

Observations of VLF Hiss at Very Low L Values

DONALD A. GURNETT

*Department of Physics and Astronomy
University of Iowa, Iowa City, Iowa 52240*

1. INTRODUCTION

Observations of intense bursts of very-low-frequency (VLF) radio noise at low altitudes near the magnetic equator are reported using data from the Injun 3 satellite. The spectral characteristics of these radio noise events typically consist of hiss extending from about 1 kHz to above 8.8 kHz (the highest frequency measured). These equatorial VLF hiss events are very similar to VLF hiss commonly found near the auroral zone.

During the ten-month lifetime of Injun 3, a total of ten VLF hiss events occurred below 35° magnetic latitude with noise spectral densities exceeding 3×10^{-10} gamma² Hz⁻¹. All of these events occurred below 350-km altitude and at L values less than 1.2. Nine of the events occurred below 20° magnetic latitude.

The frequency-time spectra of these equatorial VLF radio noise events typically consist of broad-band (1–10 kHz) noise classified as VLF hiss, in accordance with the classifications given by Gallet [1959]. The spectral characteristics of these equatorial VLF hiss events, which we call *equatorial VLF hiss*, are very similar to a type of broad-band VLF hiss found near the auroral zone and variously called auroral hiss [Martin *et al.*, 1960], VLF hiss [Morozumi, 1963; Jørgensen, 1966; Gurnett, 1966] or, as we shall call it, *auroral-zone VLF hiss*.

The observation of VLF hiss at low altitudes near the magnetic equator is significant in several respects. (i) Ground-based studies of the occurrence of VLF emissions by Laaspere *et al.* [1964], Helliwell [1965], Jørgensen [1966], and others have shown that VLF emissions activity decreases rapidly for magnetic latitudes below about 50° . Thus, one would not expect to find intense VLF radio noise at low altitudes near the equator. Before the observations presented here, the lowest latitude at which VLF hiss has been observed is, to our knowledge, at Moshiri,

Japan, 34.3° magnetic latitude [Iwai *et al.*, 1964]. (ii) Because the VLF wave energy is guided approximately along the geomagnetic field line, the instability mechanism for generating equatorial VLF hiss must be operative at low altitudes in the ionosphere (probably below 500 km). (iii) The intense fluxes of charged particles with energies from a few hundred ev to several tens of kev, which are believed to be responsible for VLF emissions at middle and high latitudes, are not known to occur at the L values (less than 1.2) where these equatorial VLF hiss events occurred.

2. CRITERIA FOR IDENTIFYING VLF HISS EVENTS

The discovery of VLF hiss at low altitudes near the magnetic equator came about as the result of a previously published study of auroral-zone VLF hiss [Gurnett, 1966]. VLF hiss events were selected for analysis by requiring that the magnetic spectral density at 5.5 kHz, 7.0 kHz, and 8.8 kHz, as determined from the satellite-borne spectrum analyzer, exceed 3×10^{-10} gamma² Hz⁻¹ for a period of 8 seconds. This noise intensity threshold is approximately five times the VLF receiver noise level and corresponds to a VLF power flux on the order of 10^{-14} watts (m² Hz)⁻¹.

From the 4000 revolutions of Injun 3 VLF data available, a total of 171 revolutions occurred for which the above noise intensity threshold was exceeded. Of the 171 revolutions satisfying this noise intensity criteria, the majority (140 events) occurred at high magnetic latitudes (above 60° invariant latitude) and were classified as auroral-zone VLF hiss. The frequency spectra of these auroral-zone VLF hiss events typically consisted of a flat noise spectrum extending from a lower frequency limit of about 2–4 kHz to above the upper frequency limit of the VLF receiver (8.8 kHz). The maxi-

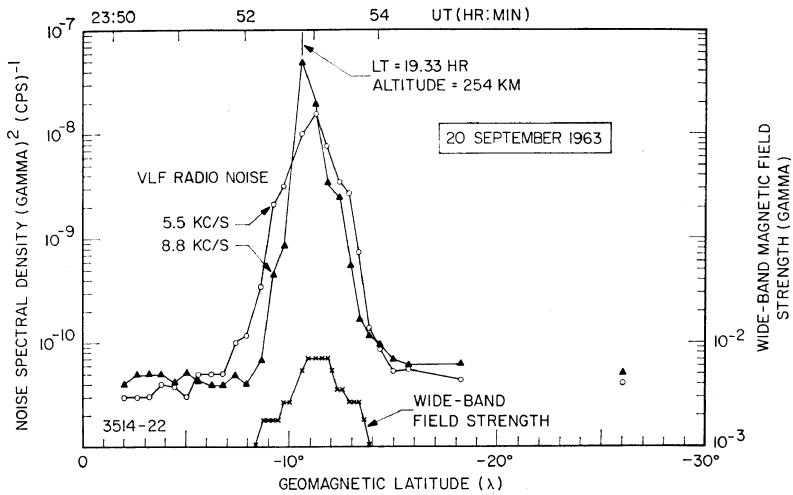


Fig. 1. Equatorial VLF hiss event on September 20, 1963.

imum magnetic spectral density of these auroral-zone VLF hiss events was about 4×10^{-8} $\text{gamma}^2 \text{ Hz}^{-1}$ corresponding to a VLF power flux of about 10^{-12} watt $(\text{m}^2 \text{ Hz})^{-1}$.

Of the remaining 31 revolutions satisfying the noise intensity criteria described earlier, ten events were found with spectral features very similar to auroral-zone VLF hiss (wideband

noise with little temporal structure on a time scale less than 1 second) but which occurred at magnetic latitudes less than 35° . All of these events occurred below 350-km altitude and at L values less than 1.2. Nine of the ten events occurred below 20° magnetic latitude. We shall call these low-latitude VLF hiss events *equatorial VLF hiss*.

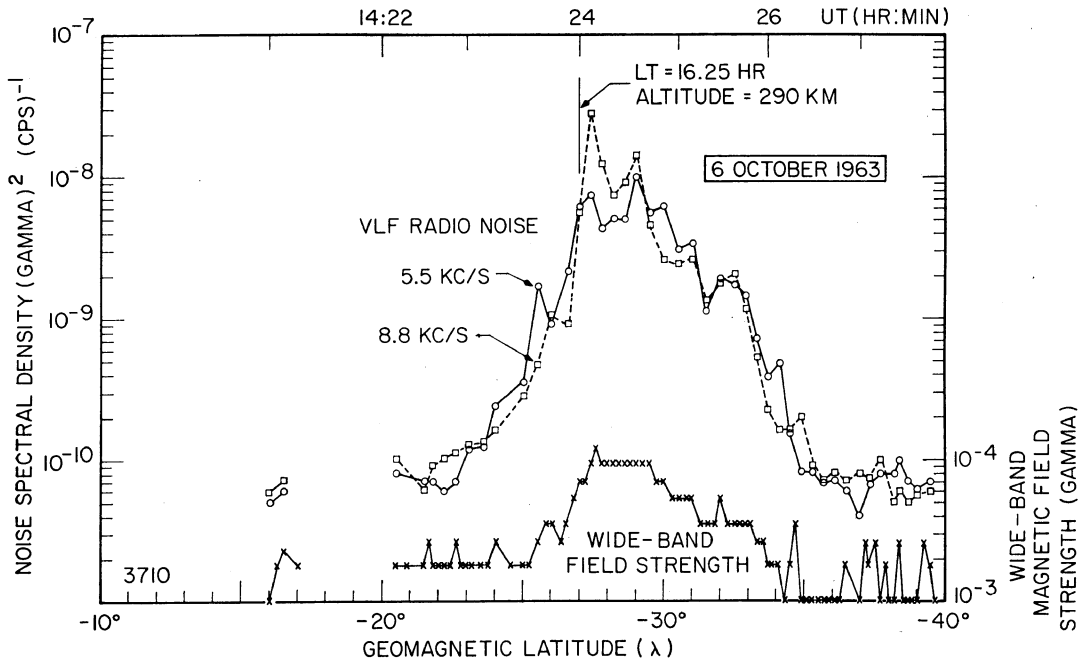


Fig. 2. Equatorial VLF hiss event on October 6, 1963.

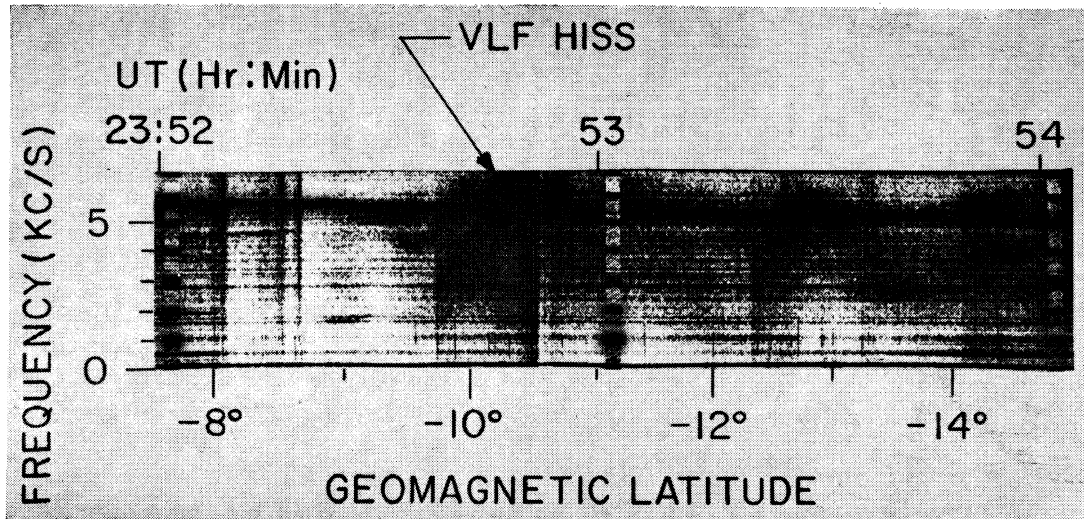


Fig. 3. Frequency-time spectrogram for the September 20 event.

3. CHARACTERISTICS OF EQUATORIAL VLF HISS

From the ten equatorial VLF hiss events found in the Injun 3 data, two events, occurring on September 20 and October 6, 1963, have been selected to illustrate the general features of equatorial VLF hiss. The magnetic noise spectral density at 5.5 and 8.8 kHz and the wide-band (200 cps to 7 kHz) magnetic field strength for these two events are shown as a function of magnetic latitude in Figures 1 and 2. (For details on the satellite instrumentation, see *Gurnett and O'Brien [1964]*.) Frequency-time spectrograms of the wide-band VLF signals for these two events are shown in Figures 3 and 4, respectively.

In Figure 1 (the September 20 event) the

5.5- and 8.8-kHz spectrum analyzer channels show a strong noise burst (5×10^{-8} gamma² Hz⁻¹, peak) approximately 5° wide in geomagnetic latitude and centered on -11.5° magnetic latitude. Although not shown, the spectrum analyzer channels at 7.0, 4.3, and 2.7 kHz also indicate a similar enhancement. Thus, we can conclude that the frequency spectrum of the noise burst is relatively flat, extending from less than 2.7 kHz to above 8.8 kHz. In Figure 1 the wide-band magnetic field strength shows a corresponding enhancement centered on approximately -11.5° geomagnetic latitude with a peak amplitude of about 7mgammas. The frequency-time spectra of the September 20 event, shown in Figure 3, consists of a wide-band noise spec-

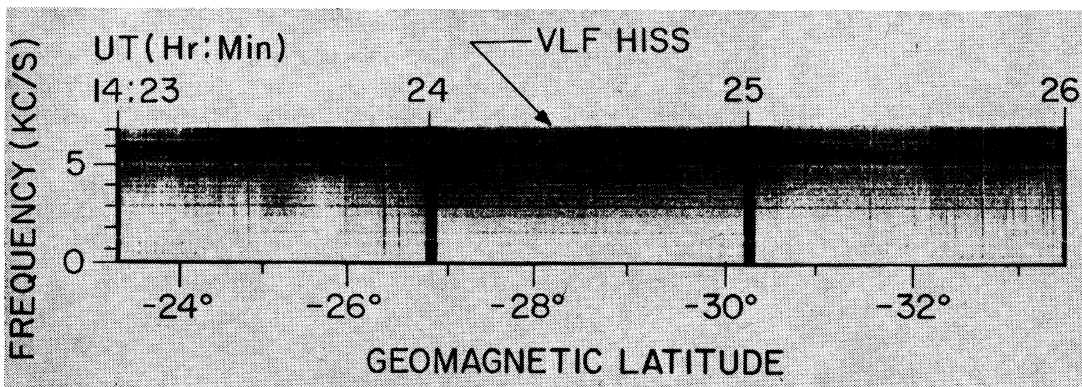


Fig. 4. Frequency-time spectrogram for the October 6 event.

trum from about -9.5° to -14° magnetic latitude with little temporal structure on a time scale less than a few seconds. On the basis of the spectrogram in Figure 3 we have classified this radio noise as VLF hiss.

Also appearing on the spectrogram in Figure 3 is a tone with a frequency varying between about 5 and 6 kHz. This tone appears on all the equatorial hiss events investigated and is not found on higher latitude data. The duration of this tone is usually several minutes and is generally much longer than the duration of the equatorial VLF hiss events. Thus, we do not believe that this tone is associated with the VLF hiss. The origin of this quasi-constant frequency tone has not been established.

No energetic charged-particle flux (electrons with energy > 40 keV or protons with energy > 500 keV) above the background level of the Injun 3 charged-particle detectors was detectable during this VLF hiss event.

The noise intensity at 5.5 and 8.8 kHz for the October 6 event is shown in Figure 2. The noise enhancement for this event extends from approximately 25° to 35° geomagnetic latitude and has a peak intensity of about 3×10^{-8} gamma² Hz⁻¹. The peak wide-band magnetic field strength is very large, approximately 12.0 mgammas. The frequency-time spectrogram for this event is shown in Figure 4 and appears as a white noise spectrum above about 2 kHz with very little frequency-time structure. Since the automatic gain control (AGC) circuit in the satellite maintains the signal at constant ampli-

tude, it is very difficult to distinguish the VLF hiss in Figure 4 from the VLF preamplifier noise. Evidence that the AGC circuit is decreasing the gain during the event can be seen in Figure 4 from the fact that the number of whistlers and their amplitude decreased markedly during the period when the VLF hiss event occurred, from about 25° to 35° geomagnetic latitude.

The above two events were selected to illustrate the general characteristics of the equatorial VLF hiss events found in the Injun 3 data. These characteristics are: (i) a wide-band magnetic noise enhancement in the frequency range from about 2 kHz to above 8 kHz, (ii) peak intensities on the order of 10^{-8} gamma² Hz⁻¹, (iii) occurrence at low magnetic latitudes (less than 35°) and at low altitudes (below 350 km).

4. REGION OF OCCURRENCE

In Table 1 we summarize the relevant coordinates at peak intensity for the ten equatorial VLF hiss events found in the Injun 3 data. The magnetic latitude of these events is very low, with nine of the ten events being below 20° magnetic latitude, and the lowest magnetic latitude being 7.2° . Nine of the ten events occurred at L values [McIlwain, 1961] less than 1.20. The altitude at which these events were observed is also very low, in all cases below 350 km, and near the perigee altitude for Injun 3 (237 km).

In the interpretation of Table 1 it is impor-

TABLE 1

Universal Time, 1963				Geomagnetic Latitude	Altitude, km	Local		B , gauss	L	K_p	
Day	Hr	Min	Sec			Time, hr	Longitude				Latitude
Sept. 9	02	49	18	-16.7°	242	21.7	-77.6	-32.2	0.263	1.20	3
Sept. 10	01	41	25	$+7.2^\circ$	303	20.8	-73.2	-8.6	0.254	1.10	4
Sept. 12	18	45	19	-17.2°	290	20.3	23.31	-8.07	0.291	1.17	0
Sept. 14	18	36	05	-19.0°	269	19.9	20.98	-10.12	0.293	1.20	0
Sept. 15	17	33	07	-16.5°	275	19.7	33.31	-7.92	0.298	1.15	1
Sept. 16	01	17	20	-12.4°	246	20.3	-75.37	-28.3	0.250	1.15	1
Sept. 17	17	23	10	-18.4°	260	19.3	31.0	-9.6	0.300	1.17	1
Sept. 20	23	53	03	-11.5°	260	19.4	-67.6	-28.5	0.236	1.16	1
Oct. 6	14	25	04	-30.4	313	16.1	29.7	-23.1	0.292	1.51	3
Oct. 25	10	28	05	-11.5	307	12.6	30.0	-2.6	0.290	1.09	1

tant to consider how much data were obtained in different altitudes, latitudes, and local-time regions. We shall consider these coordinates one at a time.

A. Altitude. Since the perigee altitude was 237 km, we cannot determine whether equatorial VLF hiss occurs below this altitude. We can, however, be reasonably certain that equatorial VLF hiss does *not* generally occur from about 350 km up to the Injun 3 apogee altitude (2785 km) because there were approximately 1000 revolutions available in this altitude range for which no VLF hiss was observed near the magnetic equator. Thus, we can conclude that equatorial VLF hiss with intensity greater than about 3×10^{-8} gamma² Hz⁻¹ generally occurs only below about 350-km altitude.

Because the region viewed by the ground telemetry station decreases rapidly with decreasing altitude, only 29 revolutions occurred with data below 350-km altitude and within $\pm 35^\circ$ magnetic latitude. Of these 29 revolutions, four occurred during May–June 1963, for which no VLF hiss was observed, and 25 revolutions occurred during September–October 1963, for which the ten events discussed above were observed. Thus, VLF hiss was observed on approximately one-third of the revolutions that passed through the region below 350 km and within $\pm 35^\circ$ geomagnetic latitude.

B. Latitude. It can be noted from Table 1 that all except one of the equatorial VLF hiss events were observed in southern (negative) magnetic latitudes. This absence of northern latitude events is due to ground telemetry station locations. No data were available at low altitudes (less than 350 km) in the range of geomagnetic latitudes from approximately $+10^\circ$ to $+25^\circ$. Thus, we cannot determine whether equatorial VLF hiss occurs at the conjugate point in the northern magnetic hemisphere.

C. Local time. The revolutions with data below 350 km and within $\pm 35^\circ$ of the magnetic equator occurred primarily during September and October. The local-time sample is, therefore, very nonuniform, and no conclusions can be drawn from Table 1 concerning the diurnal variations in the occurrence of equatorial VLF hiss.

5. DISCUSSION

These observations of VLF hiss at low altitudes near the magnetic equator represent, to our knowledge, the lowest L value (1.09) at which VLF radio noise emissions have been observed. Since the wave energy for the whistler mode of propagation is guided approximately along the geomagnetic field line [Storey, 1953], it follows that the source region for these equatorial VLF hiss events must also be at very low L values, probably $L < 1.20$. (For frequencies below the lower hybrid resonance frequency, the wave energy is not necessarily guided along the geomagnetic field line [Hines, 1957]. However, in the lower ionosphere the lower hybrid resonance frequency, about 3 kHz at 350-km altitude, is generally below the frequencies of equatorial VLF hiss.) Further evidence that the source region for these equatorial VLF hiss events is at very low L values (less than ~ 1.2) is provided by the fact that VLF hiss is generally not observed by Injun 3 at L values greater than 1.2, except at much higher L values in the outer radiation zone.

Whereas VLF hiss at auroral-zone latitudes is believed to be associated with intense fluxes of electrons ($> 10^7$ electrons/cm² ster sec) with energies of a few keV or less [Gurnett, 1966], no comparable fluxes are known to exist at L values less than 1.20. Although no measurements of charged-particle energy fluxes in the above energy range have been made for L less than 1.20, the closest data given by Frank and Swisher [1967] places an upper limit on the energy flux at $L = 1.25$, $B = 0.20$, of 0.2 erg (cm² sec ster)⁻¹. This upper limit is to be compared with typical charged-particle energy fluxes in the auroral zone of several tens of ergs (cm² sec ster)⁻¹ occurring during auroral-zone VLF hiss events. The absence of intense fluxes of energetic charged particles in the region where equatorial VLF hiss is observed would seem to eliminate some of the traditional mechanisms used to explain VLF hiss, such as Cherenkov radiation [Gallet, 1959; Ellis, 1957; and Jørgensen, 1967], or cyclotron resonance interactions [Kennel and Petschek, 1966].

Acknowledgment. This research was supported in part by the Office of Naval Research under contract Nonr 1509(06) and by NASA grant NGR-16-001-043.

REFERENCES

- Ellis, G. R., Low-frequency radio emission from aurorae, *J. Atmospheric Terrest. Phys.*, *10*, 303, 1957.
- Frank, L. A., and R. L. Swisher, On the energy fluxes of low-energy protons and positive ions in the earth's inner radiation zone, *U. of Iowa Res. Rept. 67-33*, June 1967.
- Gallet, R. M., The very-low-frequency emissions generated in the earth's exosphere, *Proc. IRE*, *47*, 211, 1959.
- Gurnett, D. A., and B. J. O'Brien, High-latitude geophysical studies with satellite Injun 3, 5, Very-low-frequency electromagnetic radiation, *J. Geophys. Res.*, *69*, 65, 1964.
- Gurnett, D. A., A satellite study of VLF hiss, *J. Geophys. Res.*, *71*, 5599, 1966.
- Helliwell, R. A., *Whistlers and Related Ionospheric Phenomena*, Stanford University Press, Stanford, California, 1965.
- Hines, C. O., Heavy-ion effects in audio-frequency radio propagation, *J. Atmospheric Terrest. Phys.*, *11*, 36, 1957.
- Iwai, A., J. Otsu, and Y. Tanaka, The observations of VLF emissions at Moshiri, *Proc. Res. Inst. Atmospheric Nagoya Univ.*, *11*, 29, 1964.
- Jørgensen, T. S., Morphology of VLF hiss zones and their correlation with particle precipitation events, *J. Geophys. Res.*, *71*, 1367, 1966.
- Jørgensen, T. S., On the generation of wideband electromagnetic noise above 1 kHz in the high latitude magnetosphere, paper presented at URSI Spring Meeting, May 23-26, Ottawa, Ontario, Canada, 1967.
- Kennel, C. F., and H. E. Petschek, Limit on stably trapped particle fluxes, *J. Geophys. Res.*, *71*, 1, 1966.
- Laaspere, T., M. G. Morgan, and W. C. Johnson, Chorus, hiss, and other audio frequency emissions at stations of the whistlers-east network, *Proc. IEEE*, *52*, 1331, 1964.
- Martin, L. H., R. A. Helliwell, and K. R. Marks, Associated between aurorae and very-low-frequency hiss observed at Byrd Station, Antarctica, *Nature*, *187*, 751, 1960.
- McIlwain, C. E., Coordinates for mapping the distribution of magnetically trapped particles, *J. Geophys. Res.*, *66*, 3681, 1961.
- Morozumi, H. M., Diurnal variation of auroral zone geophysical disturbances, *Rept. Ionosphere and Space Res. Japan*, *19*, 286, 1963.
- Storey, L. R. O., An investigation of whistling atmospherics, *Phil. Trans. Roy. Soc. London*, *A246*, 113, 1953.

(Received September 5, 1967;
revised October 5, 1967.)