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

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Overview

- Experimental Description
- Time-of-Arrival analysis
- Modified TOA method
- “Notching”
- Results
- Conclusions

Experimental Description

- HF Carrier Wave
- VLF Amplitude Modulation
- Ionospheric Heating
- Non-linearities
- Linear Frequency-time ramp

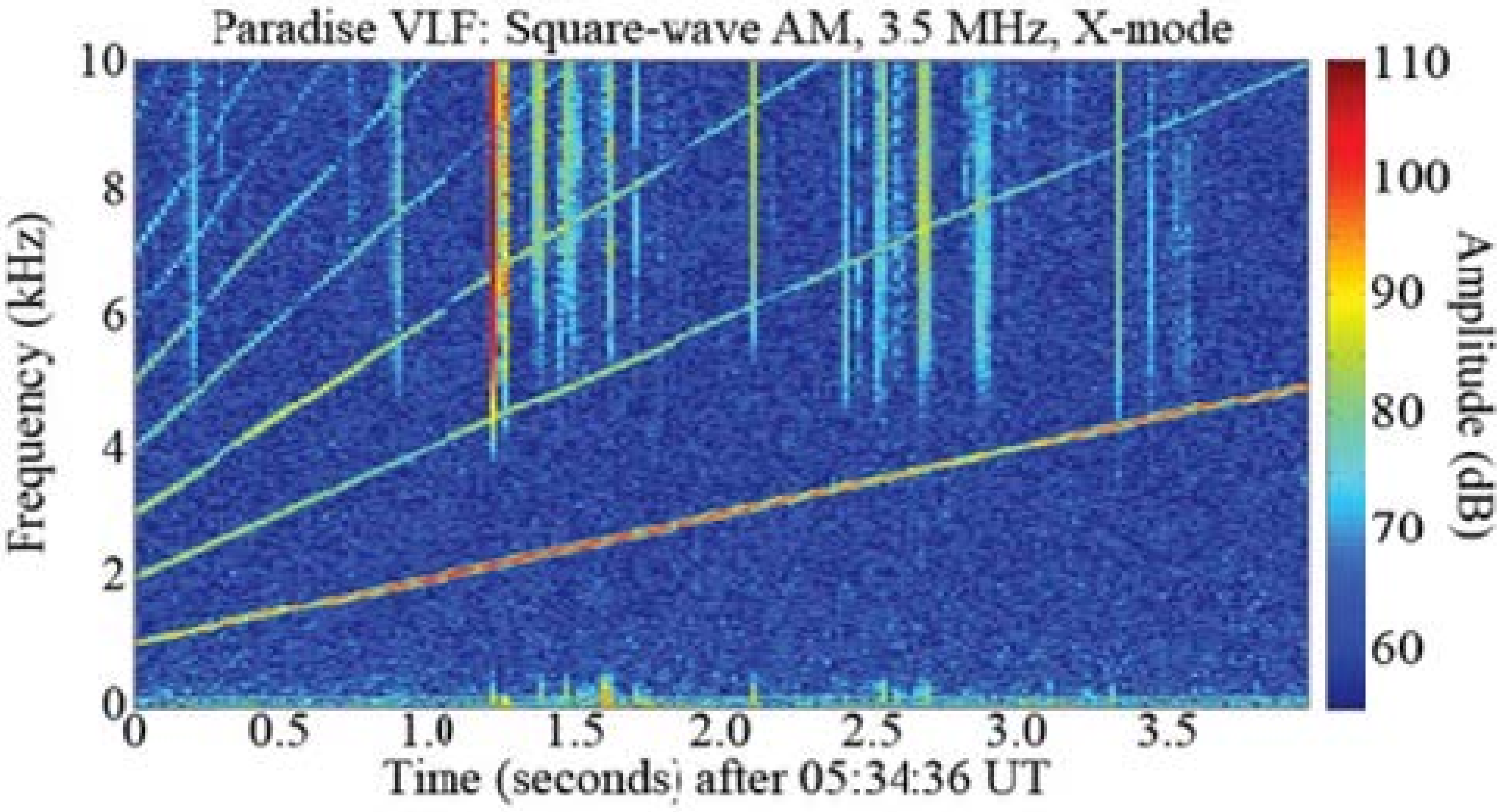
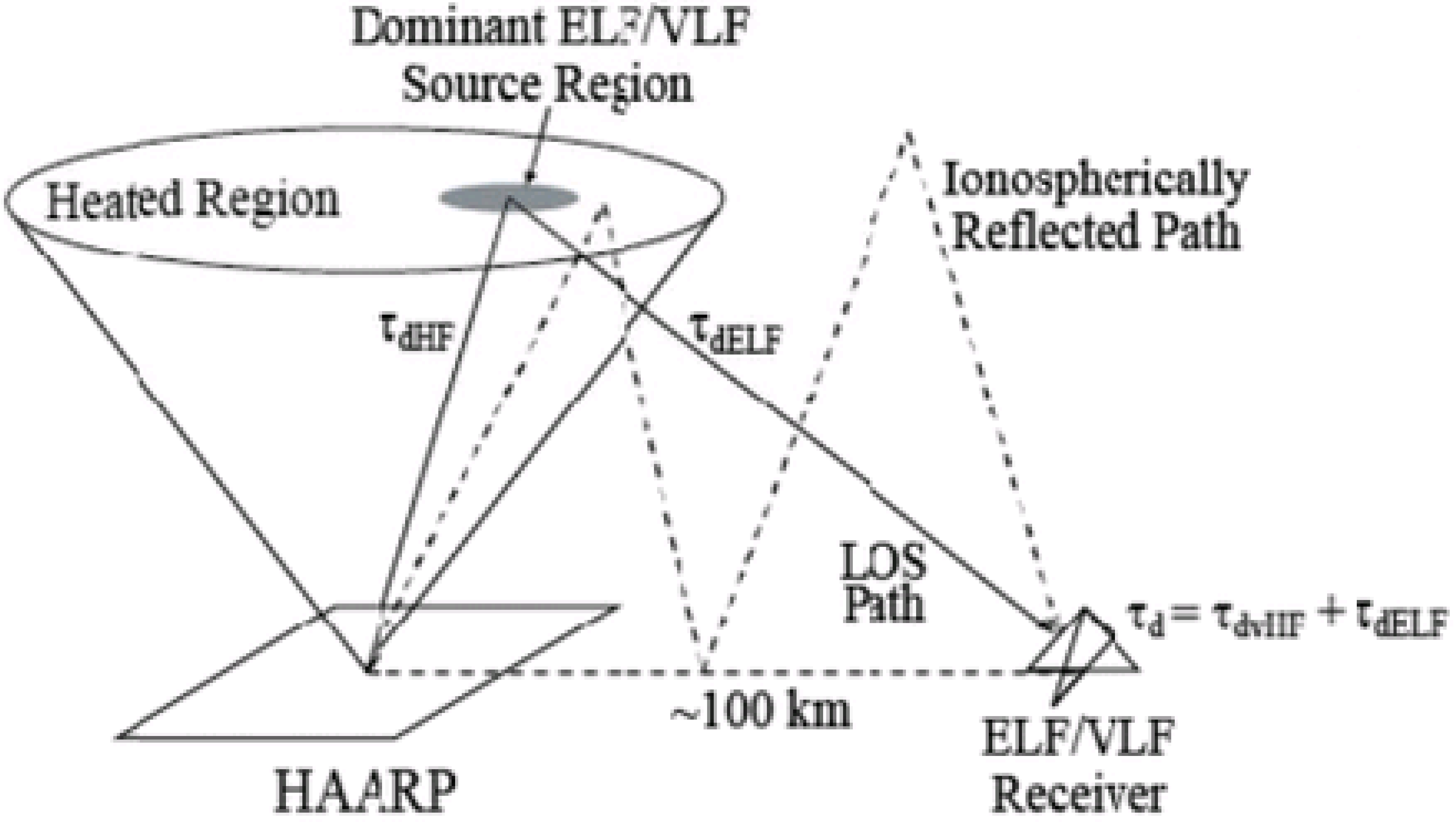


Diagram of Experimental Setup

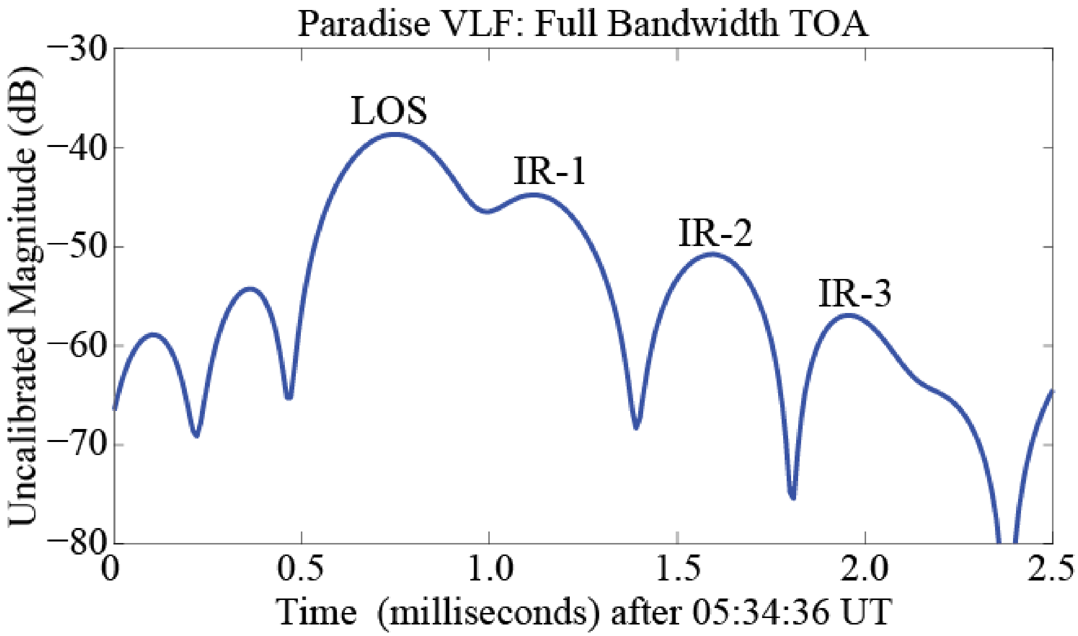


Experimental Details

- The experiment related to the modified TOA method was conducted at the HAARP Observatory in Gakona, Alaska.
- HF beam directed 15^{o} off zenith and at 81 ^{o} azimuth, towards the receiver at Paradise. (~ 100 km distant)
- HF transmission at 3.25 MHz (x-mode) and square wave AM Modulated at 100% depth with linear VLF frequency-time modulation from 1-5 kHz over 4 seconds
- The receiver used is composed of 2 orthogonal magnetic loop antennas, sampled at 100 kHz and synchronized by GPS. Located approx. 100km distant HAARP

Time-of-Arrival (TOA) Analysis

- Measures signal propagation delay
- Determines amplitude and phase as a function of time
- Time resolution dependent on reciprocal of bandwidth
- Large bandwidth required for accurate frequency resolution



Modified TOA analysis method

- Begins at signal reception
- Filtering process
- Impulse Response Function
- Preparing for “notching”
- Taylor-Series Expansion
- Solve quadratic
- Calculate amplitude, phase, and TOA with enhanced frequency resolution

The Impulse Response

$$h(t) = \sum A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \text{sinc}(BW(t-\tau_n)) \sim A e^{j\phi} e^{j2\pi f_c(t-\tau)} \text{sinc}(BW(t-\tau))$$

- Not approximate

$$h(t) = \sum_{n=0}^{f_{\min}} A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \text{sinc}(BW(t-\tau_n)) + \sum_{n=f_{\max}}^{5\text{ kHz}} A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \text{sinc}(BW(t-\tau_n))$$

- Approximate

The “Notching” process & solved Quadratic

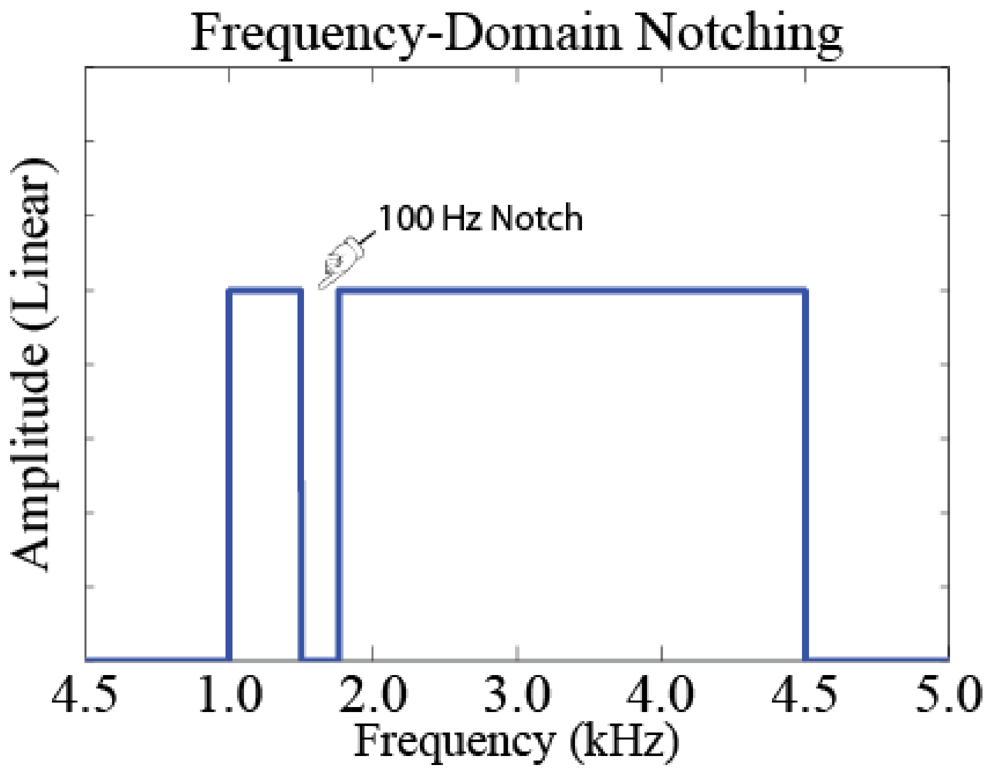
$$h(t) = \sum A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \,\mathrm{sinc}(\mathrm{BW}(t-\tau_n)) \sim A e^{j\phi} e^{j2\pi f_c(t-\tau)} \,\mathrm{sinc}(\mathrm{BW}(t-\tau))$$

$$\Downarrow$$

$$h(t) = \sum_{n=0}^{f_{min}} A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \,\mathrm{sinc}(\mathrm{BW}(t-\tau_n)) + \sum_{n=f_{max}}^{5\text{ kHz}} A_n e^{j\phi_n} e^{j2\pi f_c(t-\tau_n)} \,\mathrm{sinc}(\mathrm{BW}(t-\tau_n))$$

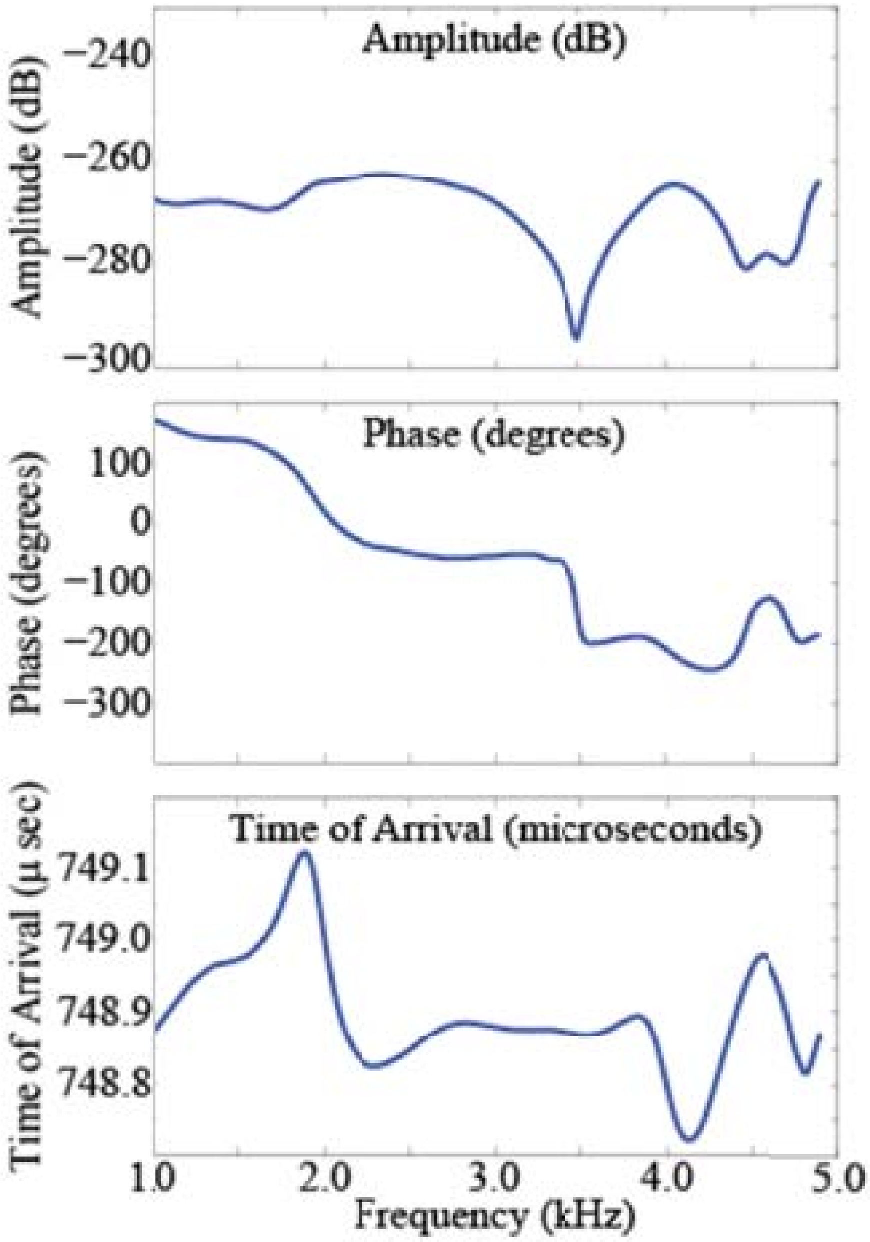
$$\Downarrow$$

$$A_f e^{j\phi_f} = \frac{A_T e^{j\phi_T}[1 + j2\pi f_c(\tau_D-\tau_T) - (2\pi^2 f_c^{\,2} + \pi^2\mathrm{BW}^2)(\tau_D-\tau_T)^2] - A_D e^{j\phi_D}}{[1 + j2\pi f_c(\tau_D-\tau_f) - (2\pi^2 f_c^{\,2} + \pi^2\mathrm{BW}^2)(\tau_D-\tau_f)^2]}$$



Results

- Modified TOA method successfully calculates frequency dependence
- Some error is introduced in the signal processing technique
  (e.g., amplitude null near 3.5 kHz)



Conclusions

- The high frequency resolution TOA method produces results consistent with expectations below approximately 3 kHz.
- The null observed near 3 kHz is likely a signal processing effect.
- Future plans involve higher order Taylor-Series approximations and investigating the role that Ionospheric Reflections play at higher modulation frequencies.