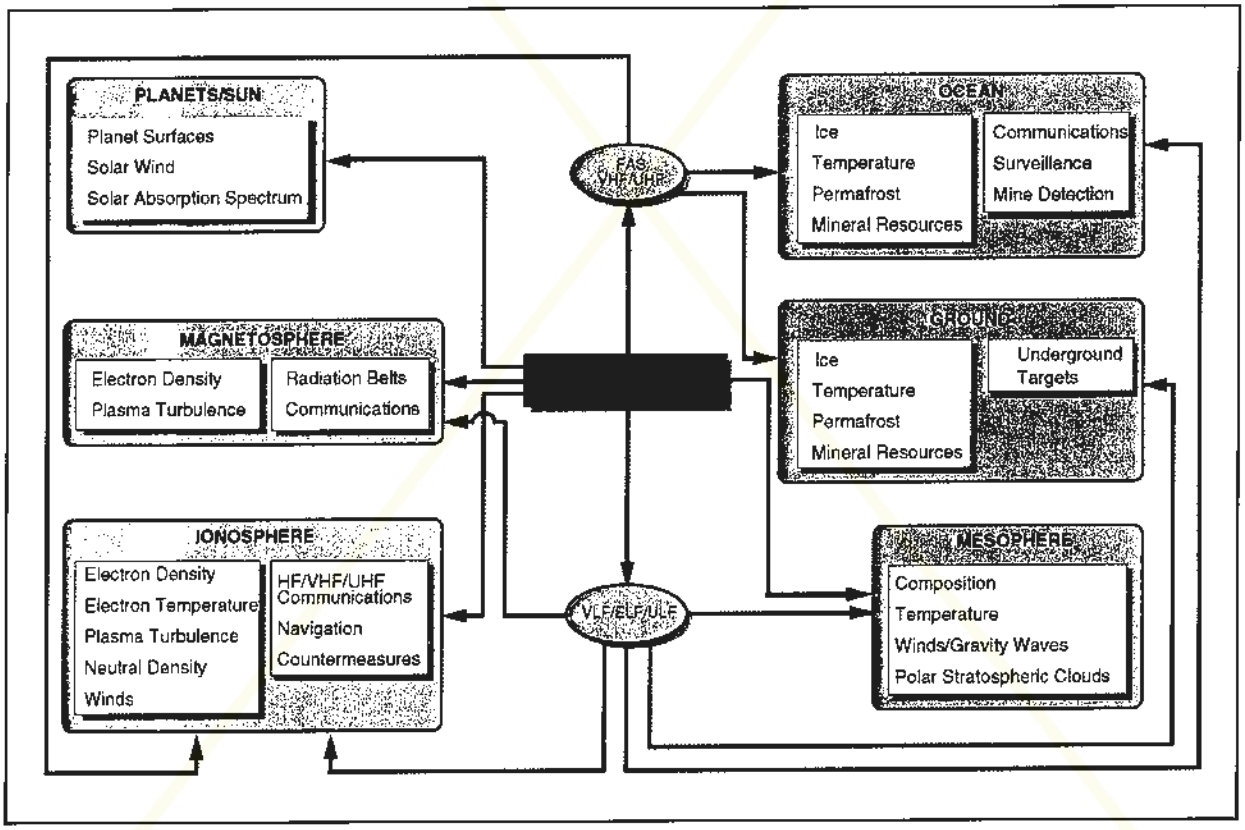


Overview of basic research

CONCLUDING REMARKS

HAARP USHERS IN A NEW SCIENTIFIC ERA FOR THE 21ST CENTURY.

The HAARP represents a technological advancement with capabilities that allow for new and unique dual-use research and application opportunities. Use of the ionosphere as an active, nonlinear medium allows the primary HF energy to be transformed in a controlled fashion into coherent radiation from 0.001 Hz to 40 kHz and into incoherent IR and visible wavelengths. This function, supplemented with the generation of FAS and with the use of the transmitter as a radar, makes the HAARP transmitter a unique source for remote sensing and communication uses.



Three modes of operations of the HAARP heater (radar, VLF/ELF/ULF source, and FAS reflector). Civilian (blue) and military (green) uses and applications are listed for various geophysical regions.

GLOSSARY

ELF	extremely low frequency (0.01–3 kHz)
EM	electromagnetic
FAS	field-aligned scatterers
FO	fiber optic
GCRP	Global Change Research Program
GFLOPS	one billion floating point operations per second
GPS	Global Positioning Systems
HAARP	High-frequency Active Auroral Research Program
HF	high frequency (3,000–30,000 kHz)
IR	infrared
kHz	kilohertz
kW	kilowatt
MB	megabyte
MHz	megahertz
SWIR	short wavelength infrared (700–900 nm)
UHF	ultrahigh frequency (300–3,000 MHz)
ULF	ultralow frequency (< 10 Hz)
VHF	very-high frequency (30–300 MHz)
VLF	very-low frequency (3–30 kHz)

ACKNOWLEDGMENTS

Special thanks to the following persons for their technical assistance.

Don Anderson, Advanced Power Technology, Inc.
John Heckscher, Air Force Research Laboratory
Edward Kennedy, Naval Research Laboratory
Paul Kossey, Air Force Research Laboratory
Sidney Ossakow, Naval Research Laboratory
Ramy Shanny, Advanced Power Technology, Inc.

• • • • • • •

Produced by the Technical Information Division
NAVAL RESEARCH LABORATORY
4555 Overlook Avenue, SW
Washington, DC 20375-5333
Code 5200

Additional copies of this publication are available from the HAARP Program Office, 29 Randolph Rd., Hanscom AFB, MA 01731-3010.

From the AboveTopSecret.com Clifford Stone Document Archive
Commercial use is forbidden. Visit stone.abovetopsecret.com for more information on usage.