Ionospheric modification for pump frequencies around the second electron gyro-harmonic: First results

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High-power high-frequency (HF) radio waves beamed into the ionosphere with O-mode polarization cause plasma turbulence, which can accelerate electrons. These electrons collide with the F-layer neutral oxygen causing artificial optical emissions identical to the natural aurora. The brightest optical emissions are O(1D) 630 nm, with a threshold of ~2 eV, and O(1S) 557.7 nm, with a threshold of ~4.2 eV. The optical emissions give direct evidence of electron acceleration by plasma turbulence. HF pumping of the ionosphere also causes electron temperature enhancements as well as magnetic field-aligned plasma density irregularities. These so-called striations have a symbiotic relationship with electrostatic upper-hybrid waves, which are efficiently produced from the electromagnetic pump wave a few kilometers below the HF reflection altitude. The striations scatter probing radio waves, causing coherent radar backscatter as well as anomalous absorption, which act as proxies for sensing upper-hybrid waves. Stimulated Electromagnetic Emission (SEE) measurements indicate when the pump wave is interacting with the striations for conversion to other electrostatic and electromagnetic waves by mode conversion and parametric decay processes.

O-mode pumping at electron gyro-harmonic frequencies in the ionosphere (multiples of ~1.4 MHz) has special significance as many phenomena change their character. In particular, artificial optical emissions, electron temperature enhancements, anomalous absorption and coherent radar backscatter become strongly reduced for the third and higher gyro-harmonics. SEE change their spectral character when pumping the ionosphere on, close to, or far away from an electron gyro-harmonic frequency.

The HAARP facility in Alaska is unique in that it can operate near the second electron gyro-harmonic frequency. On 25 February 2004, whilst pumping into the magnetic zenith at 2.84 MHz, HAARP made the first known frequency pass through the second gyro-harmonic. Two novel observations are: (1) a strong enhancement of the artificial optical emission intensity, which is opposite to higher gyro-harmonics; (2) the optical enhancement maximum occurs ~7 kHz above the second gyro-harmonic. In addition, two other phenomena were observed: (1) a ring-like optical structure when pumping just above the second gyro-harmonic, which may be similar to the artificial optical annuli reported near the fourth gyro-harmonic from the EISCAT facility in Scandinavia; (2) bright irregular optical structures were created when the pump frequency was up to 450 kHz above the ionospheric critical frequency, which is similar to those reported for higher pump frequencies. On 4 February 2005, the first Kodiak SuperDARN radar backscatter and optical observations were made at HAARP whilst pumping during a frequency pass through the second electron gyro-harmonic. These data show that the striations are greater/smaller for pump frequencies just above/below the second gyro-harmonic, when mode conversion into trapped/untrapped upper-hybrid/electron-Bernstein waves is expected.

Very little theory for plasma turbulence close to the second electron gyro-harmonic (~2.8 MHz in the F-layer ionosphere) exists. However, the threshold for striation onset may be reduced on the second gyro-harmonic, which is consistent with our observations. The ~7 kHz offset is suggestive of the lower hybrid frequency in the ionosphere, which is consistent with parametric decay of the pump wave into an upper-hybrid and lower-hybrid wave. The second gyro-harmonic has an advantage over higher gyro-harmonics in that the upper-hybrid wave's dispersion curve is very symmetric about the second gyro-harmonic, which makes possible a greater frequency range where coupling with the pump wave is possible. This may explain the unusually bright optical emissions observed. Also, the optical data shows evidence that the Thermal Parametric Instability as well as the Parametric Decay Instability are acting simultaneously, switching on or off independently as conditions change in the ionosphere to encourage or discourage each mechanism.