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Observations and Results From the "Hiss Recorder," an Instrument to Continuously Observe the VLF Emissions

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An instrument, developed at NBS, has enabled continuous observations of VLF emissions. The continuous data has permitted the identification of some new characteristics of VLF emissions, and new information on the statistics of the occurrence of VLF emission activity.

The continuous recordings are able to document the morphology of VLF emission events and, therefore, accurate correlations with other geophysical phenomena are possible. Correlations of VLF emission activity with abnormal *D*-region absorption, X-ray events, and magnetic activity are presented.

1. Introduction

At the beginning of the IGY, techniques for recording whistlers and VLF emissions were developed whereby the stations recorded the naturally generated VLF noises on magnetic tape in 2 min samples at 35 to 37 min past each hour [Helliwell and Carpenter, 1961]. With this method, time could be resolved to within a few hundredths of a second. Discrete phenomena, lasting on the order of a second, could be thoroughly studied, but it soon became obvious that a continuously recording system was needed for the accurate investigation of the morphology of the longer duration events such

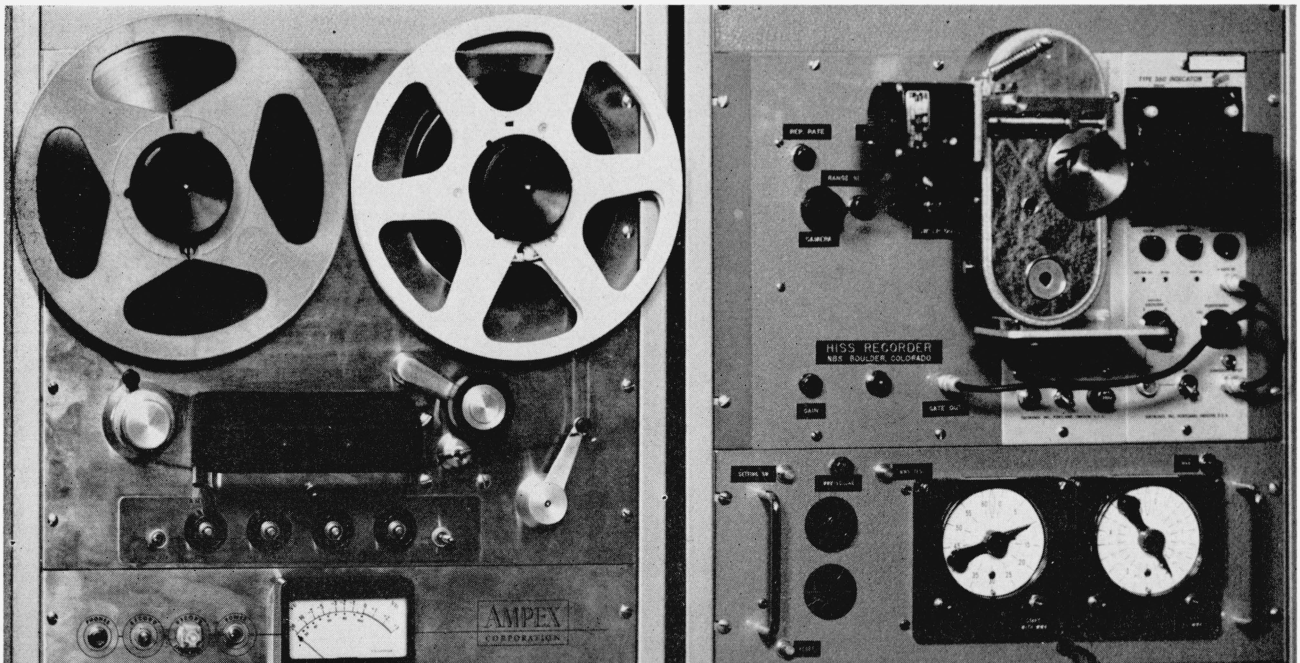

FIGURE 1. *National Bureau of Standards VLF emission recording equipment.*

Tape recorder unit on left, hiss recorder and programmer on right.

as hiss. The design of a recorder to continuously monitor VLF emissions was begun at NBS in 1959, and the first instrument was installed at Minneapolis, Minn. (L=3.2) in 1961 (fig. 1).

The instrument, named the "hiss recorder," intentionally gives a low time resolution in order to continuously record VLF emission events, thus it is particularly suited for observing quasi-steady state phenomena. Since 1961, hiss recorders have been operated in conjunction with magnetic tape recorders at Boulder, Colo. (L=2.3), and various temporary sites such as the NBS conjugate point stations at LeRelais, Quebec, Canada, and Eights, Antarctica (L=4.0), and Cape Sarichef, Alaska, and Waimate, New Zealand (L=2.6). The purpose of this paper is to discuss the design of the hiss recorder and to present some observations obtained with this instrument that would not have been possible with the 2-min data samples recorded on magnetic tape.

2. Design of the Hiss Recorder

The hiss recorder is essentially a spectrum analyzer of the frequency scanning type coupled to a recording system which produces a photographic film having variable density. The coordinates of the film represent frequency and time, and the power density of the received spectrum is represented by variation in film exposure. A recorder of this type has been used by Ellis [1959] for studying VLF emissions, and also by Obayashi et al. [1960], for logging the spectral density of the received atmospherics. The parameters of the hiss recorder have been chosen to allow operation over long periods of time and to minimize the cost of obtaining data. The output is 16-mm film moving at the rate of approximately 1 in./hr. A 3-in. commercial oscilloscope is used, but it is modified by the addition of a beam-current monitor meter and large beam current feedback to insure proper film exposure for long periods of time. Dynamic range of the oscilloscope intensity function is extended by a network consisting of zener diodes and resistors which cause the beam modulating voltage to have an approximately logarithmic characteristic. Other electronic features of the system are quite straightforward, and only the block diagram is presented (fig. 2).

3. Observations

3.1. Some Phenomenological Characteristics of Long Duration VLF Emissions

The records from a number of hiss recorders at various sites have revealed several interesting characteristics of VLF events which could only be observed with a low time resolution instrument. The emissions are integrated by the hiss recorder in such a way that the general spectral shape of the event is apparent.

1. Sometimes a marked change in the upper limit of the continuous VLF emissions occurs. Changes of as much as 5 kc/s can occur within a few minutes.
2. Continuous VLF emissions may end and begin several times during an event giving a "patchy" appearance. Several interruptions may occur during an event.
3. The same structure of a long-duration event may be observed simultaneously at stations located in the same hemisphere more than 1,000 miles apart.
4. Long-duration VLF emission events are observed simultaneously at conjugate points, i.e., stations at opposite ends of a line of force.

Two examples of rapid frequency changes in the upper limit of the emissions are presented in figure 3. Both recordings were taken at Minneapolis. (Time proceeds from right to left.) On 19 December 1962, the upper frequency limit changed several times over a period of 4 hr. On 30 November 1962, the upper frequency limit of the emissions increased from 3 to 7 kc/s within 30 min. This rising in frequency has been observed quite often by the hiss recorders at several stations.

Figure 4 illustrates the "patchy" appearance given to an event by sudden interruptions and beginnings. Again, both the events were observed at Minneapolis. On 26 July 1962, a band of hiss centered at 2 kc/s was interrupted for 4 min from 1416 to 1420 UT.

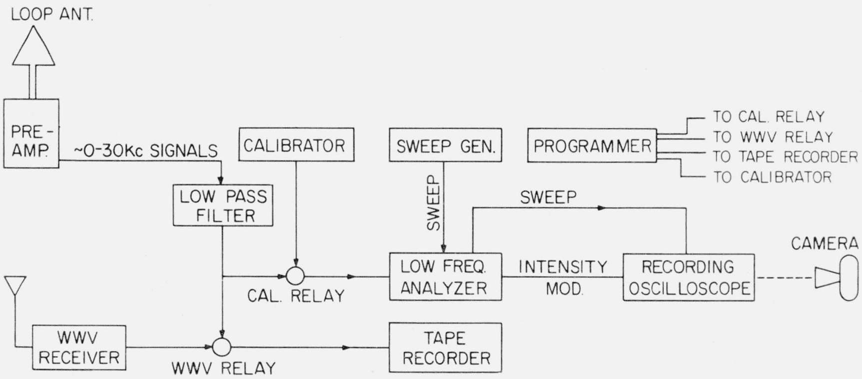

FIGURE 2. *Hiss recorder block diagram.*

The hiss reappeared for 10 min and was interrupted again. A similar event was observed on 21 November 1962. At 2146 UT an interruption of 10-min duration occurred; the hiss reappeared for 22 min; it was interrupted for 10 min, and then again reappeared. These abrupt interruptions in VLF events might be indications of a depletion of the particles causing VLF emissions, or of excessive ionospheric absorption obscuring the VLF event for a time.

In some cases, the interruptions and abrupt beginnings of an event are observed simultaneously at widely separated stations in the same hemisphere as well as at conjugate points. Interruptions in an event composed of chorus were observed simultaneously on 1 December 1961, at LeRelais, Quebec, Minneapolis, Minn., and Boulder, Colo. (fig. 5). The patches of emissions are of several minutes' duration with the interruptions lasting for 5 to 20 min.

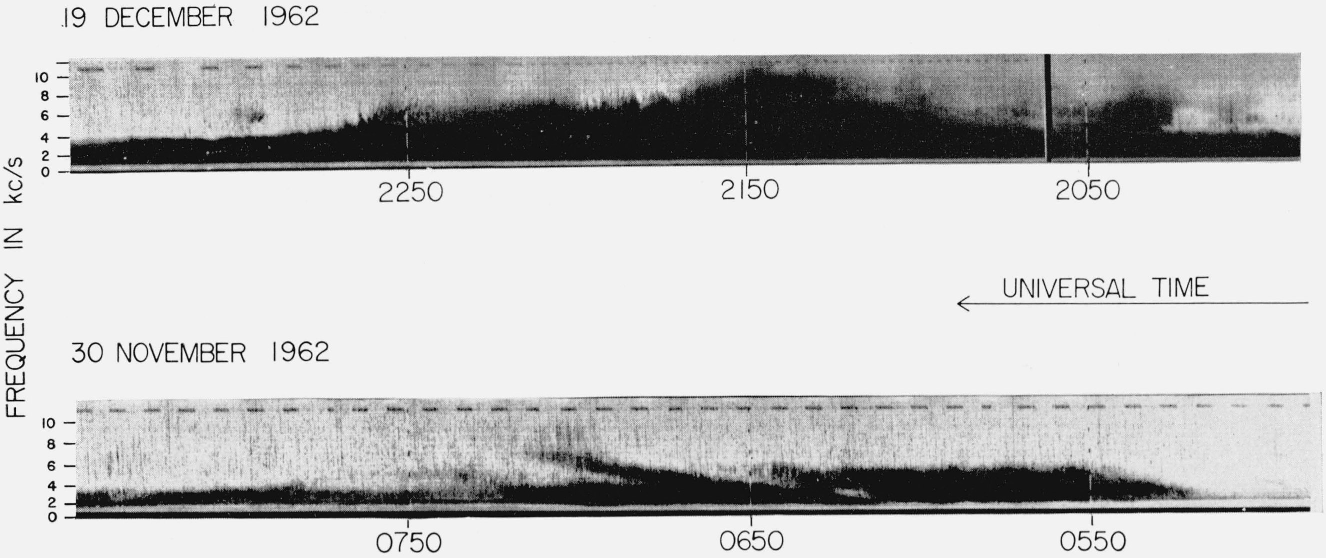

FIGURE 3. *Examples of the change in the upper frequency limit of VLF emission events.*

Both records were taken at Minneapolis. In the top picture, the highest frequency attained varies over a period of 3 hr. In the bottom picture, the upper frequency band rises from 3 to 7 kc/s within 30 min.

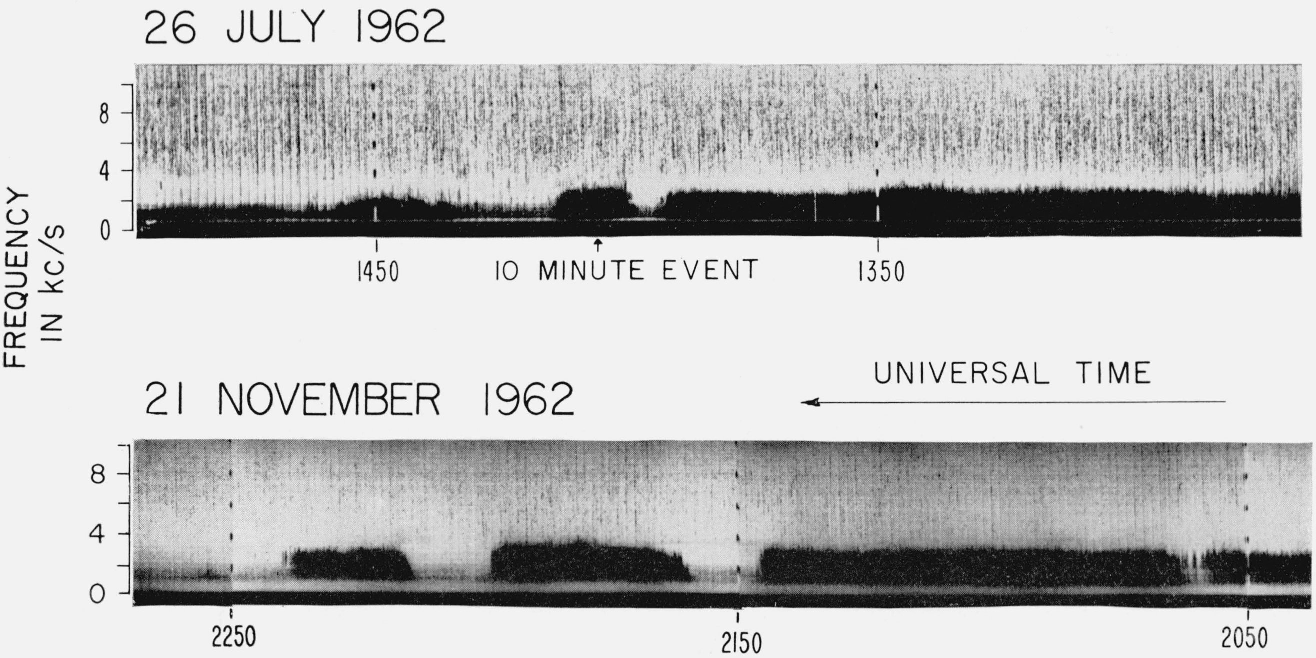

FIGURE 4. *"Patchy" appearance in VLF events caused by sudden interruptions and beginnings.*

Both records were taken at Minneapolis. The cutoff of the event on 21 November 1962, at 2155 to 2226 UT occurs within 15 sec

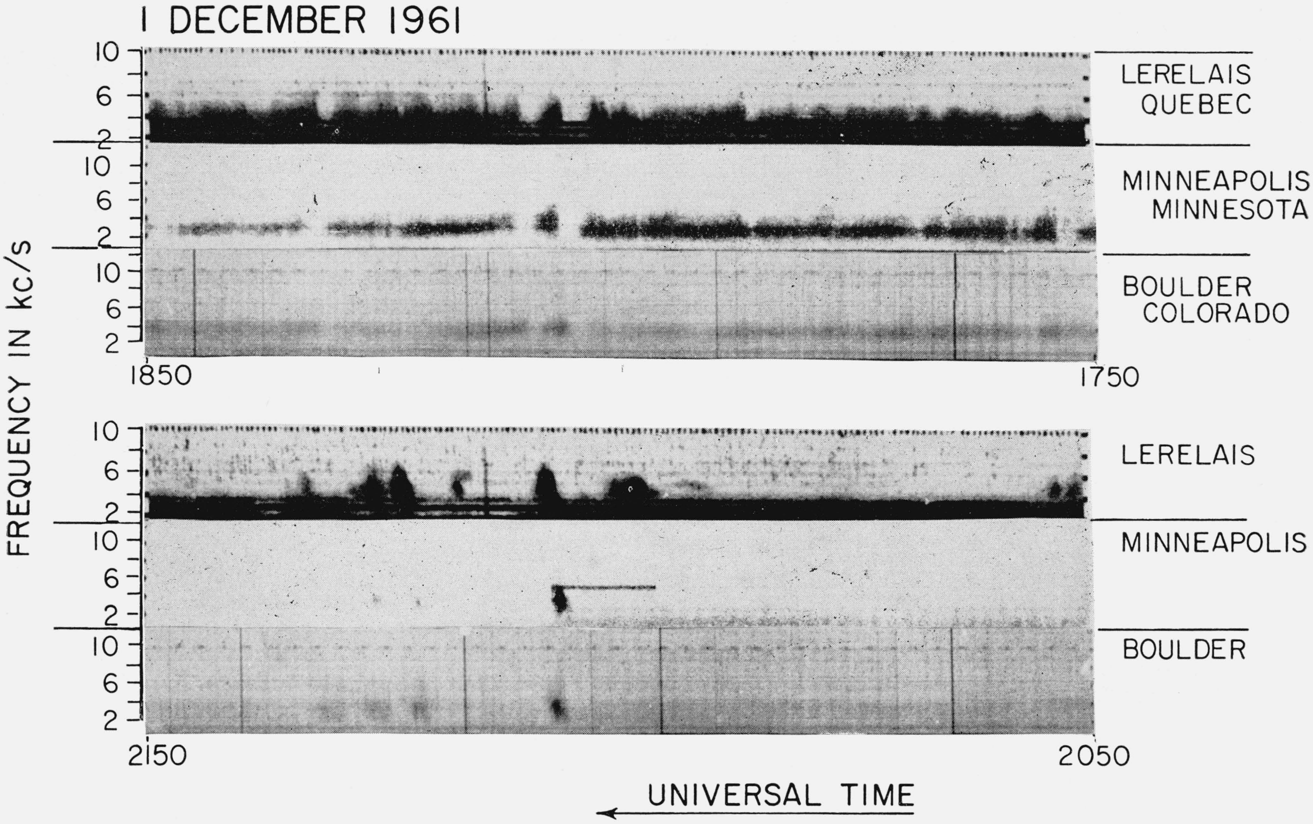

FIGURE 5. *Simultaneous observation of VLF events at three stations in the Northern hemisphere.*

The top three records were taken from 1750 to 1850 UT at LeRelais, Minneapolis, and Boulder. The "patches" are 2-minute bursts of chorus. At 1828 UT, the same patch of chorus is observed at all three stations. The bottom three records have a simultaneous burst at 2129 UT.

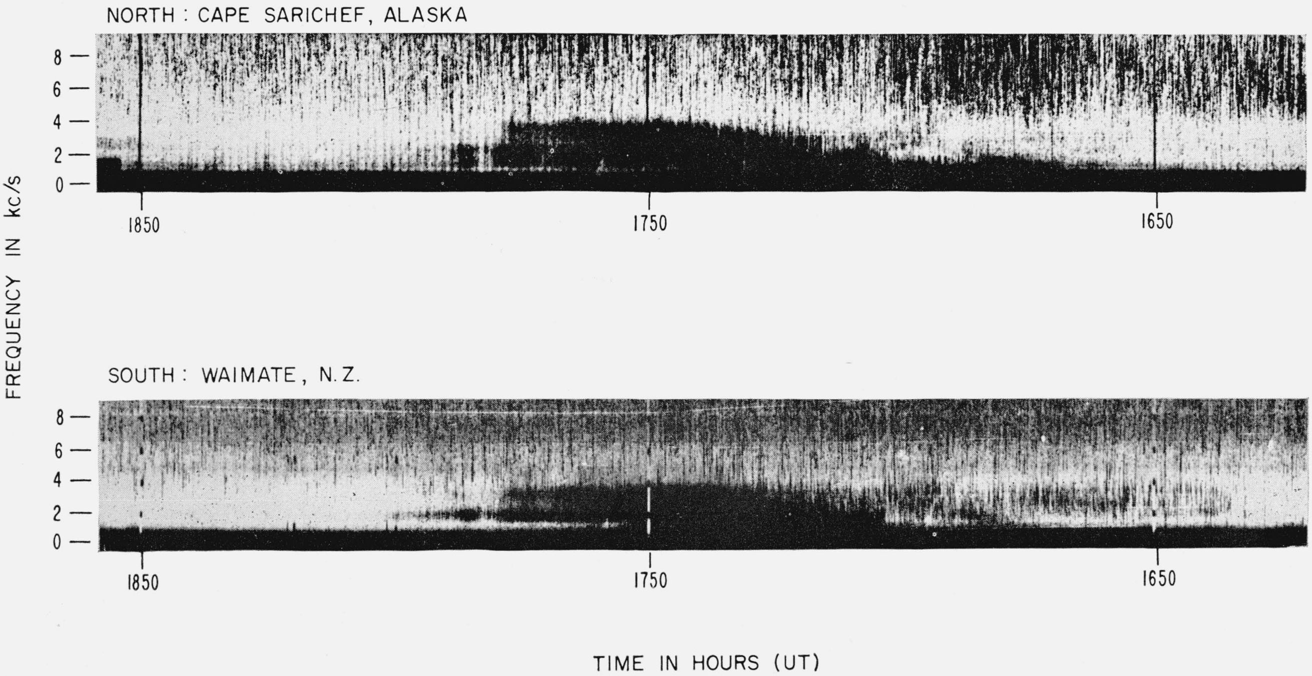

FIGURE 6. *Simultaneous observation of a VLF emission event at conjugate points observed on 22 September 1962.*

The event is composed of hiss and chorus integrated by the hiss recorder in such a way that the general spectra shape of the event is apparent.

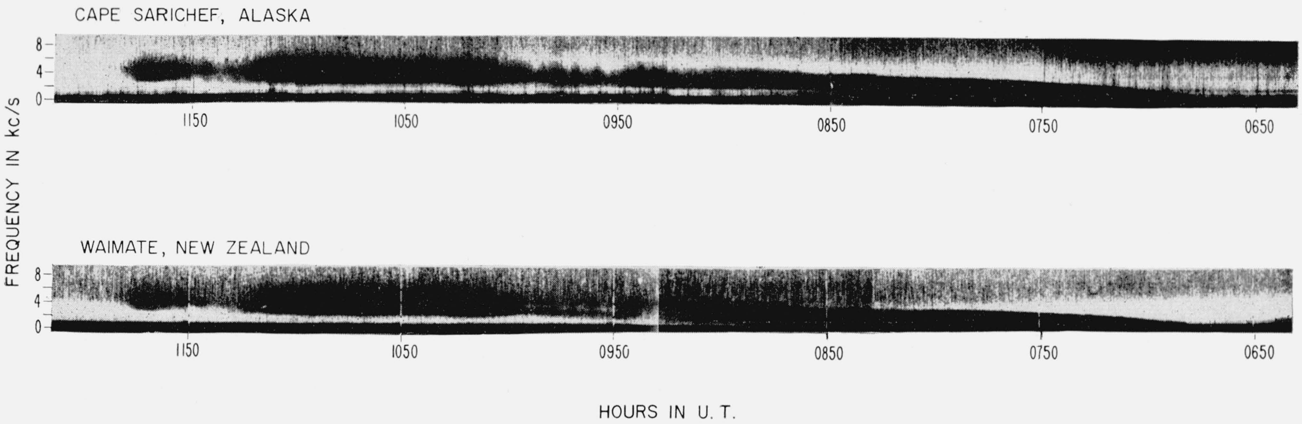

FIGURE 7. *VLF event observed simultaneously at conjugate points on 27 October 1962.*
The spectral shape remains quite similar for over 5 hr.

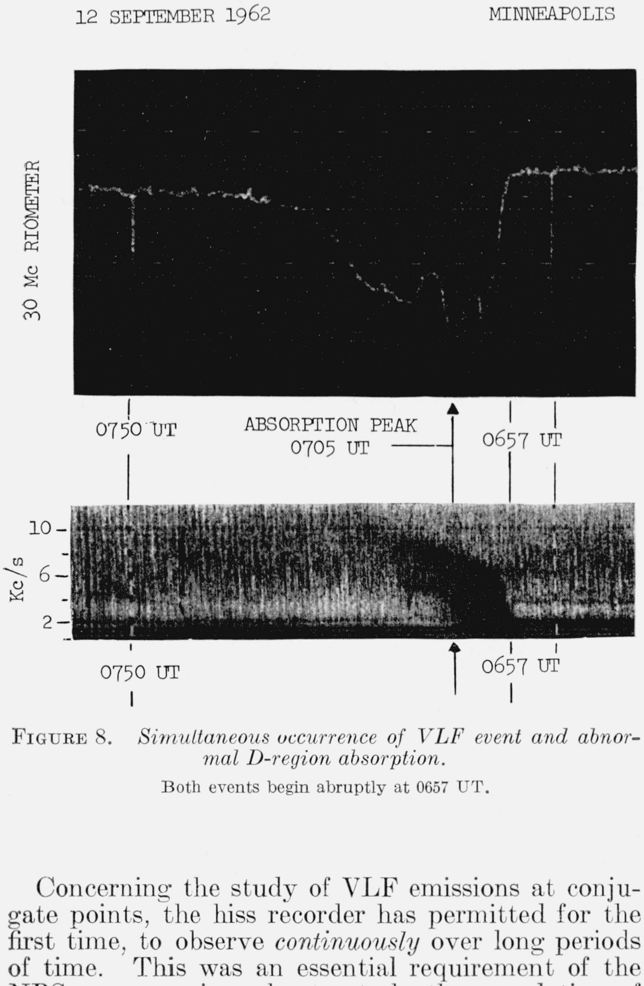

FIGURE 8. *Simultaneous occurrence of VLF event and abnormal D-region absorption.*
Both events begin abruptly at 0657 UT.

Concerning the study of VLF emissions at conjugate points, the hiss recorder has permitted for the first time, to observe *continuously* over long periods of time. This was an essential requirement of the NBS program, in order to study the correlation of such VLF events with the continuous riometer records of abnormal low ionosphere absorption. VLF events exhibiting the same general spectral form for several hours at conjugate points have been observed on many occasions. For example on 22 September 1962 (fig. 6), hiss and chorus appeared at conjugate stations located in Alaska and New Zealand. The spectral forms of the event remain very similar between the hemispheres from 1700 to 1800 UT. From 1750 to 1810 UT the event has emissions in two frequency bands which are observed in both hemispheres.

On 27 October 1962, hiss appeared at 0700 UT at the conjugate stations (fig. 7). The hiss slowly rose in frequency over a period of 5 hr. The spectral shape is almost identical between the hemispheres.

Events such as these observed with the hiss recorders have revealed that when VLF activity of a few minutes to a few hours duration occurs at one conjugate station, it occurs at the other simultaneously. The data from the NBS conjugate point hiss recorders will be more fully discussed in a paper by Gallet and Koch [to be published].

3.2. Comparison of Long Duration VLF Events With *D*-Region Absorption and X-Rays

The continuous recordings of the hiss recorder reveal the morphology of the VLF emission events and permit correlation with other geophysical phenomena. On 12 September 1962, a sudden burst of VLF emissions was received on the hiss recorder at Minneapolis (fig. 8). This burst began at 0657 UT at exactly the moment that the riometer [Little and Leinbach, 1959] detected the beginning of excess *D*-region absorption. The VLF event began to diminish in intensity by the time the absorption had reached a maximum. The VLF activity continued to rise in frequency, however, until it disappeared. Another example of comparison of VLF emissions and ionospheric absorption is presented in figure 9. On 5 March 1962, at Minneapolis, hiss was observed at 0935 UT. The hiss disappeared between 1235 and 1330 UT and reappeared at the same time that the riometer began to measure excess absorption. The hiss lasted until 1535 UT.

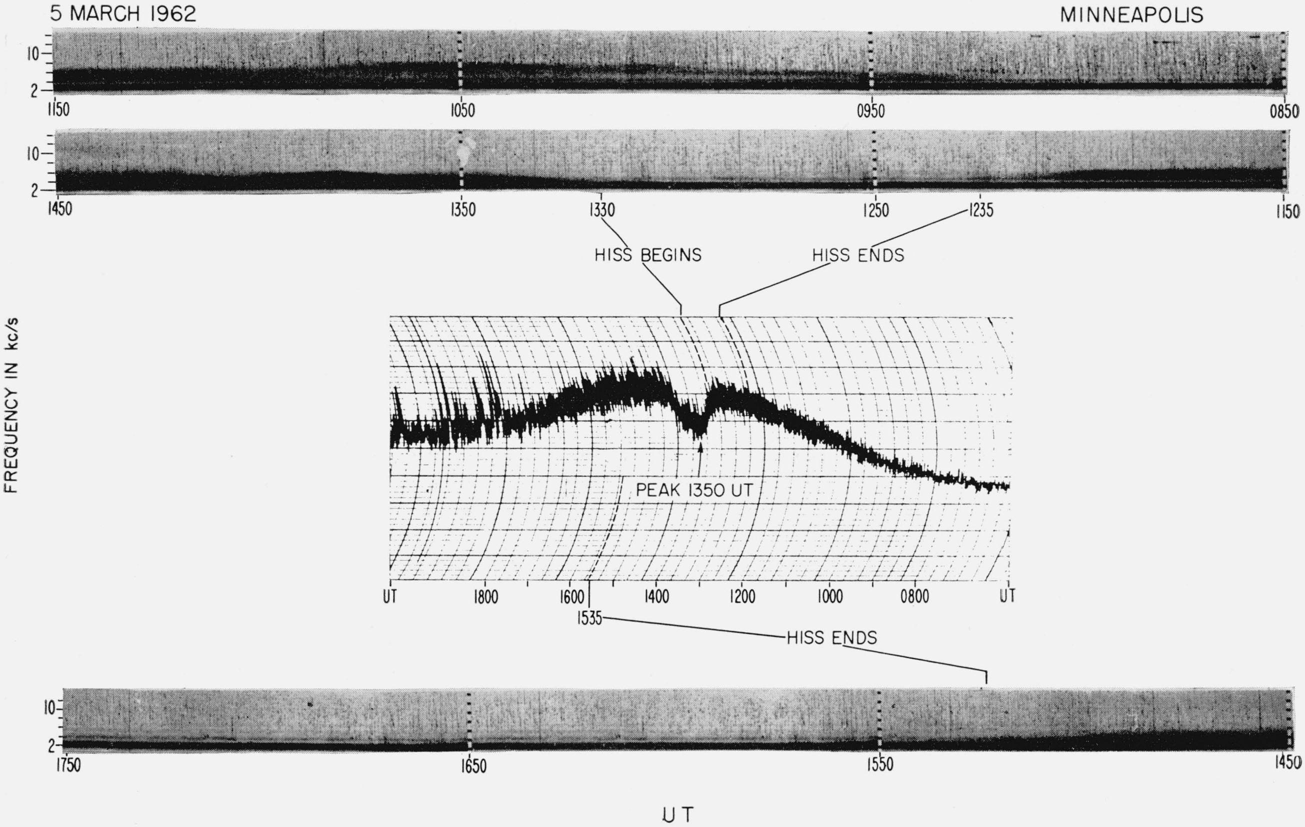

FIGURE 9. *Simultaneous occurrence of hiss and abnormal D-region absorption.*

Hiss begins at 0940 UT (top record) and continues until 1235 UT. At 1330 UT the hiss reappears coincident with the beginning of the absorption event.

A number of similar cases have been observed in which the VLF emissions begin at just the moment that excess absorption is detected. However, in some cases, the VLF activity which was present before the absorption event abruptly ended, and did not resume during the absorption.

VLF emissions have also been observed to occur at just the moment of an X-ray burst as measured by balloons launched at the same location. During an expedition to Flin Flon, Manitoba, Canada, in September 1962, several good cases of this simultaneous occurrence were observed [Anderson, 1962].

3.3. Statistics on the Occurrence of VLF Emission Events

The continuous coverage of the hiss recorder has provided statistics for the study of such questions as the month-to-month and diurnal variations in VLF emissions. In the past, such statistics were made from the hourly 2-min samples recorded on magnetic tape [Allcock, 1957; Pope, 1960; Dinger, 1960; Martin, 1960; Morgan, 1960]. Although this method was fairly satisfactory for counting the discrete events, it was unsuccessful for estimating the amount of hiss or other long duration events. In addition, in the case of the discrete VLF emissions, their low density presents a problem for defining when they are present or not. Due to the low resolution of the hiss recorder, the effect of the discrete VLF emissions is integrated and it is only above a certain duration threshold (>15 sec), that the instrument discriminates between the presence or absence of VLF emissions. But, since the hiss recorder operates continuously, quite accurate statistics can be obtained for the occurence of VLF events which last in excess of 15 sec. The percentage of such VLF events observed at Minneapolis from May 1961 to February 1963 is presented in table 1. In the summer of 1961, VLF emissions were observed 2.7 percent of the time. In the summer of 1962, 12.8 percent was observed. The increase is significant even though the equipment gave more usable data for 1962. VLF events were observed 8.1 percent of the time during the winter of 1961–62, compared to 25.4 percent during the winter of 1962–63. From July 1962 to February 1963, a substantial increase in VLF events over the preceding year was recorded.

TABLE 1. *Percentage of VLF events observed at Minneapolis, Minn.*

May 1961–February 1963

Month	Percent of VLF events		Percent of good data
Summer:			
May 1961	3.8	2.7%	97.3
June 1961	4.5		65.6
July 1961	0.2		67.5
August 1961	2.2		59.7
September 1961	(0)		56.1
October 1961	(3.2)		35.2
Winter:			
November 1961	11.0	8.1%	64.9
December 1961	4.3		84.9
January 1962	4.0		80.0
February 1962	13.0		99.6
March 1962	5.2		88.9
April 1962	18.5		95.9
Summer:			
May 1962	10.5	12.8%	68.7
June 1962	9.6		97.4
July 1962	12.7		95.9
August 1962	18.3		97.3
September 1962	35.2		82.0
October 1962	31.2		99.2
Winter:			
November 1962	26.9	25.4%	82.8
December 1962	32.5		90.3
January 1963	24.6		85.3
February 1963	17.7		96.9

3.4. VLF Emissions During Magnetic Storms

It is well known that VLF emissions are more frequently observed during magnetically disturbed periods. Many studies on the occurrence of discrete emissions during magnetic storms using data from tape recordings have been reported [Crouchley and Brice, 1960; Rybner and Ungstrup, 1959; Corcuff and Legrand, 1962; Maeda, 1962; Outsu, 1962; Yoshida and Hatanaka, 1962; Tokuda, 1962; Pope, 1963].

A more complete study of VLF activity during magnetic storms can be accomplished by using the continuous records from the hiss recorder. The morphology of the VLF emission events can be compared with that of the magnetic storm. Studies on the relationship are presently being conducted.

Examples of VLF emissions received at Minneapolis during two magnetic storms are presented in the following figures. VLF emissions received during the magnetic storm on 21 November 1962 are presented in figure 10. The storm began at 0600 UT. VLF activity is present by 0800 UT and continues throughout the day. From 2240 to 0520 UT there was no activity. Then VLF emissions were present for most of the 22d. The storm ended about 0500 UT on the 23d. Some VLF activity was present for several hours later.

Very intense VLF activity was received during the magnetic storm beginning at 0200 UT on the 30th of January 1963 (fig. 11). VLF emissions are present from 0840 to 2215 UT on the 30th. The activity resumed at 0450 UT on the 31st and remained strong through the 1st of February. The storm ended at 1500 UT on the 1st.

3.5. VLF Pulsations With Long Periods

Another characteristic of VLF emissions which has only been observed with the low time resolution continuous recordings of the hiss recorder is a new phenomenon called long period VLF pulsations. At certain times, the normally continuous steady hiss begins to assume a structure that is very periodic. An example of these VLF pulsations is presented in figure 12. On the 21st of December 1962, beginning at 1222 UT, 30 VLF pulsations with a period of 56 sec were observed at Minneapolis. Two and one-half hours later another group of 39 pulsations was recorded. These latter pulsations had a period of 41 sec. When the tape recordings were examined it was found that the pulsations were bursts of hiss (fig. 13).

Another similar pulsation event was received at Minneapolis on 1 February 1963 (fig. 14). The periods of the pulsations did vary slowly in time, and their range is from 20 to 50 sec. A strictly periodic group of four of these pulsations was recorded on magnetic tape during the 2-min recording period at 0450 UT (fig. 15). These pulses are composed of hiss and rising tones. The event was also observed at Great Whale River, Quebec ($L=6.8$), with exactly the same structure and period.

These long period pulsations (20 sec to 3 min), have periods which are similar to micropulsations and some X-ray events [Evans, 1963] and may be related. A more complete study of these pulsations and their correlation with other geophysical phenomena is to be published [Gallet, unpublished].

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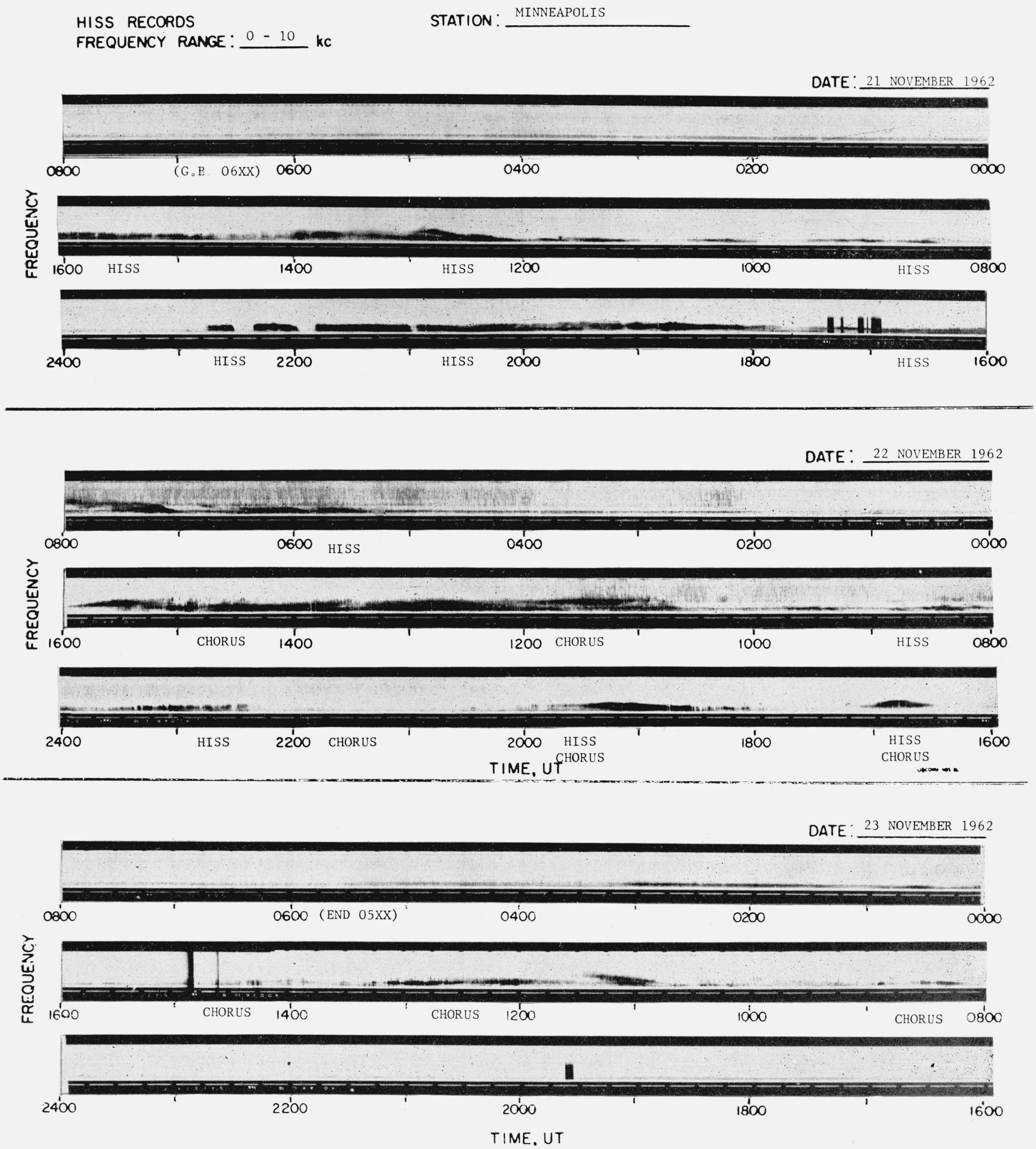

FIGURE 10. *VLF emissions received at Minneapolis during a magnetic storm beginning on 21 November 1962.*

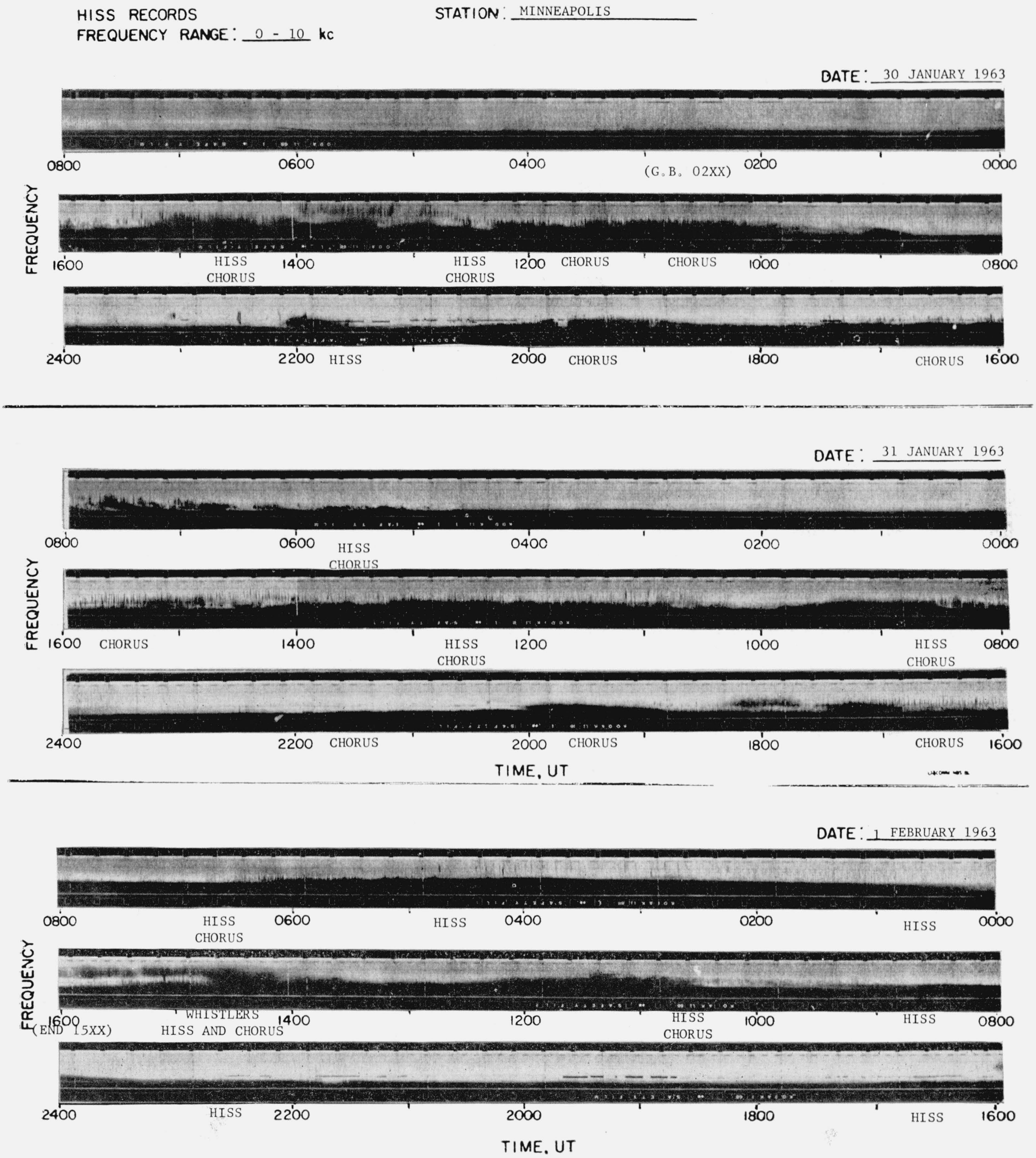

FIGURE 11. *VLF emissions received at Minneapolis during a magnetic storm beginning on 30 January 1963.*

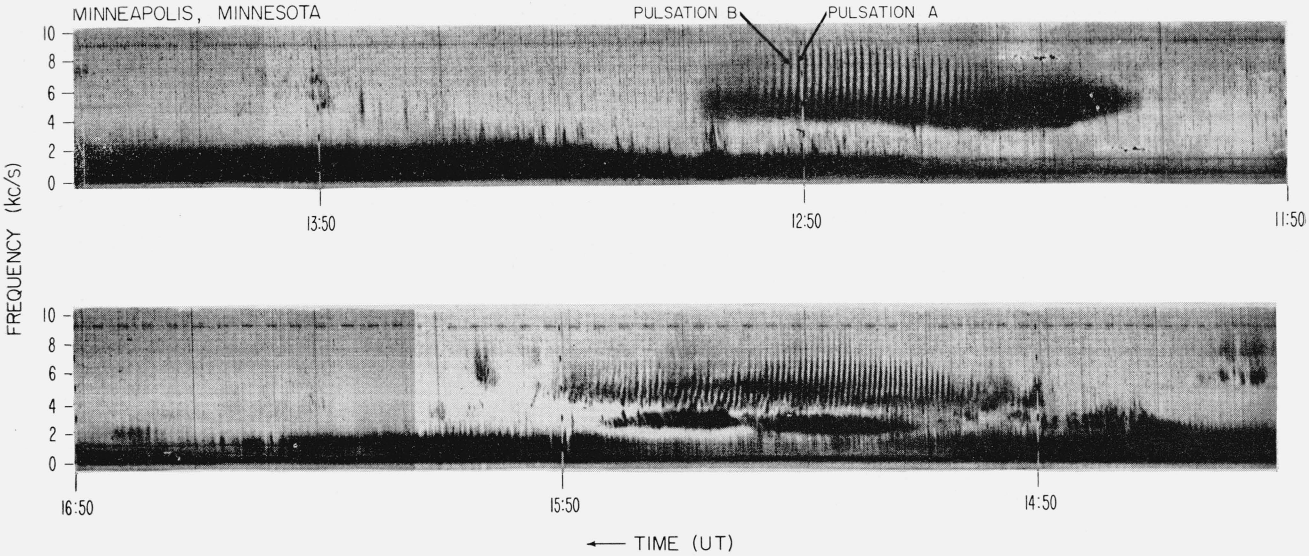

Figure 12. *VLF pulsations received at Minneapolis on 21 December 1962.*
The group occurring at 1220 UT has a period of 56 sec, and the group occurring at 1510 UT has a period of 41 sec.

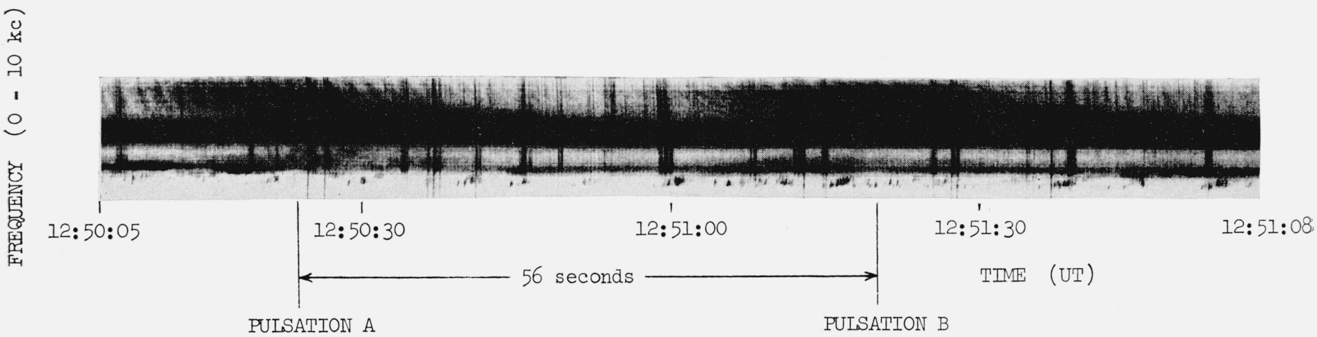

Figure 13. *Magnetic tape recording of two of the VLF pulsations received at Minneapolis on 21 December 1962 at 1250 UT.*
These two pulsations, A and B, are indicated on the hiss recorder record in figure 13. (An echoing whistler is superposed on pulsation A.)

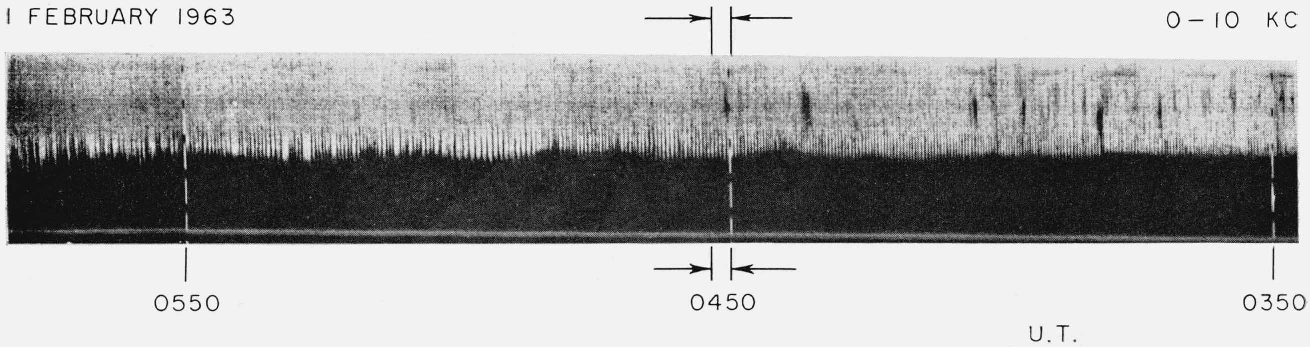

Figure 14. *VLF pulsations observed by the hiss recorder at Minneapolis on 1 February 1963.*
The period of the pulsations ranges from 20 sec to 50 sec. The arrows at 0450 UT mark the duration of the magnetic tape recording period.

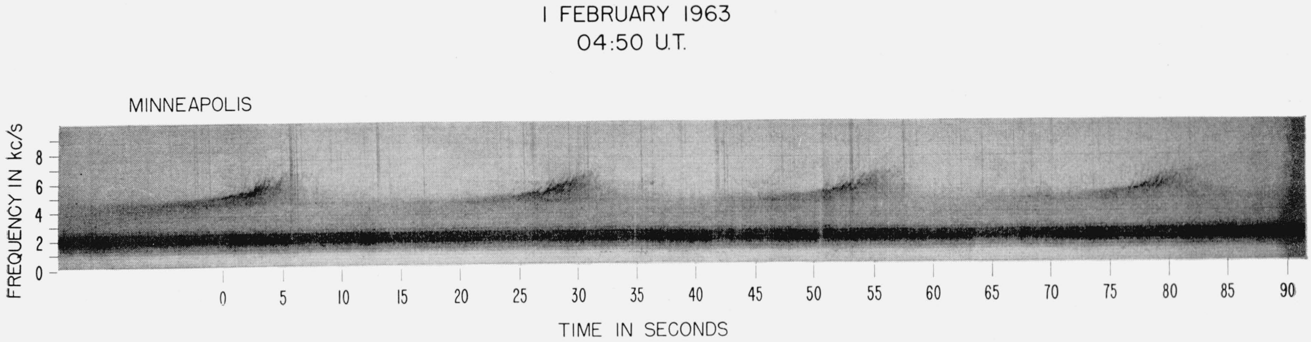

FIGURE 15. *Fine structure of the pulsations observed on the hiss recorder records on 1 February 1963.* Four pulsations were recorded on magnetic tape at 0450 UT. (See fig. 14.)

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