A Thesis presented for the
degree of Doctor of Philosophy.

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DETECTOR LOOP

GALVANOMETER AMPLIFIER

LOG. AMPLIFIER

1.5 cps FILTER AMPLIFIER

2-CHANNEL RECORDER

CALIBRATION OSCILLATOR
<table>
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Figure 2.5. Comparison of mean hourly all-sky meteor rates and mean 1.5 cps micropulsation occurrence rates over the period March 5-16, 1962.
MEAN HOURLY METEOR RATE

LOCAL TIME (HRS.)

MICROPULSATIONS

METEORS
Figure 2.6. Mean hourly localized meteor rates for the period March 23 through April 5, 1962.
Figure 2.7: Comparison of mean hourly localized meteor rates and mean 1.5 cps micropulsation occurrence rates over the period March 23 through April 6, 1962.
100

MEAN HOURLY METEOR RATE

METEORS

MICROPULSATIONS

LOCAL TIME (HRS.)

MICROPULSATION NO./HR.
Figure 2.8. Hourly localized meteor and micropulsation rates for three representative hours in the period March 23 through April 10, 1962.
Figure 2.9. Mean hourly 1.5 cps micropulsation rates for September 14 through October 6 and October 9 through November 6, 1962.
Figure 2.10. Sample of chart obtained on May 27, 1962, giving simultaneous presentation of meteors and micropulsations. The time markers on the bottom trace are at 1 minute intervals.
Figure 3.1. Z component record of the magnetic disturbance produced by the July 9, 1962 high-altitude nuclear explosion. Full-scale deflection is 0.5 γ/sec peak-to-peak.
Figure 3.2. Reconstructed record of the magnetic disturbance from the July 9, 1962 nuclear explosion. The dotted and dashed lines indicate off-scale peak-to-peak signal levels greater than 0.95 $\gamma$/sec, and between 0.5 $\gamma$/sec and 0.95 $\gamma$/sec respectively.
Figure 4.1. Five-day averages of magnetic activity at 1.5 cps recorded within the period September 15 to November 6, 1962.
Figure 4.2. Magnetic effects due to power grid supplying electric trains.  
Top:  $f = 1.5 \text{ cps magnetic record.}$

Middle:  $f = 0.008 - 1.6 \text{ cps magnetic record showing impulsive interference with maximum peak-to-peak amplitudes of } 0.05 \gamma / \text{ sec.}$

Bottom:  1 minute time marks. (Time moves from right to left.)
Figure 4.3. Correlation of electric train fluctuations due to train movements, and resulting magnetic effects. Time moves from right to left, and the length LC = 17 minutes. **Top:** electric-power-factor variations (arrows indicate scheduled stopping times at intermediate stations). **Middle:** simultaneous magnetic effects in the frequency band 0.008-0.25 cps. **Bottom:** train movements. L = Lyttelton; C = Christchurch.
Figure 5.1. Equivalent circuit of the detector coil galvanometer-photocell amplifier system.

The symbols used are:

- $e_s$ - voltage generated by the detector coil
- $N$ - number of turns on the detector coil
- $a$ - cross-sectional area of the detector coil core
- $B_o$ - component of the geomagnetic field along the axis of the coil
- $\omega$ - angular frequency of the oscillations of $B_o$
- $\mu'$ - effective permeability of the detector coil core
- $\theta$ - angular deflection of the galvanometer mirror
- $G$ - galvanometer constant
- $V_G$ - back e.m.f. induced in the galvanometer coil
- $A$ - gain of the optical-transistor amplifier
- $R_L$ - resistance of the detector coil
- $L$ - inductance of the detector coil
- $R_g$ - galvanometer resistance
- $R_o$ - output impedance of the optical-transistor amplifier
- $R_f$ - feedback resistance.
Figure 5.2. A family of theoretical frequency response curves for the galvanometer photocell amplifier. The corresponding values of feedback resistance \( R_f \) are also indicated.
The graph shows the response as a function of frequency for different resistances: $R_f = \infty$, $2.5 \, \text{M} \Omega$, $500 \, \text{k} \Omega$, and $150 \, \text{k} \Omega$. The response is measured in dB (decibels) and the frequency is given in cps (cycles per second).
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Figure 7.2. Block diagram of the data analysis system.
DATA ANALYSIS SYSTEM.
Figure 7.3. Frequency response curves for the record-playback system. The solid curves indicate the response with equalization applied and the dotted curves give the unequalized record-playback characteristics.
Figure 7.4. Calibration signals.

(a) Frequency calibration signals with amplitudes of 25 m.$

(b) Sensitivity calibration with a 1 cps constant frequency signal. The minimum detectable signal is 3 m.$

(c) and (d) Sweep frequency calibrations with ramp signals increasing with frequency at rates of 0.02 cps/min and 0.18 cps/min.
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Figure 8.2. Frequency-time display of a long duration hydromagnetic emission event exhibiting fine structure.
(The activity occurring between 1840 and 1845 hr UT is broadband interference.)
Figure 9.1. Theoretical frequency-time displays of hydromagnetic emissions resulting from ion cyclotron wave packets propagating along field aligned paths at $L = 4$ ($\phi_s = 60^\circ$) and $L = 5.6$ ($\phi_s = 65^\circ$). The horizontal dotted line at 2.7 cps indicates the equatorial ion cyclotron frequency at $L = 5.6$. (Diagram after Obayashi, 1964).
\[ \phi_0 = 65^\circ \]
\[ N_0 = 10^4 \text{ cm}^{-3} \]

\[ \phi_0 = 60^\circ \]
\[ N_0 = 10^4 \text{ cm}^{-3} \]
Figure 9.2  Hydromagnetic wave attenuation processes. Curve (a) Ionospheric attenuation characteristic for hydromagnetic waves propagating downwards through the ionosphere under daytime sunspot minimum conditions. The slope is approximately 6db/octave. (From Karplus et al. 1962). Curve (b) Magnetospheric attenuation due to cyclotron damping for ion cyclotron waves propagating along the field aligned path $L = 4.8$ and $f_{Hc} = 4.5$ cps. (From Scarf, 1962)
IONOSPHERIC ATTENUATION

Daytime sunspot minimum

(a) THERMAL DAMPING

(b)

- $T_i = 10^4 \, ^\circ K$
- $T_i = 7.5 \times 10^4 \, ^\circ K$
- $T_i = 1.25 \times 10^5 \, ^\circ K$

$T_i =$ ION TEMPERATURE

FREQUENCY (CPS)
Figure 10.1  Schematic frequency-time diagram illustrating the hm emission parameters measured from sonagrams. The midband frequency $f_m = (f_1 + f_2)/2$ and the mean fine structure band spacing $T = (t_n - t_1)/(n - 1)$, where $n$ is the number of coherent bands present. The relative bandwidth is $\Delta f/f_m$ and the mean band slope is $m = (m_1 + m_n)/2$ where $m_1$ to $m_n$ express the slope of individual bands.
Figure 10.2  Typical broad-band and narrow-band emissions. The relative bandwidths $\Delta f/f_m$ are 0.75 and 0.12 respectively. The constant frequency signal at 1 cps in the bottom sonagram is of instrumental origin. This signal also appears on many of the sonagrams in the following Figures.
Figure 10.3 Narrow-band hm emission in which the fine structure bands do not overlap in time. The individual bands on the sonagram correspond to the envelopes on the amplitude-time chart. The mean band spacing on the sonagram is $2.10 \pm 0.05$ min and the envelope spacing on the 1.0 cps channel of the amplitude time record is $2.2 \pm 0.1$ min.
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Figure 10.5 (a) Enlargement of a section of the April 5, 1964 emission event shown in Figure 10.2. Note the discontinuities in fine structure band slope at approximately 0.05 - 0.1 cps intervals between 1530 hr. and 1550 hr. UT. (b) Example of individual narrow-band emissions exhibiting an increase in band spacing within a broad-band emission. The mean band spacing for the four numbered narrow-band emissions are listed below.

1. \( f = 0.40 - 0.48 + 0.05 \text{ cps}, \ T = 2.52 + 0.06 \text{ min} \)
2. \( f = 0.45 - 0.55 \), \( T = 2.65 + 0.05 \)
3. \( f = 0.55 - 0.65 \), \( T = 3.00 + 0.05 \)
4. \( f = 0.75 - 0.85 \), \( T = 3.30 + 0.05 \)
APR. 5, 1964, 1530 hr UT.

FEB. 23, 1964, 1330 hr UT.
Figure 10.5 Variation in hm emission midband period with mean band spacing. Emissions occurring during the local daytime between 22 - 06 hr. UT (0930 - 1730 hr. LT) and within the three days following the commencement of a geomagnetic storm containing $K_p \geq 6$ are also indicated.
BAND SPACING $T$ (MIN.)

MEAN OSCILLATION PERIOD $t_m$ (SEC.

COLLEGE ———
CHAMBER ———
CHCH.  
DAYTIME •
STORM-TIME △
Figure 10.7 Variation in the mean fine structure band slope with mean band spacing for 51 data samples from broadband emissions.
Mean band slope $m$ (C/S.min$^{-1}$)

Band spacing $T$ (minutes)
Figure 10.8  Occurrence of hm emissions and geomagnetic activity.

Top  Distributions of twenty minute hm emission occurrences with $K_{AM}$ and $K_p$ over the period November 27, 1963 to July 20, 1964

Middle  Distributions of $K_p$ and $K_{AM}$ over the same period.

Bottom  Normalized hm emission occurrence distributions.
STRUCTURED PC1 EMISSIONS

NUMBER OF OCCURRENCES (20min)

Kp DISTRIBUTION

KAM DISTRIBUTION

NORMALIZED OCCURRENCES

% OCCURRENCE

Kp

KAM
Figure 10.9  Hm emission event recorded simultaneously at four middle and high latitude stations.
Figure 10.10  Three examples of narrow-band storm-time Pc1 emissions.
Figure 10.11  The occurrence of narrow-band irregular and non-structural Pc1 emissions and geomagnetic activity.

Top  Distributions of twenty minute emission occurrences with $K_{AM}$ and $K_p$ over the period November 27, 1963 to July 20, 1964.

Middle  Distributions of $K_{AM}$ and $K_p$ over the same period.

Bottom  Normalized emission occurrence distributions.
NON-STRUCTURED AND IRREGULAR-STRUCTURED PC1 EMISSIONS

NUMBER OF OCCURRENCES (20 min)

NUMBER OF OCCURRENCES (3 hr)

Kp DISTRIBUTION

Km DISTRIBUTION

NORMALIZED OCCURRENCES

% OCCURRENCE

0 1 2 3 4 5 6 7

Kp

0 1 2 3 4 5 6 7

Km
Figure 10.12  Diurnal variation in the twenty minute occurrence rates of narrow-band storm-time emissions. The full line indicates rates smoothed in sliding groups of three.

AVERAGED IN SLIDING GROUP OF THREE
Figure 10.13 Irregular structured and non-structured broadband storm-time emissions.
Figure 11.1 Diurnal variation in the twenty minute occurrence rates of hm emissions. The full line represents rates smoothed in sliding groups of three

AVERAGED IN SLIDING GROUP OF THREE.
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Figure 11.6  Day and night hm emission frequency spectra for the period December 1, 1963 to July 20, 1964 and the two four month periods December - March and April - July.
DAY 2200-0600 UT.

DEC.-JUL.

30

DEC.-MAR.

10

NO. 20MIN. OCC.

20

MIDBAND FREQUENCY $f_m$ (CPS).

0

0.5

1.0

1.5

NIGHT 1000-1800 UT.

DEC.-JUL.

20

DEC.-MAR.

10

APR.-JUL.

10

APR.-JUL.
**Figure 11.7** Low frequency daytime hm emissions.

**Top.** An unusually intense low frequency daytime emission. Note also the very narrow-band emissions occurring between 0420 - 0440 hr and 0455 - 0530 hr. UT. (The activity in the range 0.7 - 1.2 cps between 0600 - 0645 hr. represents the second harmonics of this event)

**Bottom** A more typical low amplitude daytime emission.
Figure 11.8  Relationships between the hourly values of hm emission upper frequency cutoff for daytime emissions occurring between 10-18 hr UT (0930 - 1730 hr LT) and the ion densities of the E, F1 and F2 regions. The ion densities were calculated from the critical frequencies $f_{oEs}$, $f_{oF1}$ and $f_{oF2}$. 
Variation in the nighttime hourly values of fine structure band spacing with daily magnetic activity as indicated by $\Sigma K_p$. 
EMISSIONS ON DAYS WITH $K_p \geq 6$
Figure 12.2 (a) The mean hourly values of midband frequency for nighttime data plotted as a function of $K_p$ values taken in groups of five.

(b) The mean hourly values of band spacing plotted in a similar manner. In both graphs each point is the mean of the indicated number and the vertical line segment centred on each point indicates the standard deviation.
Figure 13.1 Latitude variations of the hm wave packet bounce period calculated using equation 13.1. The propagation velocity is assumed to be the Alfvén velocity. An inverse cube law plasma density distribution is assumed with $N_0 = 1.41 \times 10^{10}$ / m$^3$ for the normal curve. The knee curve assumes a plasma density one-sixth of that of the normal curve.
Figure 13.2 Locus of the emission source as deduced from the diurnal variation in fine structure band spacing. The full curve corresponds to the average T values plotted in Figure 11.5 and the dashed curves correspond to the maximum and minimum hourly T values. The minimum curve represents the location of the emission source at disturbed periods. The dotted curve is the average position of the source for a magnetospheric plasma density distribution with a knee at L=5.
Figure 13.3. Variation in h m emission occurrence at fourteen stations.
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Figure 2.2  Galvanometer-photocell amplifier.
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Figure A2.4 Overall frequency response of the high sensitivity data recording channel. The 3db band-width is 0.08 - 3.3 cps.
Figure 2.5  500 cps bias oscillator and amplifier.
Figure A2.6. 50 cps squaring amplifier and motor drive power amplifier. The output of the squaring amplifier feeds to the frequency dividers providing the 2 ppm time signals. The power amplifier is rated at 1.5 W and drives the tape transport and calibration oscillator motors in parallel.
The 50 cps tuning fork signal is reduced to 2 ppm using four monostable circuits and three binary circuits. Details of the monostable circuits are listed below.

<table>
<thead>
<tr>
<th>Division Factor</th>
<th>$R_1$ (hi stab.)</th>
<th>$C_1$ (μf)</th>
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<tr>
<td>M1</td>
<td>5</td>
<td>283 K</td>
</tr>
<tr>
<td>M2</td>
<td>5</td>
<td>47 K</td>
</tr>
<tr>
<td>M3</td>
<td>5</td>
<td>100 K</td>
</tr>
<tr>
<td>M4</td>
<td>3</td>
<td>100 K</td>
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Figure A2.8 1000 cps filter amplifier and output stages. The amplifier has a $\psi$-factor of 8.
Figure 2.9 Battery voltage regulator.
Figure A3.1 Equalization amplifier.
Figure A3.2  Frequency response of the equalization amplifier.
Figure 3.3. Pulse shaping amplifier.
Figure A3.4. Block diagram of the pulse counter.
COUPLING AMP.

DEKATRON x1

PULSE SHAPER & DRIVER AMP

COUPLING AMP.

DEKATRON x10

COUPLING AMP.

DEKATRON x10^2

COUPLING AMP.

DEKATRON x10^3

COUPLING AMP.

DEKATRON x10^4

GATE

PULSE IN

PULSE OUT

SONAGRAPH ERASE HEAD

FROM PULSE AMP
Figure 43.5. The pulse counter gate circuit.