Synthesizing Arbitrary HF Beam Patterns for ELF/VLF Wave Generation

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This paper presents the results of an experimental method to analyze the ELF/VLF generation capability of nearly arbitrary HF beam patterns. The method provides a means to guide future HF heater designs by identifying "ideal" HF beam patterns for ELF/VLF wave generation. Arbitrary HF beam patterns are artificially synthesized in post processing using multiple narrow-beam ELF/VLF wave generation transmissions at the High-frequency Active Auroral Research Program (HAARP) observatory. Experimental observations performed during the February and May 2012 HAARP campaigns as a function of HF beam polarization, azimuth, and zenith angle are used to approximate the results that would occur for broader HF beam patterns formed as a linear sum of the multiple narrow HF beams. The hypothesis is tested experimentally by demonstrating that HAARP's broad-beam transmission pattern can be artificially synthesized using three separate narrow beam transmissions. Based on this successful result, we are able to predict the effective HF beam pattern that would maximize the ELF/VLF wave amplitude at a given ELF/VLF receiver location.

During the February and May 2012 HAARP campaigns, the HF beam was aimed in nine different directions: vertical, and the eight cardinal and ordinal azimuthal directions at 15° off-zenith. At each location, the HF beam transmitted at 3.25 MHz (both X- and O-mode separately) with a narrow HF beam modulated by an AM sine wave. The modulation frequency varied linearly from 0.5 kHz to 6.5 kHz over 6 seconds. The observed amplitudes and phases for each heating location are combined in post-processing to identify the ideal synthesized HF beam pattern. Time-of-arrival (TOA) analysis is applied in this experiment to study the interference pattern created as a function of ELF/VLF propagation path, in addition to a conventional frequency analysis that is used to study the synthesized HF beam pattern as a function of frequency.