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FIRST OBSERVATIONS OF STIMULATED ELECTROMAGNETIC EMISSION (SEE) AT THE SPEAR HEATING FACILITY

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Abstract. The results of the first stimulated electromagnetic emission (SEE) observations at the SPEAR (Space Plasma Exploration by Active Radar) heating facility are reported. SEE observations are one of the key ground-based diagnostics of ionospheric plasma excitation by powerful radio frequency (RF) transmissions. The observations presented here were recorded during the February-March 2007 experimental campaign at the SPEAR heating facility. During time periods when foF2 was higher then pumping frequency (4.45 MHz, near the 3rd gyroharmonic) well developed features of SEE were observed. As examples of these features, here the down-shifted maximum and broad continuum of SEE spectra are presented. The observations of the SEE demonstrate clearly that the ionospheric plasma was excited by the SPEAR heating facility. The polar cap location of the SPEAR makes it a new and convenient tool for the investigation of nonlinear plasma processes in the very high latitude regions.

1. Introduction

The stimulated electromagnetic emission (SEE) is a weak signal generated as result of the excitation of the ionospheric plasma by powerful, O-mode polarised radio waves transmitted from the ground and occupy a band of ~300 kHz around the transmit frequency. A SEE spectrum consists of a number of features which depend on the ionospheric conditions, gyroharmonic and the duty cycle employed in the pump wave. The frequency of the pump waves (f_{pump}) is chosen to be slightly lower than the F2-region critical frequency (f_oF2). The ionospheric conditions, oder of gyroharmonic wich is close to the f_{pump} and duty cycle determine what non-linear processes will be generated in the ionospheric plasma. This fact allows various spectral features to be attributed to different plasma processes. During high duty cycles steady state spectral features such as the downshifted maximum (DM) and broad continuum (BC) are attributed to the formation of field-aligned striations (FAS) in the ionosphere (Leyser, 2001 and references therein). Usually such steady state features are generated by long pulses of the radio frequency (RF) pump wave (~ minutes) or through continuous wave (CW) transmission. The DM and BC are amongst the most intense spectral features of the SEE which were observed at the first experiments when the SEE was discovered at the EISCAT heating facility (Tromsø, Norway) in 1981 (Thidé et al., 1982).

During ionospheric heating experiments high power radio waves are transmitted into the ionospheric plasma. The ionospheric heating facility consists of powerful high frequency (HF) transmitters and an antenna array which focuses the transmitted power into a narrow ionospheric region to increase the effectiveness of the plasma stimulation. The resulting SEE signal is, however, weak and takes up a wide frequency band, thus the SEE measurements require a ground-based receiver with a high dynamic range and a wide frequency band. Usually a digital system is required. The intensity of SEE can be about 60 dB lower than the pump wave reflected from the ionosphere, and thus the dynamic range of the receiving equipment must be at least ~100 dB. Simple electric dipole antennas are commonly used as receiving antennas. The distance between heating facility and receiver is typically tens of kilometres, although this distance is not critical.

2. Experiment description

The SPEAR (Space Plasma Exploration by Active Radar, Robinson et al., 2006; Yeoman et al., 2006) heating facility is situated on Spitzbergen in the Svalbard archipelago at geographic coordinates 78.15°N and 16.06 °E. SPEAR is designed to carry out a range of space plasma investigations of the polar ionosphere and magnetosphere. The SPEAR site is located adjacent to the EISCAT Svalbard Radar (ESR). The SPEAR antenna system comprises a 6×4 array of full-wave, crossed-dipoles, 16 m above the ground, with an antenna spacing of 48.4 m, allowing the transmission of both linear and circularly polarised signals. The individual dipoles are rhombically broadened to allow operation between 4 and 6 MHz. The resulting beam has a quasi-elliptical cross-section, with an average half-power width of 21° along its major axis and 14° along its minor axis. This results in an overall antenna gain of 21 dB. Individual phase-control provides beam-steering within ±30° from zenith, at any azimuth, without significantly altering the antenna gain or introducing significant side-lobe signals. The beam may thus be pointed in directions which include vertical and field-aligned. Beam-steering to angles further from the zenith may be achieved but in this case significant side-lobes are introduced into the radiation pattern. SPEAR has a distributed transmitting and receiving system consisting of individual 4-kW solid-state transmitters connected to the antenna array. Each transmitter consists of a single driver-stage and 4 individual 1-kW modules, the outputs of which are combined and fed to the antenna. In the 4×6 configuration 48 such transmitters are required. These are made up of 192 power-amplifier modules, 48 driver stages and a total of 240 power-supply units. Each transmitter contains an embedded controller and an individual Direct Digital Synthesiser (DDS) which provides a transmit signal and the IF for the receiver front-end.

For the amplitude measurements of the SEE presented here one channel of an HF-inteferometer designed in the Polar geophysical institute (PGI) is employed. This interferometer has previously been used for the determination of the angle-of-arrival of SEE signals at the Sura (Nizhniy Novgorod, Russia) and EISCAT (Tromsø, Norway) heating facilities (Isham et al., 2005; Tereshchenko et al., 2006). The HF-interferometer consists of an HF-receiver with a high dynamic range and a band width of 300 kHz, a digital system for the conversion and recording of the received signal, and HF and IF notch filters. The receiver has 4 channels, but for the amplitude measurements presented here only one of them was used. The receiving antenna consisted of a dipole antenna with 9 m masts. The data logging system uses 2 16-bit analogue-digital converters (ADC) with 2 channels on each and a sampling frequency of 60 MHz. All channels of the ADC can work in synchronous and nonsynchronous modes. The HF and IF notch filters can be used for enlarging the dynamic range of the ADC. The receiving point was located at a PGI observatory with coordinates: 78.094°N and 14.208°E, located at about 40 km distance in a south-west direction from the SPEAR site.

3. Experimental results

On 5th March 2007 the SPEAR heating facility operated with the complete 6×4 SPEAR array available (48 transmitters) at $f_{\mathrm{pump}} = 4.45$ MHz, which produced an antenna gain of 21 dB. The transmitters were operated at 2kW, resulting in an Effective Radiated Power (ERP) for SPEAR of ~ 15 MW. The beam direction was field-aligned (8° south of vertical), and the duty cycle was 2 min.-on 2 min-off.. The ionogramme observed by the SPEAR ionosonde at 10:30 UT is shown in Figure 1. The vertical dotted line denotes the lowest sounding frequency, and the vertical dashed line the pump wave frequency. It is clearly seen that f_oF2 at this time was slightly higher than the pump frequency (on the figure the pump frequency is indicated by a dashed line). Figure 2 presents a spectrum calculated from records observed at about 10:28 UT. For this calculation a 3.2 s time record of the signal has been used. The width of the spectrum is 60 kHz on either side of the pump frequency. The spike at 4.45 MHz is due to the pump wave reflection from the ionosphere. The central part of the spectrum, with a width of about 3 kHz is suppressed about 30 dB by the IF notch filter. Narrow spikes symmetric around the pumping frequency are harmonic components of the transmitter power supply. In the higher frequency part of the spectrum these harmonics are clearer, because in the lower frequency part the harmonics are masked by the intense SEE signal.

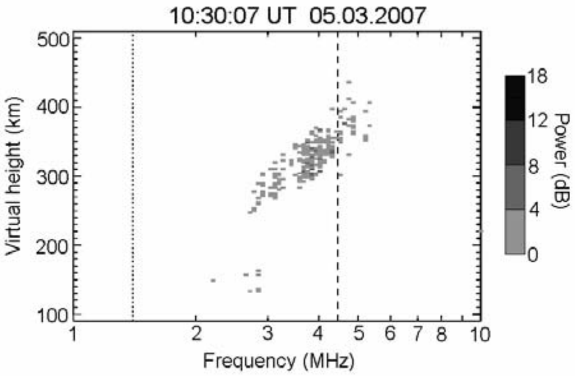

Figure 1. The ionogramme observed by the SPEAR ionosonde on 5th March 2007 at 10:30 UT.

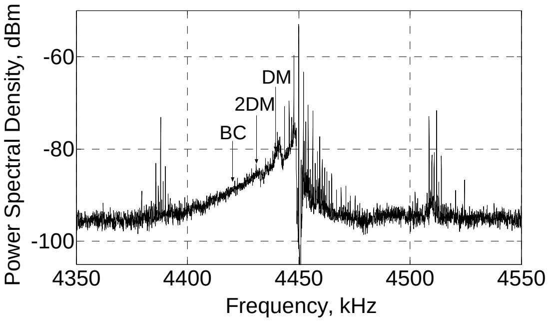

Figure 2. The SEE spectrum observed on 5th March 2007 at 10:30 UT.

The SEE spectrum presented in Figure 2 demonstrates the asymmetry of the SEE spectrum (with the lower frequency part more intense than higher frequency part). At $\Delta f_- = 9.5$ kHz below the reflected signal the DM component of the SEE can be seen. The intensity of the DM signal is about -78 dBm (it is about 18 dB higher then a noise level). There is also clear evidence of a frequency specific character of the DM feature: the higher frequency part of the DM is shorter than the lower frequency part. At a frequency $f_{2\mathrm{DM}} = 4431$ kHz ($\Delta f_- = 19$ kHz) lower than the pump frequency, the second harmonic of the DM (2DM) can be seen with intensity about -85 dBm. A wide band feature of the SEE, BC appears in the lower frequency part of the DM at a frequency of 4.397 MHz ($\Delta f_- = 53$ kHz).

A second observation, obtained under different prevailing ionospheric conditions on 9th March 2007 is presented next. The ionospheric conditions are illustrated by the ionogramme from 12:06 UT in

Figure 3. The ionospheric critical frequency was again just above the pump frequency, but the ionosphere was stronger, and the virtual reflection height lower, than in the first interval. At this time SPEAR was operating at the same frequency and beam direction, but a CW duty cycle was used, apart from the first 10 mins. of each hour, in order to enable the ESR to take data from an unmodified ionosphere, and to allow the SPEAR ionosonde to take a clear ionospheric sounding. In this case 45 of the 48 transmitters were available, resulting in an ERP for SPEAR of ~ 13 MW. The SEE spectrum measured at 12:12 UT is presented in Fig. 4. In this spectrum the DM (with an intensity of -82.5 dBm) and the 2DM (with an intensity of -90 dBm) can both be seen. In this case the DM signal exceeds the noise level by 20.5 dB but the BC is narrower (Δf_- = 42 kHz).

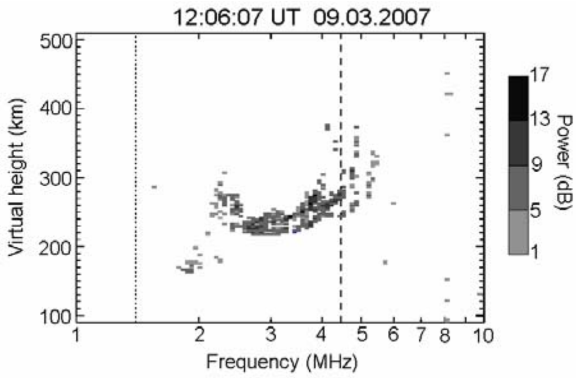

Figure 3. The ionogramme observed by the SPEAR ionosonde on 9th March 2007 at 12:06 UT.

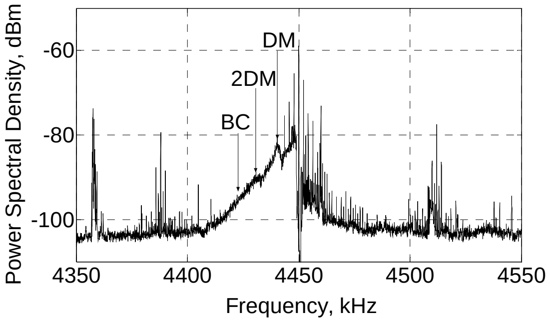

Figure 4. The SEE spectrum observed on 9th March 2007 at 12:12 UT.

4. Conclusions

The results of a series of RF heating experiments show the well-known features of steady state SEE during periods when f_oF2 were higher then pump frequency (4.45 MHz, near the 3rd gyroharmonic). The observed intensity of the DM was about 20 dB higher than the observed noise levels. Simultaneously with the DM a well developed BC was also observed. The BC signal takes up a ~50 kHz frequency interval. During time periods when f_oF2 fell below the pump frequency SEE was not observed. The variability of the polar cap ionosphere makes the SEE observation difficult, but also of great interest.

The observations of the steady state features of the SEE demonstrate that the ionospheric plasma was clearly excited by the SPEAR heating facility, and are the first such observations at the large magnetic dip angle (82°) at SPEAR. The polar cap location of the SPEAR makes it a new and convenient tool for the investigation of nonlinear plasma processes in the polar region.

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