Excitation of Magnetospheric Resonators with HAARP

Anatoly V. Streltsov
Embry-Riddle Aeronautical University
HAARP can excite ULF waves inside 1) Global Magnetospheric Resonator and 2) Ionospheric Alfven Resonator

Mechanism of the wave generation is changing of the ionospheric conductivity by heating the ionosphere with RF waves when the electric field exists there.
Global Resonator
HAARP Heating Experiment
Simulations of different heating regimes for IFI excitation

\[ \nabla \cdot \left[ (\Sigma_0 + E \Sigma_P) \right]_\perp = -j_{||} \]

continues heating

single-pulse heating

periodic heating

[Streltsov et al., 2005]
Different Heating Regimes for IFI Excitation

Old approach: heating of the same spot in the ionosphere [Streltsov et al., 2005]
New approach: moving the spot with the phase velocity of the wave [Streltsov and Pedersen, 2010]
HAARP Experiment 29 Oct 2008

HAARP HF digisonde
(A. Lee Snyder)
HAARP Experiment  29 Oct 2008

Gakona, AK

start

end
HAARP all-sky imager
(Todd Pedersen)
UAF/GI magnetometer array (MAGI)

Alaska
Alaska
This is how it happens …
Substorms
HAARP 3D
3D simulations of constant heating (high ionospheric conductivity)
Observations and 3D simulations of effects from the constant heating of F-region

3D simulations of a constant heating of the same spot in the ionosphere (effect at 100 km altitude)

Observations of ring-like structures caused by the ionospheric heating
[Pedersen et al, GRL, 2009]
Ionospheric Alfvén Resonator
Wave reflection from the ionosphere:

\[ E_{\perp r} = R \ E_{\perp i} \]

\[ R = \frac{\Sigma_A - \Sigma_P}{\Sigma_A + \Sigma_P} \]

\[ \Sigma_A = \frac{1}{\mu_0} \nu_A \]

high \( \Sigma_P \): \( R = -0.310 \)

low \( \Sigma_P \): \( R = 0.032 \)

very low \( \Sigma_P \): \( R = 0.510 \)
Night (very low conductivity)
Night (very low conductivity)

N-S B Field (pT²/Hz) (Gakona NI BF4) - UTC 2010-11-09 05:28:00 to 2010-11-09 05:53:00

E-W B Field (pT²/Hz) (Gakona NI BF4) - UTC 2010-11-09 05:28:00 to 2010-11-09 05:53:00
Night (very low conductivity)
IAR, very low conductivity, 1.75 Hz
Conclusions:

1. HAARP can efficiently generate large-amplitude ULF waves inside the global magnetospheric resonator and inside IAR.
2. The wave generation is most efficient when the ionospheric conductivity is very low (nighttime) and the heating is performed with X-mode waves in a frequency range from 2.8 to 4.5 MHz.
3. The structure of the waves inside IAR does NOT allow to make any conclusions about frequency of the resonator by measuring magnetic signals on the ground.
4. The resonant wave can be determined from measuring electric field on the ground or electric and magnetic field on satellites and/or sounding rockets.
Density cavities in a vicinity of auroral arcs

Shepherd et al. [1998]
Density cavities in the downward current channel