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# WIDEBAND VLF ELECTROMAGNETIC BURSTS OBSERVED ON THE DE 1 SATELLITE

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*Abstract.* Wideband VLF electromagnetic bursts are observed on the DE 1 satellite by both the electric and magnetic field sensors in the frequency range of 0.650 kHz to 16.0 kHz. The impulsive signals endure for a relatively short time (~1 s or less) and exist in the frequency range from well below to well above the local gyrofrequency. They are typically found at $L > 4$ over a $\sim 40°$ range of latitudes including the geomagnetic equator and are often accompanied by discrete emissions or a band of hiss. Some observed features are consistent with previous observations of electrostatic plasma waves [*Ondoh et al.*, 1989; *Reinleitner et al.*,1983]; however, the magnetic measurements clearly indicate that the impulsive signals are electromagnetic in nature, a result that has not been reported before. The possibility of spacecraft discharge effects as the cause of these signals is discussed.

## 1. Introduction

The broadband electric field spectra of the wideband VLF electromagnetic burst emissions observed on DE-1 are found to be similar to those reported for electrostatic bursts observed on the ISEE 1 satellite [*Reinleitner et al.*, 1983] and impulsive plasma waves observed on the DE 1 satellite in the earth's magnetosphere [*Ondoh et al.*, 1989], and on Voyager 1 and 2 in the Jovian and Saturnian magnetosphere [*Barbosa et al.*, 1981; *Reinleitner et al.*, 1984]. The previous observations were interpreted as electrostatic signals generated by a resistive medium instability [*Reinleitner et al.*, 1983; *Ondoh et al.*, 1989]. Although the results presented in this paper are consistent with several features of the signals documented in earlier studies, we present for the first time evidence of the electromagnetic nature of burst type emissions. We also show that the frequency range and the bandwidth of the emissions is much larger than previously reported for similar burst type emissions [*Ondoh et al.*, 1989]. In the light of these new observations, the previous theories of the generation mechanisms of impulsive emissions, at least in some cases, may need to be revised.

## 2. Observations

The data utilized in this paper were acquired on the DE 1 satellite during the period January 1985 - December 1989. The data were acquired using the linear wave receiver (LWR) and wideband receiver (WBR) on the DE 1 satellite [*Shawhan et al.*, 1981].

Figure 1 shows typical spectra of broadband electromagnetic bursts. Figure 1a top panel shows the VLF spectra received on the LWR in the 10-18 kHz range on 1 Feb 1985. The LWR was switched from $E_x$ antenna to $B$ loop at 1703:50 UT. The wideband bursts indicated by dashed lines are the signals under consideration in this paper. Note that they cover the entire spectral band shown and are detected on both electric and magnetic antennas. A sudden increase in the background level at 1703:54 UT is due to a change in the gain state of LWR. The duration of the bursts is of the order of ~100 ms to ~1 s. They rise and fall quite abruptly exhibiting negligible dispersion. At times they occur in quick succession giving appearance of a continuous noise lasting several seconds. The local gyrofrequency ($f_H$) during this DE 1 pass was 9.9 to 11.4 kHz, so that the bursts shown occur above the local $f_H$. The typical plasma frequency ($f_P \sim 9\sqrt{N}$, $N$ in el/cc) at the satellite location is >20–30 kHz [*Carpenter and Park*, 1973]. Note that there is no propagating cold plasma wave mode above $f_H$ and below the local plasma frequency ($f_P$) [*Helliwell*, 1965]. The bottom panel of Figure 1a shows the 1.5-4.5 kHz spectra received by WBR on the $E_x$ antenna. A band of chorus is observed between 2.5 and 3.5 kHz. Dashed lines joining top and bottom panels indicate a temporal correlation between rising chorus elements in the lower panel and the electromagnetic bursts in the top panel. While many chorus elements are correlated with electromagnetic bursts, not every chorus element corresponds to an electromagnetic burst. The spectral and temporal characteristics of the electromagnetic burst emissions reported here and their association with rising chorus elements are very similar to those reported by Reinleitner and coworkers for electrostatic burst emissions observed on ISEE 1 and Voyager 2 [*Reinleitner et al.*,1983; *Reinleitner et al.*, 84].

Figure 1b shows the spectrum of electromagnetic bursts in the 0–5 kHz frequency band observed on 8 Jan 1987. Several bursts are seen on the magnetic field spectra between 2335:27 and 2335:38 UT and two bursts are seen on the the electric field spectrum at 2335:44 and 2335:46 UT. The bursts occur below the local gyrofrequency, $f_H$ (10.4 kHz), and are accompanied by a strong band of hiss between 1 and 2 kHz, with no chorus present. Unlike chorus which is characterized by discrete elements, hiss generally has a diffuse spectrum [*Helliwell*, 1965]. Such signals were previously observed on the DE 1 satellite using the WBR (0.65 - 10 kHz) connected to the $E_x$ antenna [*Ondoh et al.*, 1989]. Our data shows the bursts as received on both electric and magnetic antennas.

Figure 1c shows the spectrum of electromagnetic bursts observed in the 0–20 kHz range on 01 FEB 1985. The LWR was in the 10–16 kHz band and the WBR was in the 0.65–10 kHz band. The LWR was toggled between $E_x$ and $B$, while WBR was connected to $E_x$ throughout. Impulsive bursts are found simultaneously on both the electric and magnetic antennas on the LWR and on the electric antenna on the WBR, showing that the frequency of electromagnetic bursts cover a frequency range from well below the local gyrofrequency to well above local gyrofrequency.

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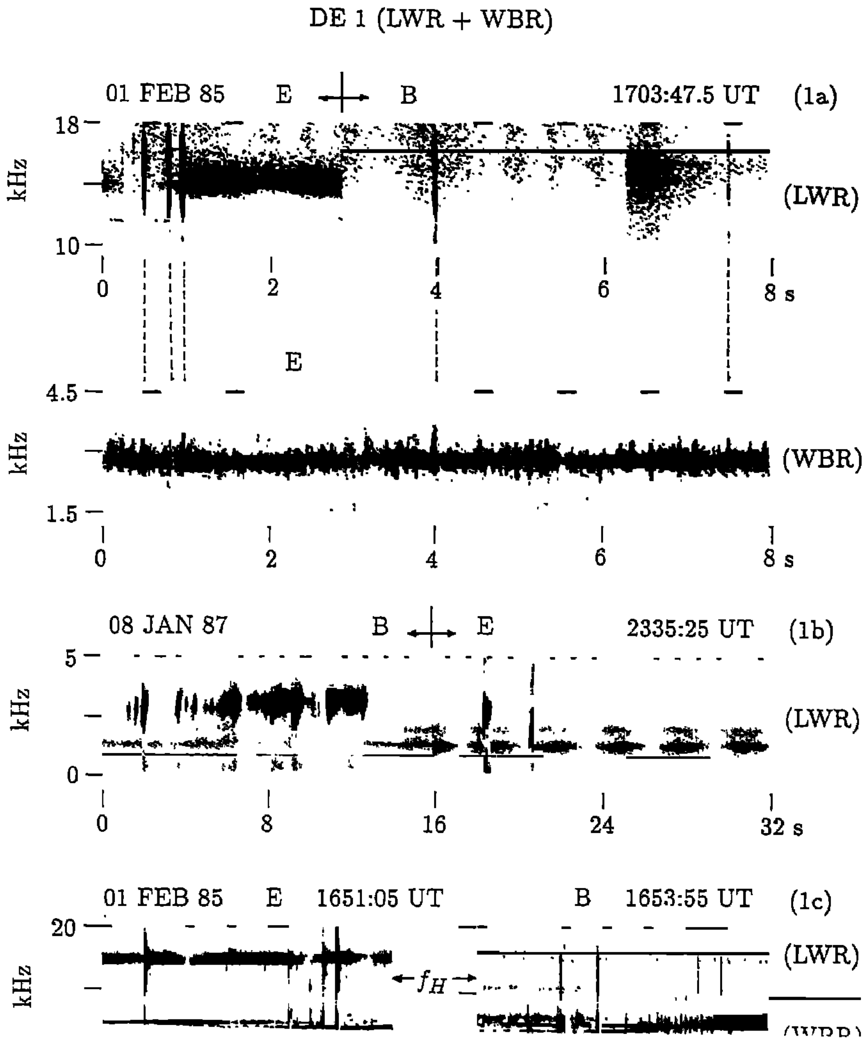

Fig. 1. (a) Association of electromagnetic burst emissions measured on electric and magnetic antenna (top panel) with individual chorus elements measured on electric antenna. (bottom) ($L = 4.5, \lambda_m = 10°N, \phi_g = 134°W, f_H \sim 10.5$kHz) (b) occurrence of electromagnetic bursts emissions in the presence of hiss ($L = 4.9, \lambda_m = 15°N, \phi_g = 125°W, f_H \sim 10$ kHz), (c) occurrence of electromagnetic burst emissions in the frequency band extending from well below to well above local gyrofrequency ($L = 4.4, \lambda_m = 7°N, \phi_g = 137°W, f_H \sim 10$ kHz).

Table 1 gives the local time, $L$-shell range, geomagnetic latitude and frequency of burst emissions observed on five representative passes. The table also contains local gyrofrequency estimated from dipole model and location of plasmapause estimated from $K_{P_{max}}$ using an empirical formula given by Carpenter and Park[1973]. In general these emissions are found near and outside the plasmapause in the geomagnetic latitude range of ±40°; a similar latitude range and L-shell range was found by *Ondoh et al.* [1989] in their study of impulsive emissions. While the latitude range of electrostatic bursts observed by *Reinleitner et al.*[1983]was same, they reported observations at higher L-shells (9-12 $R_e$). While the burst emissions are found commonly at locations and local times shown in Table 1, a detailed investigation of the occurrence rates has not yet been done.

Figure 2 gives absolute intensities of electric and magnetic fields observed on 01 Feb 1985. At any time the LWR can be connected to either $E_x$ antenna or $B$ antenna. Thus no simultaneous measurements of electric and magnetic fields are possible. In Figure 2, the electric and magnetic field intensities were measured in a 1 kHz band centered around 13.5 kHz. The signal frequency was above the local gyrofrequency of $< 12$ kHz, where no propagating cold plasma mode exists (assuming $f_p > 18$ kHz, or $N > 4$ el/cc) [*Helliwell*, 1965]. The average $cB/E$ ratio for burst emissions is 3.4. On another day, 8 Jan 1987, the electric and magnetic intensities were measured in a 2 kHz band centered at 3.2 kHz, placing the signal frequency below the local gyrofrequency ($\sim 10$ kHz). The propagating mode at this frequency is the whistler mode. The average $cB/E$ ratio for burst emissions observed on this day was 6, somewhat below, but not inconsistent with the average expected value of 8-10 for cold plasma whistler mode propagation for the locations of DE 1 observations [*Helliwell*, 1965]. Figure 2 also shows that (1) the bursts often

TABLE 1

| | 01FEB85 | 08JAN87 | 14NOV87 | 17AUG89 | 06JUL89 |
|---|---|---|---|---|---|
| **UT** | 1651-1720 | 2318-2344 | 1113-1143 | 1620-1650 | 0616-0644 |
| **LT** | 0130 | 1445 | 0720 | 0030 | 0230 |
| **L-Shell** | 4.3-4.8 | 4.6-5.2 | 3.8-6.0 | 3.3-4.0 | 4.35-4.85 |
| $\lambda_m$ | 5°N-13°N | 12°N-20°N | 23°N-38°N | 5.5°S-8°N | 5.6°S-13.7°S |
| **Freq(kHz)** | $< .65- > 16$ | $< 1.5- > 5$ | $< .65- > 16$ | $< .65- > 16.0$ | $< 1.5- > 3.0$ |
| $f_H$ | 9.9-11.4 | 10.5-10.9 | 14.8-22.8 | 14.0-25.1 | 9.9-11.0 |
| $K_{P_{max}}$ | 4 | 2 | 5 | 5 | 5 |
| $L_{PP}$* | 3.8 | 4.7 | 3.3 | 3.3 | 3.3 |

*$L_{PP} = 5.6 - 0.46K_{P_{max}}$ [*Carpenter and Park* 1973]

occur in bunches usually of 15-30 s duration, (2) the intensity of these emissions varies over an order of magnitude within a bunch, and (3) in general the average intensity increases with the increases in the L-shell and latitude of the satellite location.

## 3. Discussion

We begin our discussion with a brief summary of our observations and a comment on the magnetic field measurements. Then we compare our observations with previous observations[*Reinleitner et al.*, 1983; *Ondoh et al.*, 1989], and finally, we suggest a possible generation mechanism for electromagnetic burst emissions.

1. The burst emissions reported here are found near and outside plasmapause in geomagnetic the latitude range of ±40°. These emissions are characterized by their wide bandwidth and bursty nature in time (fast rise and fall time) and endure for < 1s. They often occur in bunches and at times they occur in a quick succession giving appearance of a continuous broadband noise.

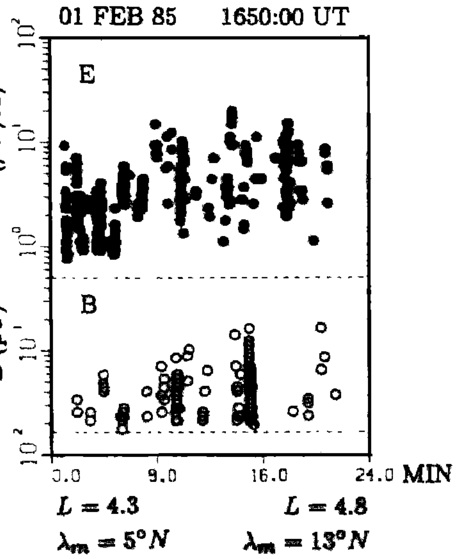

Fig. 2. The electric (shaded circles) and magnetic (unshaded circles) field strengths for electromagnetic burst emissions observed on 01 FEB 1985. The top and bottom dashed lines indicate the background noise level for electric and magnetic field respectively.

2. The burst emissions are observed on both electric and magnetic antennas. Their $cB/E$ ratio is ~5. They are found more often on electric antenna compared to magnetic antenna, possibly due to lower sensitivity of magnetic antenna. Previous observations of electrostatic waves using electric and magnetic antennas on the DE 1 satellite clearly indicate that bursts observed on the magnetic antenna are not an instrumental effect caused by capacitive coupling in the antenna switch [*Inan and Bell*, 1985].

3. These electromagnetic burst emissions exist at frequencies below the gyrofrequency (Fig 1b), above the gyrofrequency (Fig 1a), as well extending from well below the gyrofrequency to well above the gyrofrequency (Fig 1c) to the upper cutoff of LWR at 16 kHz (This frequency is generally lower than the typical plasma frequency of 20-30 kHz or above at locations where measurements were performed).

4. Often (though not always) the impulsive emissions are correlated with chorus hooks and sometimes are accompanied by band of hiss [*Ondoh*, 1989].

The spectral and temporal character, location of occurrence and their occasional association with hiss of the burst emissions reported here, are consistent with the previous DE 1 observations of impulsive plasma wave emissions observed by *Ondoh et al.* [1989]. With only electric field measurements available on WBR (0.65-10 kHz), *Ondoh et al.* reported these emissions in the frequency range of 1-9 kHz, and provided a generation mechanism in terms of an electrostatic resistive medium instabilty (see below). Our observations increase the frequency range to 16 kHz and show that these emissions are electromagnetic, implying that the electrostatic instability mechanism previously provided may need revision.

The comparison of our observations with those of *Reinleitner et al.* [1983] is made somewhat difficult due to non-overlapping regions where the measurements were performed in these two studies. The apogee of DE 1 satellite has limited our observations to less than 4.6 $R_e$. *Reinleitner et al.* [1983] have reported observations of electrostatic bursts on the ISEE 1 satellite between 9 and 12 $R_e$, within ±30° magnetic latitude range and on the dayside magnetosphere. The principal agreements between our observations and those of *Reinleitner* *et al.* [1983] are similar temporal and spectral signatures of the phenomena, similar latitude range, and association with chorus elements. We found emissions on both electric and magnetic antennas with $cB/E$ ratio about 5. *Reinleitner et al.* [1983] found them only on the electric antenna. However, the sensitivity of their magnetic field antenna put a lower limit of 4 on measurable $cB/E$ ratio, a value close to that measured on our receiver on the DE 1 satellite. The frequency range of burst emissions observed on the DE 1 satellite ranged from well below the electron gyrofrequency to well above the electron gyrofrequency. The upper cutoff measurement was not possible due to the 16 kHz upper cutoff of the receiver (below the typical local plasma frequency of 20-30 kHz). *Reinleitner et al.* [1983] found the frequency of the emissions to lie between the gyrofrequency and the plasma frequency. *Reinleitner et al.* [1983] have given polarization measurements (at least in one case), showing that electric field vector is aligned with the geomagnetic field. We have not yet carried out these measurements. *Reinleitner et al.* [1983] also show modulation of electrostatic bursts by the chorus waveform. This detailed analysis of the intensity correlation between individual chorus elements and burst emissions is beyond the scope of this paper. Therefore, while there are several similarities and reasons to indicate that the electromagnetic burst phenomena reported here and electrostatic burst emissions reported by *Reinleitner et al.* [1983] may be the same phenomenon, further work is needed to unambiguously confirm their similarity.

The mechanism suggested by Reinleitner et al. [1983] and also used by Ondoh [1989] has two stages. In the first stage, electrons in the range of few hundred eV are trapped in the potential well of $E_{\|}$ of chorus elements (or hiss in the case of Ondoh et al. [1989]) and thus form a beam of electrons with velocity $V_0$. Then in the presence of thermal electrons of rms thermal velocity $V_T$, where $V_0/V_T$ is of the order of 1, a resistive medium instability[*Briggs*, 1964] acts to generate the burst type emissions. This mechanism has three serious shortcomings in explaining our observations: (1) The resistive medium instability is an electrostatic instability and thus can not explain the generation of the magnetic component observed in our data. (2) The resistive medium instability has relatively small growth rates for frequencies less than 60% of the local plasma frequency. The frequency range of our observations of these emissions extend down to less than 10% of the local plasma frequency. (3) The impulsive emissions can occur even in the absence of chorus or hiss [*Ondoh et al.*, 1989].

To generate wideband electromagnetic waves, a time varying current of appropriate amplitude and time duration is required. The relatively short and bursty character (fast rise and fall time) and the indication that these waves are locally generated suggest spacecraft discharge as a possible mechanism. It has been shown [*Woods and Wennas*, 1985] that blowoff electrons from differentially charged dielectrics on the spacecraft surface can get accelerated in the strong fields due to spacecraft charging. The accelerated electrons form the current that can generate electromagnetic radiation. The blowoff electrons in turn are generated by energetic particles that might fall on the dielectric surfaces. In this mechanism, the correlation of chorus elements could be understood if we keep the first stage of the Reinleitner mechanism, i.e., formation of a beam of electrons by the chorus waves. Further, as long as there is some cause (e.g. energetic particles arriving during a substorm) for blowoff electrons to be emitted, and enough spacecraft charging exists, we would expect to observe burst emissions even in the absence of chorus. Studies of the spacecraft discharge phenomenon have revealed that it is strongly dependent on the ambient plasma density and occurs more frequently at lower plasma densities[*Balmain*, 1986]. This might explain the occurrence location (outside the plasmasphere) of burst emissions.

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