HF Heating of the Ionosphere: An Interesting Source of ELF and VLF Waves

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The generation of radio waves in the extremely low frequency (ELF, 3-3000 Hz) and very low frequency (VLF, 3-30 kHz) bands is highly desirable due to their use in a wide range of practical and scientific applications. ELF/VLF waves propagate great distances (>10,000 km) around the globe with relatively low attenuation (<1 dB/1000 km) due to the fact that they efficiently reflect off of both the ground and the lower ionosphere (below ~100 km altitude). ELF/VLF waves also penetrate deeply (10's of meters) into seawater. Due to these characteristics, ELF/VLF signals are ideally suited for providing communication channels otherwise unreachable assets, such as submerged vehicles and personnel. ELF/VLF signals can also provide excellent timing synchronization across the globe among a variety of submerged and top-side assets. Global navigation and timing solutions, similar to, but coarser than those provided by the Global Positioning System (GPS) can also be achieved using phase-stable ELF and VLF signals.

Despite the large number of applications employing ELF/VLF waves, conventional methods still have difficulty efficiently generating ELF/VLF waves. High frequency (HF, 3-30 MHz) heating of the ionosphere has been investigated since the 1970's and to this day remains an important unconventional means for generating ELF/VLF waves. Controlled ionospheric heating results when HF signals propagate through the lossy lower ionosphere: the ionosphere absorbs energy from the wave, this energy is converted to heat, and the ionospheric electrons are the primary absorbers of this energy. As a result, the electron temperature increases, and tends to follow (nonlinearly) the power envelope of the HF signal. Thus, when the HF signal is modulated, the electron temperature is similarly modulated. Modulating the electron temperature of the lower ionosphere produces periodic oscillations in the collision frequency and the conductivity of the region. ELF/VLF waves are radiated when these oscillations produce an ELF/VLF current density.

Since 2007, the University of Florida has conducted experimental observations during a wide variety of HF ionospheric heating experiments at the High frequency Active Auroral Research Program (HAARP) observatory in Gakona, Alaska. We compare these observations with ELF/VLF waves generated by more conventional means (such as the Siple transmitter in the Antarctic). We consider how the HAARP-based results can be used to drive other more compact means for generating ELF and VLF waves. We present ideas for future experimental work at HAARP that could impact the development of other ELF/VLF generation techniques.