#94 Received 01/20/2015

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**Expanding the Frequency Resolution of TOA Analysis Applied to ELF/VLF Wave Generation Experiments at HAARP**

Abstract:
Modulated HF heating of the ionosphere in the presence of natural ionospheric current sources has been used to generate electromagnetic ELF/VLF waves since the 1970's. In the ~1-5 kHz band, the amplitude and phase of the received ELF/VLF signal depends on the amplitude and phase of the conductivity modulation generated throughout the HF-heated ionospheric body, as well as on the signal propagation parameters (i.e., the attenuation and phase constants) between each of the current sources and the receiver. Previous signal processing advances have produced an accurate ELF/VLF time-of-arrival (TOA) analysis technique that differentiates line-of-sight and ionospherically-reflected signal components, which allows the amplitude and phase of each component observed at the receiver. This TOA method requires a wide bandwidth in order to have accurate time resolution (_ 2.5 kHz) and therefore is relatively insensitive to the frequency-dependent nature of ELF/VLF wave propagation. In this paper, we present an improved ELF/VLF TOA method that is capable of providing high frequency resolution. The new analysis technique is applied to experimental observations of ELF/VLF signals generated by modulated heating at HAARP. We present measurements of the amplitude and phase of the received ELF/VLF signal as a function of frequency and compare the results with the predictions of an HF heating model.