Magnetic Response of the Ionosphere to Pulsed Heating

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Generation of ELF/VLF waves by modulating ionospheric currents, such as the auroral electrojet, has been accomplished using a number of ionospheric heating facilities. The observations have generated several physics puzzles predominantly due to the non-linear physics involved in the interaction of modulated HF power with the ionospheric plasma. Critical among the various outstanding issues are:

- Scaling of the HF to ELF/VLF conversion efficiency as a function of the HF frequency and ionospheric parameters
- The extent and cause of harmonic generation
- Near vs. far field propagation

In this paper it shown theoretically and confirmed experimentally that all of the above puzzles can be understood by taking into the account that the magnetic response of the ionosphere to a heating pulse depends critically on the ratio T/T_s, of the pulse duration T to the time T_s required for the electron temperature of the heated region to reach saturation. The latter is a function of the heater ERP and HF frequency and of the ionospheric electron density profile in the lower ionosphere. For current HAARP parameters and nighttime conditions is approximately $T_s \approx .125$ msecs. Using a Green's function formalism it shown that the magnetic field on the ground generated by the modulated current in the heated region by the pulse has two separate sources: The first is proportional to the time derivative of the current and has the form $\frac{1}{cR}\frac{\partial J(t)}{\partial t}$, while the second is due to the current itself and has the traditional near field form $\frac{J(t)}{R^2}$, where R is the distance between current source and the observation point. We refer to the first term as the magnetic impulse response of the ionosphere to heating. This contribution was not previously recognized nor appreciated theoretically or experimentally. It is shown theoretically and experimentally using HAARP that the impulse response is between 15-20 dB larger than the response due to the current for $T/T_s \leq 1$. For heating pulses with $T/T_s >> 1$, the magnetic response has two components: The first is on due to the time derivative of the current is a magnetic impulse with duration of the order of T_s. The second is an approximately square magnetic pulse with duration T, and amplitude 3-5 times smaller than the impulse amplitude. This is the first theoretical and experimental verification of the two time response of the ionosphere to pulsed heating. An analysis is presented that shows that by applying these results to modulated heating all of the puzzling features mentioned previously are resolved. A series of experiments conducted at HAARP using modulated heating confirmed the above analysis and revealed several critical physics aspects of the ionospheric ELF/VLF generation, including the limits of HF to ELF/VLF conversion efficiency, bandwidth limitations and signal purity. The relevance of the results to the conduct of future experiments using the upgraded HAARP heater will also be addressed.