Interharmonic modulation products as a means to quantify nonlinear D-region interactions

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Experimental observations performed during dual beam ionospheric HF heating experiments at the High frequency Active Auroral Research Program (HAARP) HF transmitter in Gakona, Alaska are used to quantify the relative importance of specific nonlinear interactions that occur within the D region ionosphere. During these experiments, HAARP broadcast two amplitude modulated HF beams whose center frequencies were separated by less than 20 kHz. One beam was sinusoidally modulated at 500 Hz while the second beam was sinusoidally modulated using a 1–7 kHz linear frequency-time chirp. ELF/VLF observations performed at two different locations (3 and 98 km from HAARP) provide clear evidence of strong interactions between all field components of the two HF beams in the form of low and high order interharmonic modulation products.

From a theoretical standpoint, the observed interharmonic modulation products could be produced by several different nonlinearities. The two primary nonlinearities take the form of wave-medium interactions (i.e., cross modulation), wherein the ionospheric conductivity modulation produced by one signal crosses onto the other signal via collision frequency modification, and wave-wave interactions, wherein the conduction current associated with one wave mixes with the electric field of the other wave to produce electron temperature oscillations. We are able to separate and quantify these two different nonlinearities, and we conclude that the wave-wave interactions dominate the wave-medium interactions by a factor of two. These results are of great importance for the modeling of transioinospheric radio wave propagation, in that both the wave-wave and the wave-medium interactions could be responsible for a significant amount of anomalous absorption.