Stimulated Electromagnetic Emission measurements from the September 2017 HAARP Campaign

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Abstract

Report is made here of **Stimulated Electromagnetic Emissions (SEE)** observed during ionosphere interaction experiments conducted at the **High Frequency Active Auroral Research Program (HAARP)** facility in Gakona, Alaska during September 2017. The HAARP facility transmit frequency was stepped in the vicinity of the 3^{rd} harmonic of the electron cyclotron frequency ($3\omega_{ce}$).

- SEE is secondary radiation produced from a high power high-frequency EM wave-ionosphere interaction.
- SEE has been observed in **Laser Plasma Interactions (LPI)** and ionospheric heating.
- **Narrowband SEE (NSEE)** is SEE that exist **within** ± 1 kHz of the pump wave frequency.
- **Wideband SEE (WSEE)** is SEE that exist **outside** ± 1 kHz of the pump wave frequency.

Powerful plasma diagnostics from SEE spectra include

- Electron temperature
- Turbulence state
- Ion composition

Second Harmonic Generation (SHG) refers to the occurrence of SEE near $2\omega_0$ upon incidence of an EM wave of frequency ω_0 on the ionosphere. Results of two investigations are presented here.

1. **Experiment #1**: Temporal evolution and comparison of NSEE/WSEE
2. **Experiment #2**: SHG dependence on transmit power and frequency offset from $3\omega_{ce}$

Experiment Design

Parameter	Experiment #1	Experiment #2
Pump wave characteristics	CW O-mode	CW O-mode
Transmit power	Constant 2.88 MW	Linear ramp 86.4 kW-2.88 MW
Beam orientation (Zenith/Azimuth)	$14^o/198^o$	$14^o/198^o$
Transmit frequency (ω_0)	4.15 MHz-4.35 MHz 20 kHz step	4.20 MHz-4.36 MHz 20 kHz step
ON/OFF timing	**60** sec ON/**15** sec OFF	**45** sec ON/**15** sec OFF

Table 1: Transmit station parameters

- Results presented are from RFSpace SDR-IP receivers connected to a linear dipole oriented orthogonal to general direction of HAARP facility.

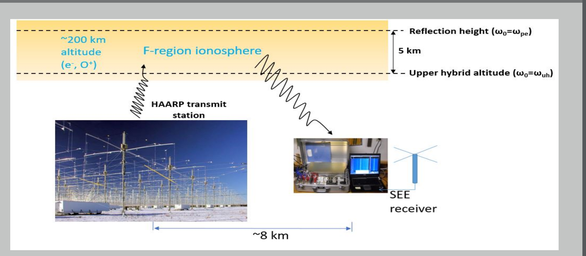

Figure 1: Experimental set-up and experiment description

Experiment #1 Results: NSEE/WSEE Temporal Evolution

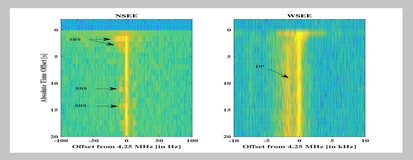

Figure 2: Spectrograms showing *bursty* NSEE (left) and *continuous* WSEE (right)

- NSEE is due to Stimulated Brillouin Scatter (SBS) at plasma resonance altitude in this case.
- WSEE e.g Downshifted Peak (DP) is due to parametric decay instabilities at upper hybrid altitude involving ion acoustic decay modes.

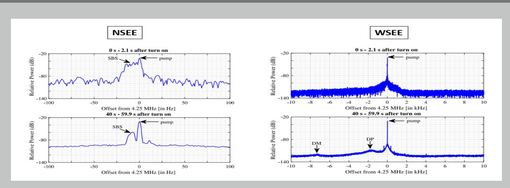

Figure 3: Power spectral density (PSD) showing different characteristics for NSEE (left) and WSEE (right)

- NSEE is broad, extremely strong at pump turn ON and becomes more distinct and slightly weakened towards end of cycle.
- WSEE is not evident initially. DP and Downshifted Maximum (DM) WSEE evident towards cycle end.

Experiment #2 Results: SHG Dependence on Transmit Power

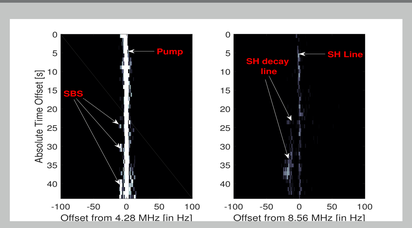

Figure 4: Spectrograms showing NSEE near $\omega_0 = 4.28$ MHz (left) and NSEE near $2\omega_0 = 8.56$ (right) MHz i.e. SHG

- Second harmonic (SH) decay line offset from $2\omega_0$ is approx. twice SBS line offset from ω_0.
- A theory in **Unmagnetized** LPI where the incident EM pump wave EM_0 decays into a Langmuir wave LW and an ion acoustic wave IA and the subsequent mixing $LW + LW$ potentially explains the generation of the SH decay line.

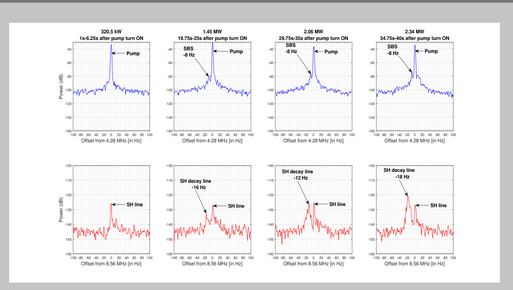

Figure 5: Power spectral density (PSD) showing transmit power dependence of NSEE near $\omega_0 = 4.28$ MHz (upper row) and NSEE near $2\omega_0 = 8.56$ MHz (lower row)

- Onset times of SBS line and SH decay line are similar.
- These are the first reported SHG observations within ± 30 Hz of $2\omega_0$.

Experiment #2 Results: SHG Dependence on Offset of ω_0 from $3\omega_{ce}$

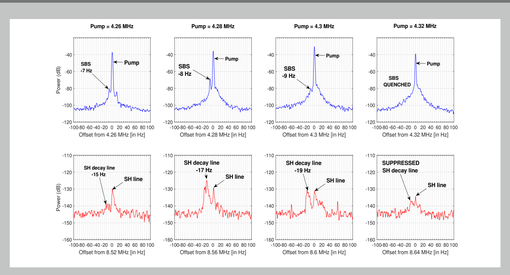

Figure 6: Power spectral density (PSD) showing SHG (lower row) and SBS (upper row) dependence on frequency stepping near $3\omega_{ce}$

- $3\omega_{ce}$ was computed from ionogram data and the IGRF model to be **4.324** MHz.
- Confirmation of past research that SBS line is suppressed close to $3\omega_{ce}$.
- SHG now shown to also be suppressed close to $3\omega_{ce}$.
- Confirms results from Experiment **#1** that second harmonic (SH) decay line offset from $2\omega_0$ is approx. twice SBS line offset from ω_0.

Conclusions

- Underlying production mechanisms for NSEE and WSEE confirmed to be fundamentally different.
- NSEE provides better resolution and more accurate plasma diagnostics than WSEE.
- First reported observations of SHG within ± 30 Hz of $2\omega_0$ and comparison with NSEE near ω_0.
- Powerful plasma diagnostics known in LPI e.g **velocity of the plasma resonance region**, **spread of plasma velocities** etc. could possibly be utilized for ionopheric heating.

Acknowledgments

The work at Virginia Tech (ADY, WAS) was supported by the National Science Foundation (NSF) under grant AGS-1633931 and the Virginia Tech IGEP-Remote Sensing Fellowship. The NRL staff (PAB, CLS) were supported by NRL 6.1 Base Program and AFRL.

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