

LMSC/N-83-69-1

Operation of a Three-Frequency
Riometer System on the NASA 711 Aircraft
During the 1968 Auroral Expedition

Contract No. NASw-1682

J. N. Bradbury

January 15, 1969

LOCKHEED PALO ALTO RESEARCH LABORATORY
Palo Alto, California

CONTENTS

<u>Section</u>		<u>Page</u>
	ILLUSTRATIONS	ii
	TABLES	iii
I	INTRODUCTION	1
II	INSTRUMENTATION	3
III	DATA ACQUISITION	14
IV	RESULTS AND DISCUSSION	17
	ACKNOWLEDGMENTS	28

ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Block diagram of the airborne three-frequency riometer system	4
2	Equipment as installed on the NASA 711 jet aircraft	5
3	Antenna installation on the NASA 711 jet aircraft	6
4	Antenna radiation patterns in the roll plane	8
5	Antenna radiation patterns in the pitch plane	9
6	Absorption events of 30 January and 1 February	19
7	Absorption events of 27 February and 29 February	21
8	Absorption events of 3 March	22-23
9	Absorption events of 4 March	25

TABLES

<u>Section</u>		<u>Page</u>
II	Measured Riometer Sensitivities	12
III	Absorption Events Observed During 1968 Auroral Expedition	17
III	Height of Peak of Absorbing Layer of Selected Events	26

I. INTRODUCTION

The ionospheric absorption of radio waves is a function of the integrated electron density and collision frequency along the path traversed by the radio wave. Enhanced electron densities, particularly in the D-region, due to charged particles, X-rays, or other sources result in increased absorption. Ground based riometer measurements of cosmic radio noise have provided considerable information on the space and time variations of various kinds of absorption events with concomitant increase in our understanding of solar-terrestrial relationships and D-region chemical processes.

The proposal for including a multifrequency riometer system for making measurements of the ionospheric absorption of cosmic noise aboard the NASA 711 aircraft during the 1968 auroral expedition was motivated by two main considerations:

- 1) Ionospheric absorption measurements from a mobile station during a polar cap absorption event (PCA) would offer a unique opportunity to study absorption profiles as a function of latitude and local time. Such measurements provide information on the latitudinal variation of the geomagnetic cutoff energy for the solar subrelativistic particles producing PCA's and hence the configuration of the outer geomagnetic field.

- 2) Auroral absorption tends to occur at appreciably lower heights than auroral luminosity and is thus primarily due to the high energy portion of the precipitating flux of charged particles. Hence absorption measurements play a complementary role to photometric measurements, and the degree to which they correlate yields information on the spatial and time

coherence of different parts of the energy spectrum of the precipitating particles.

In addition to these fundamental objectives, it was hoped that data could be obtained on the large scale morphology of absorption events, possible variations in the heights of the absorbing regions during breakup and prebreakup phases of auroras, and dawn-dusk effects on absorption in constant and accelerated local time conditions.

No PCA events occurred during the expedition so one of the prime experimental goals was unattainable. Considerable time, however, was spent studying various types of auroral activity and several auroral absorption events were observed. These events were generally correlated with the breakup phase of an aurora. Multifrequency measurements permit, in principle, an approximate height limit to be ascribed to the absorbing region and this could be done in several cases. Although the aircraft data added nothing strictly new to the accumulated ground based riometer data, the experiment did demonstrate the feasibility of airborne absorption measurements. It should be stressed that the potential increase in knowledge concerning the PCA event makes the inclusion of absorption measuring equipment very desirable for high latitude flights during periods of increased solar activity.

Section II of this report describes the equipment used in making the airborne absorption measurements and indicates the areas in which improvements could be made in such systems in the future. Section III contains the data acquisition procedure and a discussion of the noise problems encountered. In Section IV the observed absorption events are described and correlated with visual and photometric observations of the auroral conditions.

II. INSTRUMENTATION

A block diagram of the equipment for making airborne measurements of cosmic radio noise absorption is shown in Figure 1. For reasons to be discussed later, it was decided to make measurements at 20, 30, and 60 MHz. Cosmic radio noise is received by an antenna mounted on the fuselage of the NASA 711 jet aircraft. The matching network serves both to match antenna impedance at 20, 30, and 60 MHz to the 50 ohm input impedance of the three riometers and isolate the three frequency channels from one another. Each riometer compares the received signal with a local source of noise, provides a detected output which is a voltage proportional to the difference between the two signals, and uses this error voltage to control the local noise diode current in such a way as to equate its noise output to that of the received signal from the antenna. In this way any gain instability effects are eliminated. The noise diode current is recorded both on chart recorders for immediate visual observation and on a tape recorder for later detailed analysis. Figures 2 and 3 show, respectively, the equipment installed in the NASA 711 and the antenna on the aircraft fuselage. The components of the system will next be described in more detail.

Antenna

Antennas for absorption measurements should have a well-defined single-lobe in the zenith direction with a minimum of side lobe response. Improved correlation with photometric observations can be achieved by making the zenith lobe beamwidth the same as the fields of view of the optical instruments. However such highly directive antennas involve large or complicated structures. Both time limitations (the contract was signed one month prior to the scheduled test flight) and restrictions as to the type

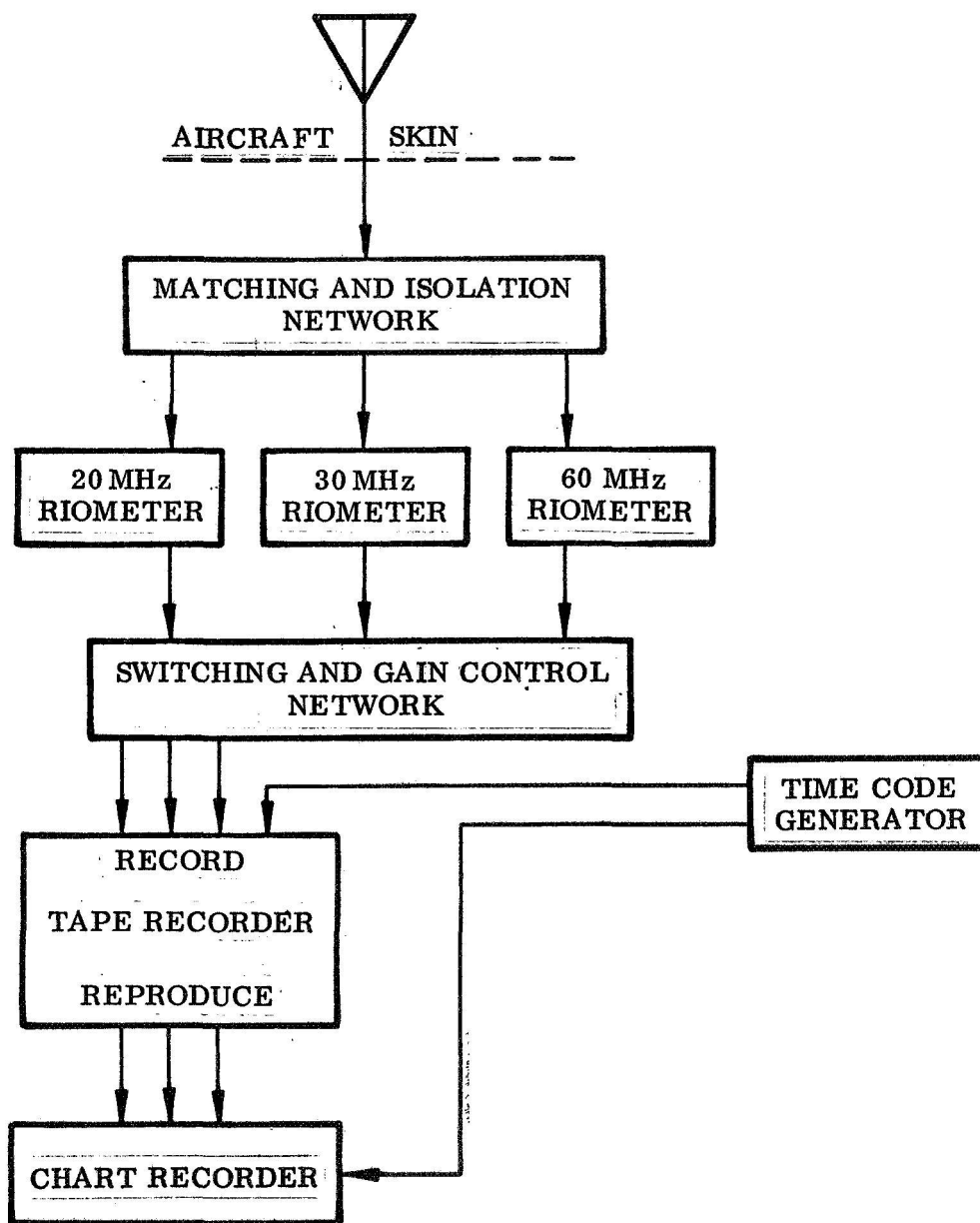


Fig. 1 Block diagram of the airborne three-frequency riometer system



Fig. 2 Equipment as installed on the NASA 711 jet aircraft

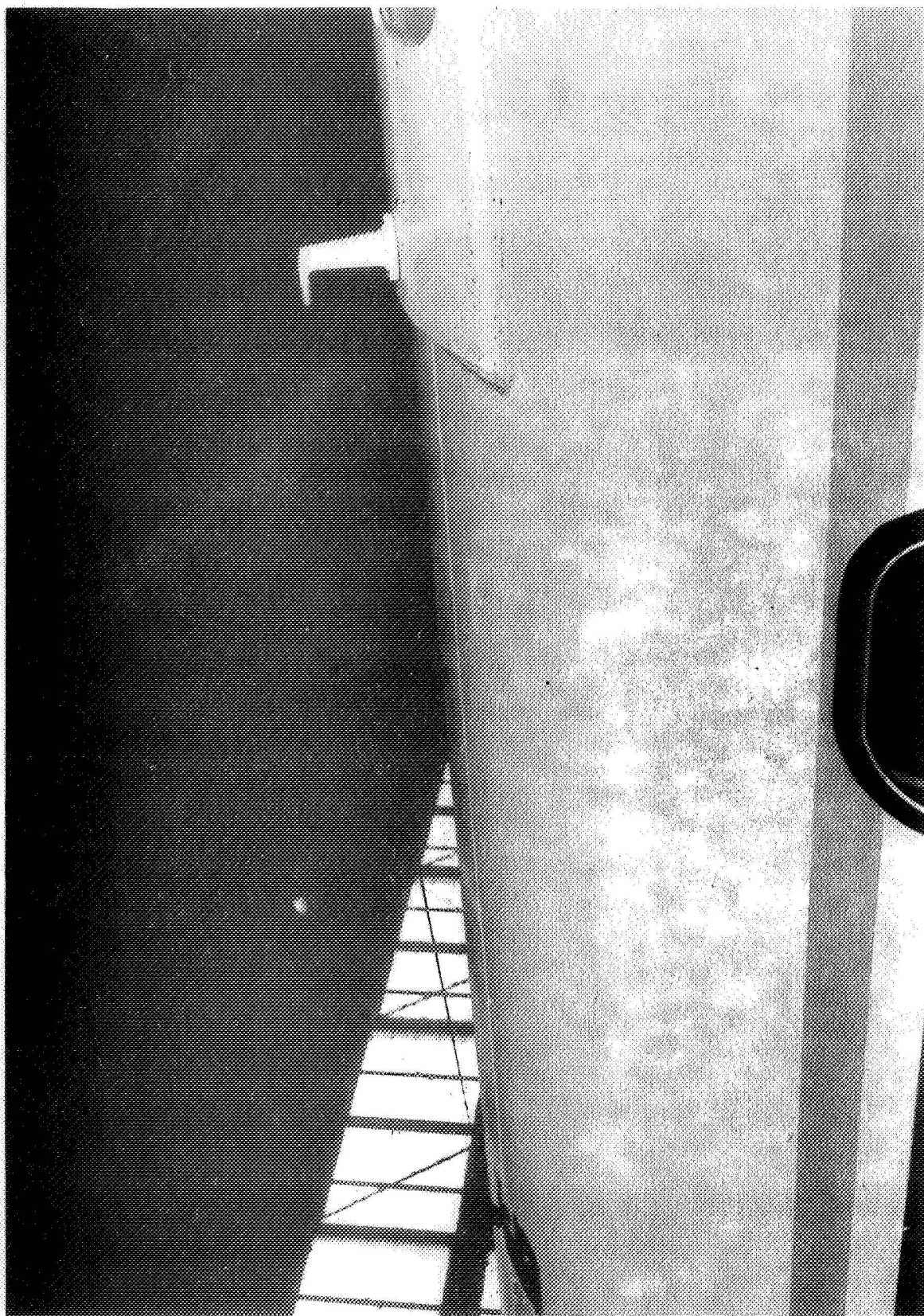


Fig. 3 Antenna installation on the NASA 711 jet aircraft

of array which can be mounted on a jet aircraft precluded the installation of a highly directive system. A careful analysis of the problem indicated that a simple end-fed wire, mounted along the fuselage near the top would both provide reasonable directivity toward the zenith (at least to the extent of rejecting much of the ionospherically propagated man-made signals and noise) and comply with the requirements of the aircraft engineers. The antenna was 11 feet long ($\sim 1/4$ wavelength at 20 MHz, $\sim 3/4$ wavelength at 60 MHz) and was mounted between two plates designed to fit the available window spaces of NASA 711 located about 20° from the top of the fuselage. The antenna pattern was thus maximized in approximately the same direction as the fields of view of the photometric equipment. The antenna was spaced about ten inches from the fuselage and slightly forward of the center of the aircraft. The fuselage and wings approximated a ground plane.

Antenna patterns were measured using a 1:54 scale model of the NASA 711 obtained from Convair and coated with conducting paint. A scaled antenna was installed and fed with microwaves corresponding to 20, 30, and 60 MHz. The far field radiation patterns are shown in Figures 4-5. Substantial directivity was obtained in the pitch dimension with somewhat less directivity in the roll plane. Also, as will be the case for any linear antenna, the patterns were not identical at the three frequencies. However the overall antenna performance was judged adequate. It is suggested that for future such experiments the possibility of installation of a more directive antenna be explored; for example, a log-periodic array, although perhaps impractical, would provide considerable gain and very similar radiation patterns and input impedances over the entire frequency range.

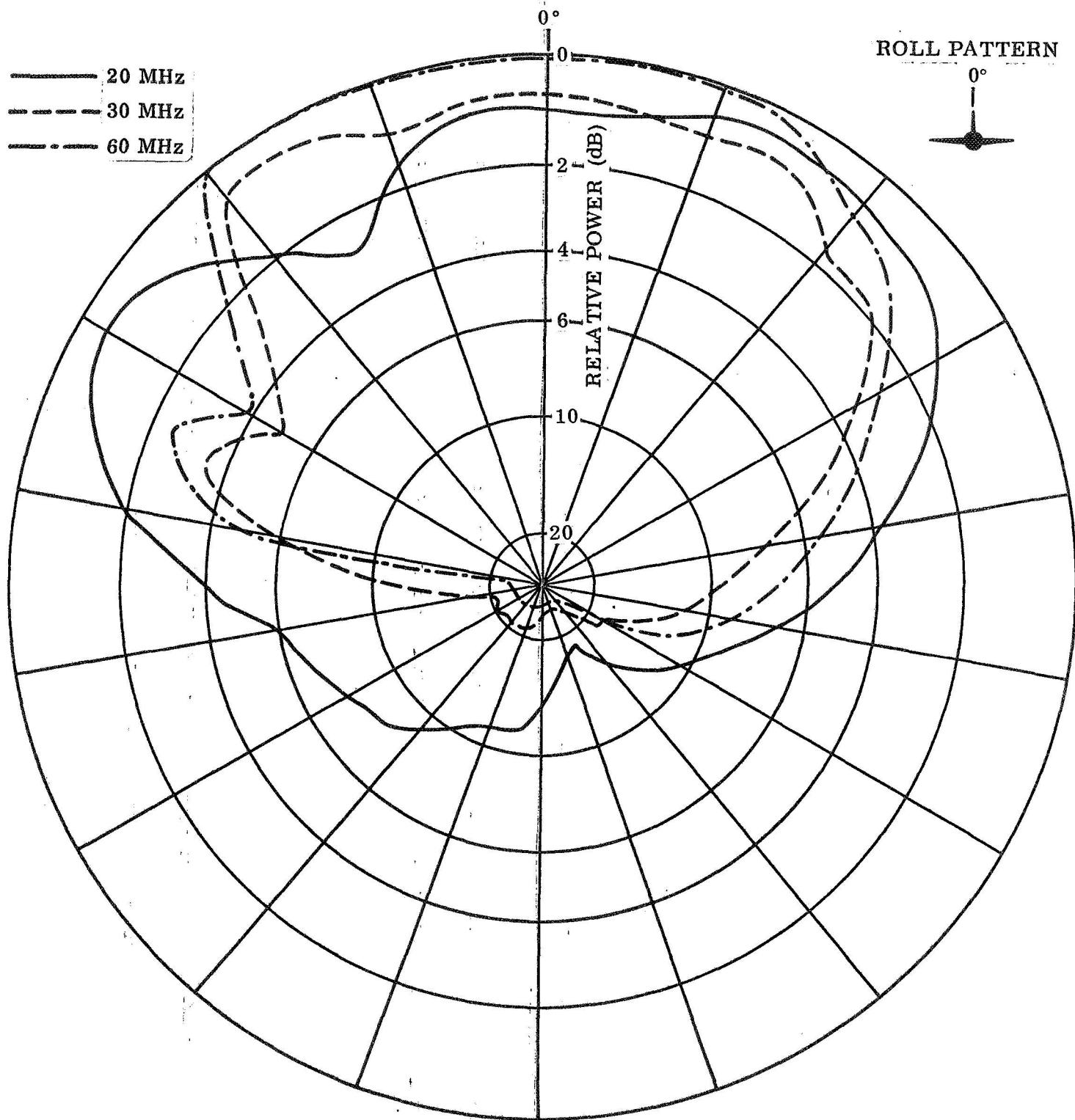


Fig. 4 .Antenna radiation patterns in the roll plane

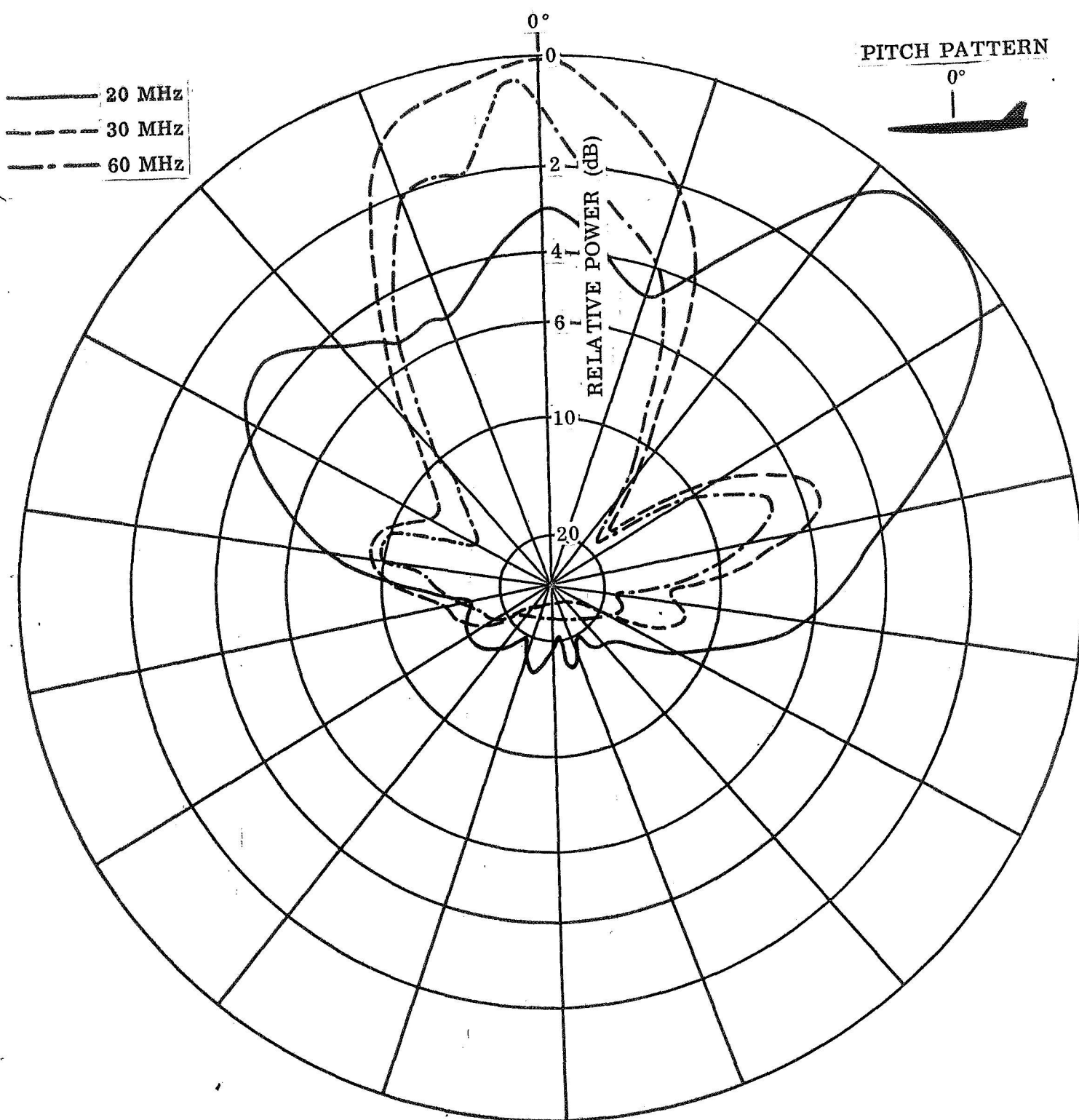


Fig. 5 Antenna radiation patterns in the pitch plane

Matching Network

Matching receivers at three different frequencies to a single antenna is a nontrivial problem and considerable effort was expended in designing and constructing a low loss network which exhibited both a low voltage standing wave ratio (VSWR) at the three frequencies and good isolation between channels. Two networks were ultimately constructed. The first, which was used almost exclusively throughout the experiment, allowed high sensitivity simultaneous reception of 20 and 30 MHz signals or high sensitivity reception of 60 MHz signals alone. Sufficient time was not available for construction of a circuit to electronically switch between the two modes, and several minutes were required to manually make the change-over. The second system allowed all three frequencies to be received simultaneously but with quite large losses. In view of the fact that absorption at 60 MHz was expected to be essentially undetectable except in intense absorption events (e.g., strong PCA events), the first system was used, and when large absorption was observed at 20 and 30 MHz, the 60 MHz riometer was operated for brief periods separately. The final adjustments of the matching network were performed after installation on the aircraft. The VSWR at the three frequencies were of the order of 1.2 and the isolation between channels was greater than 10 db.

Riometers

The matching network outputs were fed to the riometers (Aerospace Research Inc., Model ARL-100c) on RG-8U coaxial cables. These riometers are highly sensitive, ultra-stable instruments capable of long term resolution and stability of 0.1 db. This high stability is achieved by using the

receiver as part of a feed-back loop that acts to equate the noise output of a temperature limited diode to antenna noise thereby virtually eliminating receiver instabilities as a source of error. Hence the riometer faithfully records the relative intensity of cosmic noise as seen by the antenna. The riometers can be manually or automatically tuned over a range of $\pm 1/2\%$ of their center frequency to avoid interfering signals and contain automatic calibrators. Time constants and minimum detection levels can be adjusted to provide optimum rejection of unwanted noise.

Measurements of absorption at several frequencies enable heights of the absorbing region (and in some instances electron density profiles) to be estimated. The choice of operating frequencies was governed by the following considerations. The limiting factors for riometer operation at lower frequencies are interference from ionospherically propagated man-made signals (which exceed galactic radio noise over most of the world for frequencies less than ~ 10 MHz) and the reflection of cosmic noise back into space as the F-layer critical frequency is approached. A frequency of 20 MHz is thus a practical lower limit. The majority of ground based riometers operate in the vicinity of 30 MHz so this frequency was included in the airborne system for possible intercalibration purposes. Both absorption and cosmic noise intensity decrease with increasing frequency and 60 MHz is a practical upper limit. At 60 MHz absorption would be detectable only for a fairly intense event.

The sensitivities of the riometers increase with frequency to partially compensate for the cosmic noise intensity decrease with frequency. Using an R.F. signal generator the riometers were tuned for optimum

sensitivity and then were tested with a random noise generator. The results are listed in Table I. T_{α} is the antenna temperature necessary to produce a riometer output of 1 ma.

Table I

<u>Riometer</u>	<u>T_{α} ($^{\circ}$K) for 1 ma output</u>	<u>$\frac{T_{\text{cosmic noise}}}{T_{\alpha}}$ (db)</u>
20 MHz	23,500	4.8
30 MHz	4,500	8.1
60 MHz	1,100	8.2

Although the 20 MHz riometer was found to have considerably less sensitivity than advertised, all sensitivities were sufficient for cosmic noise observation even with substantial antenna and coupling losses.

Recording System

The riometer outputs were recorded on both chart recorders and magnetic tape. The signals were recorded directly on the tape recorder and the tape recorder reproduce circuitry was then used to drive the chart recorders. Observation of a signal on the chart recorder thus ensured the entire system was functioning properly. The tape recorder offered better linearity and frequency response than the chart recorders and hence was the primary means of data acquisition. Binary time codes from the aircraft time code generator were included on both the magnetic tape and one chart record.

The 14 tracks of the tape recorder (Ampex CP-100) were used to record the data of both the riometer and an optical pulsation experiment and also the comments made by the experimenters and expedition managers over the aircraft intercom system. To obtain the necessary low frequency response FM recording was used for the data channels. The tape recorder was operated at 1 7/8 ips so that one roll of tape sufficed to record the data of at least one six-hour flight. At this speed the upper limit of the system frequency response was 625 Hz, considerably in excess of the experimental requirements.

Trial Flight

The entire system was checked out during a pre-expedition flight and was found to have adequate sensitivity. It was noted that the temperature of the matching network which was affixed to the metal plate in the window frame approached -20°C at aircraft operating altitudes with a consequent degrading effect upon circuit performance. An insulating spacer was included for the expedition flights with the result that the network temperature was only slightly less than the cabin temperature.

III. DATA ACQUISITION

As indicated previously standard operation consisted in simultaneous measurements at 20 and 30 MHz with the 60 MHz riometer being separately inserted into the system during periods of possible strong absorption. The riometers were generally operated with 15 KHz bandwidths although shorter bandwidths were occasionally used for improved interference rejection. The riometer time constants were adjusted to about 5 sec., long enough to reject short spikes of interference but short enough to record rapid changes in absorption. The riometers were operated exclusively in the manual tune mode because, in each frequency range, there was almost always at least one very strong source of man-made noise which would saturate the recording equipment periodically if the bandwidth were continuously scanned. Calibrations of the riometer-recording system, utilizing the test noise diodes in the riometers, were performed at the beginning and end of each data flight. Virtually no change occurred in the calibration levels throughout the expedition.

During the first session the equipment was found to function satisfactorily and reliably. Although the experiment was scheduled for the first session only, it was determined between sessions that space was available for the equipment during the second session. Mr. Earl Peterson, assistant expedition manager, kindly agreed to turn the equipment on during the second session data flights. The tape recorder could not be installed until just prior to flight 18 so no data was acquired for flights 14-17. Also, unknown problems resulted in no data acquisition for flights 23-24. For the rest of the flights absorption data were recorded continuously on magnetic tape, although there were frequent periods of excessive noise since no tuning was performed.

A brief description of the interference problems encountered during the expedition will be presented to assist in the planning and development of any future airborne absorption measurements. Cosmic radio noise is of course, the signal which is experimentally desired. Sources of interference, which degrade the signal-to-noise ratio, include (1) precipitation static, (2) ground based man-made noise, and (3) local aircraft noise. Precipitation static occurs when an antenna moves through rain, snow, or clouds and, at the frequencies used in this experiment, could be sufficient to obscure the cosmic noise signal at low altitudes. Consequently, if overcast conditions prevailed during ascent or descent absorption data were frequently unattainable. At altitudes greater than 8 km, however, clouds are rarely encountered and this form of noise was not a severe problem.

Man-made signals (noise for the purposes of this experiment) were frequently encountered since amateur, military communication, navigational aid, and TV broadcast bands occur in the 20-60 MHz region. There was at least one such source of interference, several orders of magnitude greater than cosmic radio noise, always present within the bandwidths through which the riometers could be tuned. Appropriate tuning, bandwidth, and time constant adjustment usually permitted a quiet portion of the spectrum to be obtained. Occasionally broadband noise at 20 and 30 MHz prevented data acquisition for short periods.

In view of the diversity and extent of electronic and electrical equipment aboard the aircraft, it was anticipated that local noise would be a problem. Consequently great care was taken in shielding the matching network and riometers. Only one persistent source of interference due to

aircraft equipment was observed, and this was eventually found to be a camera system, located near the matching network which was pulsed on periodically. For the time of exposure a large noise spike (seen in one of the records shown in the next section) was received by the riometers. As the duty cycle of the camera system was less than 50%, these spikes did not ruin the data although they were annoying and decreased the time resolution of the system. Efforts to shield the camera drive unit were unsuccessful, but the unit was modified between sessions eliminating the difficulty.

Finally, conducting an airborne cosmic noise absorption experiment involves several problems not encountered with similar ground based experiments. The short duration of the flights, together with the changes in galactic region scanned, dictated that the quiet day curves obtained with ground based riometers could not be obtained. This was not too serious since the absorption curves did exhibit a smooth baseline from which short term deviations due to auroral absorption could be discerned. Due to the fairly broad antenna pattern, small changes in aircraft attitude presented no difficulties, but large course changes created new baselines. Infrequent course changes could thus be tolerated, but, for example, the "racetrack" course of the aircraft during those flights in which coordination was attempted with a rocket launch made interpretation of the absorption records difficult if not impossible. Study of the data in the light of the above considerations indicated that the overall sensitivity during a typical flight was about 0.6 db.

IV. RESULTS AND DISCUSSION

The auroral absorption events (> 1 db at 30 MHz) observed during the 1968 auroral expedition are listed in Table II below.

Table II

<u>Flight</u>	<u>Date</u>	<u>U.T.</u>	Maximum Absorption (db)	
			<u>20 MHz</u>	<u>30 MHz</u>
8	January 30	0520-0625	3.5	1.5
9	February 1	0607-0624	3.2	1.8
19	February 27	0505-0516	2.1	1.0
20	February 29	0717-0750	4.0	2.0
21	March 3	0710-0910	---	1.4
21	March 3	0915-0930	---	6.4
22	March 4	0930-1030	4.0	---

No absorption was observed at 60 MHz; indeed it would only be expected to be measurable for very intense events such as the second event of March 3, and the capability of 60 MHz measurements did not exist for the second session. Blanks in the frequency columns in the above table indicate that the records for that frequency were excessively noisy, generally to the extent of equipment saturation.

The absorption measurements reproduced from the magnetic tape data for the seven events are shown in Figs. 6 to 10. In some cases records for both frequencies are shown to illustrate the comparison. Absorption increases toward the bottom of the page and all dates and times are U.T.

The auroral conditions and photometric observations (obtained from experimenters' comments and R. H. Eather) during each event will be briefly described.

30 January

During Flight 8, a north-south flight along a geomagnetic meridian near Churchill, a relatively long absorption event occurred as shown in Fig. 6. At 0520 with the aircraft heading south, two bright arcs were observed near the zenith. The aurora increased in activity and spatial extent and, about 0537, began to exhibit considerable motion, typical of the breakup phase. Occasional red lower borders were observed, and the $\lambda 5577$ intensity was about 4 kR. At 0555 the aircraft turned north passing under a bright arc of intensity 8 kR $\lambda 5577$. During this period (0525-0600) the H β intensity increased from 10 R to 50 R. Near 0625 the activity decreased and the aurora entered a post-breakup phase. The absorption, reaching a maximum about 0600 and ending about 0625, correlates reasonably well with the general level of auroral activity. The two periods of noise occurred when the aircraft passed over Gilliam, Canada.

1 February

The flight path was again along a geomagnetic meridian near Churchill and auroral breakup began about 0605. Prior to this, strong rayed structure extending E-W was observed but no accompanying absorption. Average intensities of H β and $\lambda 5577$ were, respectively, 30 R and 10 kR. As shown in Figure 6 absorption commenced at 0607 and peaked near 0611. Zenithal luminosity was considerably decreased by 0620 but absorption persisted until about 0624. This can be explained either by a decrease in the soft

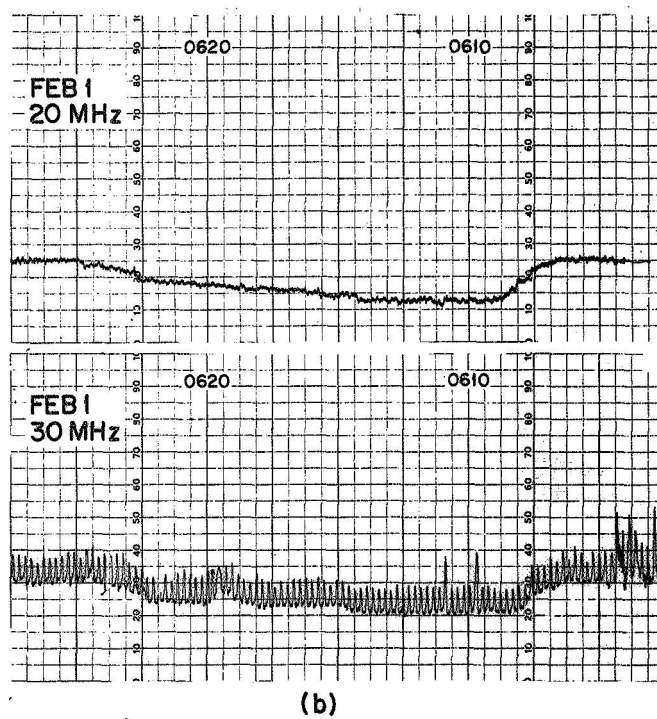
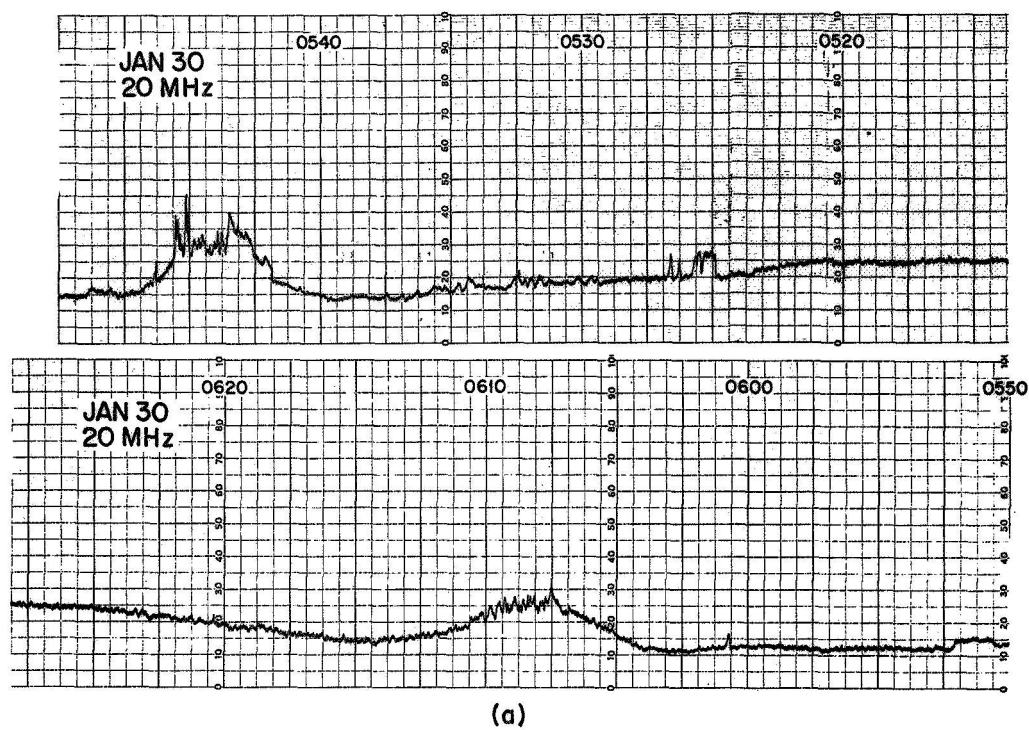


Fig. 6 Absorption events of 30 January and 1 February

flux but not the hard flux of precipitating particles, or more likely, geometric effects due to the wide field of view of the antenna. The 30 MHz record exhibits the periodic interference discussed in an earlier section.

27 February

This is an example of a quite short event not associated with auroral breakup. The aircraft was heading approximately south after an OGO IV intercept. During the period 0505-0516 the aircraft passed underneath a bright arc [5 kR of $\lambda 5577$, ~ 2 kR of $\lambda 4278$] and considerable off-zenith activity was observed. The energy spectrum of the electrons responsible for the luminosity evidently contained a hard component. The absorption record is shown in Figure 7.

29 February

This event lasted from 0717-0750. An intense breakup was observed to the east of the aircraft about 0718. Rapid changes and motion of the auroral forms and frequent pink lower borders were observed. The aircraft circled twice underneath the breakup. Maximum intensities of ~ 30 kR of $\lambda 5577$ and 40 R of H β were recorded at 0741, coinciding exactly with an absorption maximum of 2.0 db at 30 MHz.

3 March

Perhaps as many as three absorption events were recorded (see Figure 8) during this approximately constant local time flight from Churchill to Eielson AFB along the auroral oval. Until 0700 auroras were seen to the north and south which remained fairly quiet. At about 0710 the auroras to the east suddenly brightened and an auroral substorm began. Slight absorption was observed at 30 MHz. Considerable auroral activity then followed

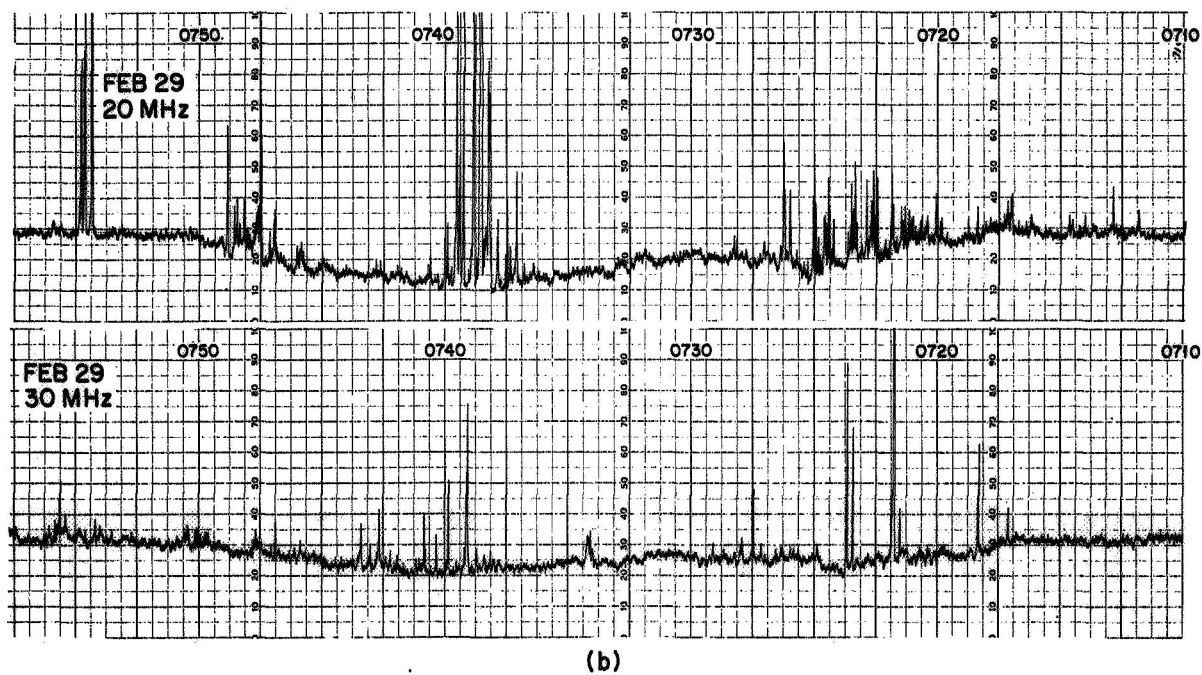
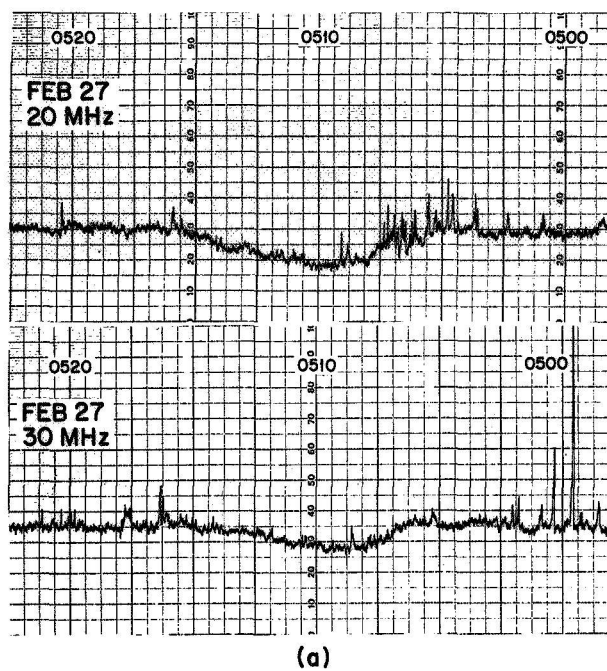


Fig. 7 Absorption events of 27 February and 29 February

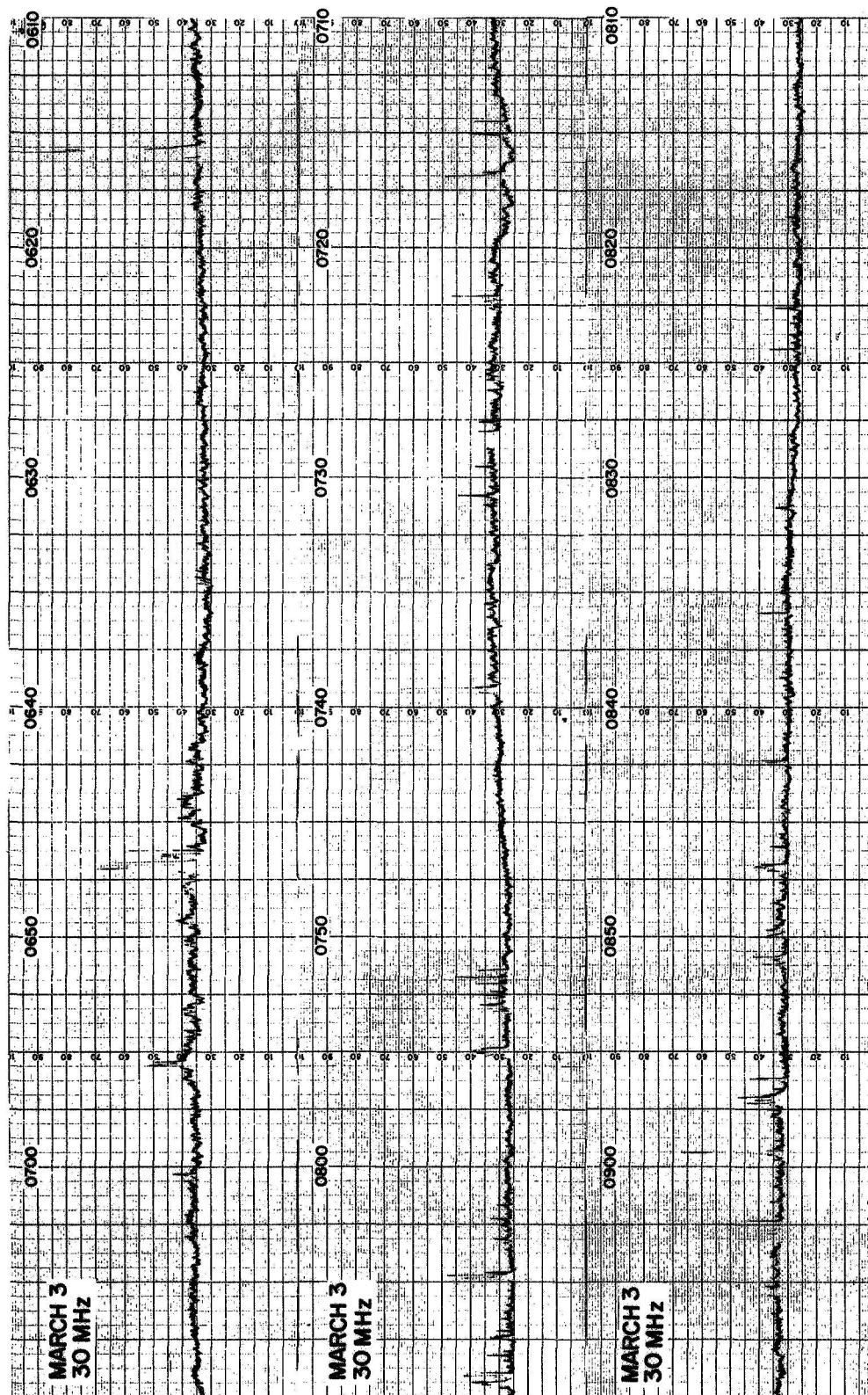


Fig. 8 Absorption events of 3 March

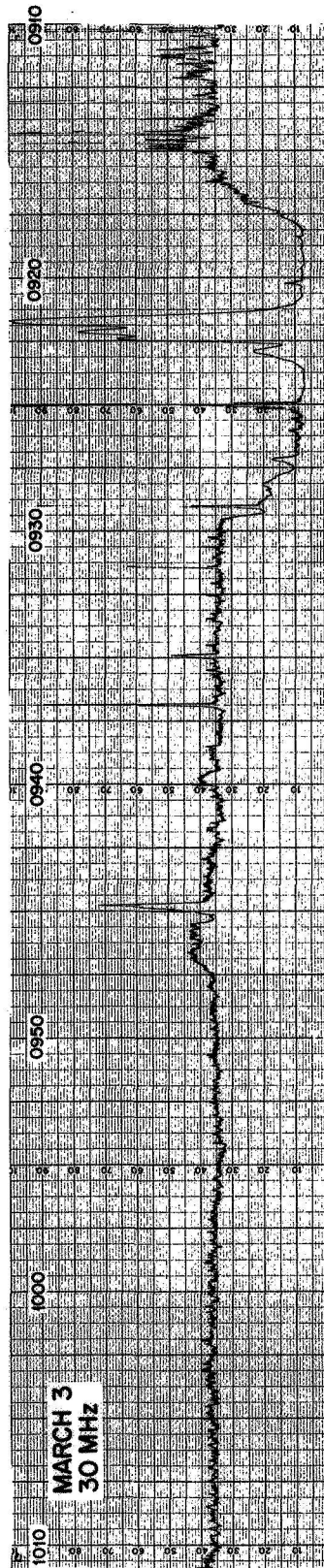


Fig. 8 (cont.) Absorption events of 3 March

until about 0830. During this period the maximum zenith intensities of H β and $\lambda 5577$ were, respectively, 50 R and 7 kR. Observers estimated, however, intensities of 50 kR of $\lambda 5577$ to the north.

The dramatic event between 0915 and 0930, with 6.4 db absorption, is a mystery. Although some luminosity was measured (45 R H β and ~ 2.5 kR $\lambda 5577$) nothing sudden occurred at the times marking the beginning and end of the absorption. The all-sky camera indicated nothing unusual during this period. The noise spike in the middle of the event occurs at the time the aircraft passed over Fairbanks, so apparently the equipment was functioning properly. At this stage this event remains unexplained.

4 March

This event, shown in Figure 9, was observed near the end of a flight from Eielson AFB to Churchill in accelerated local time. An auroral sub-storm began about 0930 and lasted until the plane landed at Churchill at 1055. Maximum intensities of H β and $\lambda 5577$, respectively, were 30 R and 3 kR. Maximum absorption at 20 MHz was 4 db. The Churchill riometer recorded this event as occurring from 0940 to 1100 with a maximum absorption of 1.5 db at 30 MHz which agrees well with the aircraft results.

For those flights in which usable data were recorded at two frequencies, estimates of the height range of the absorbing region are possible. A simplified expression for the absorption is

$$A = D \int \frac{N(h) \nu(h)}{[\nu(h)]^2 + \omega^2} dh$$

where D is a numerical constant, N(h) and $\nu(h)$ are, respectively, the height profiles of the electron density and collision frequency, and ω is

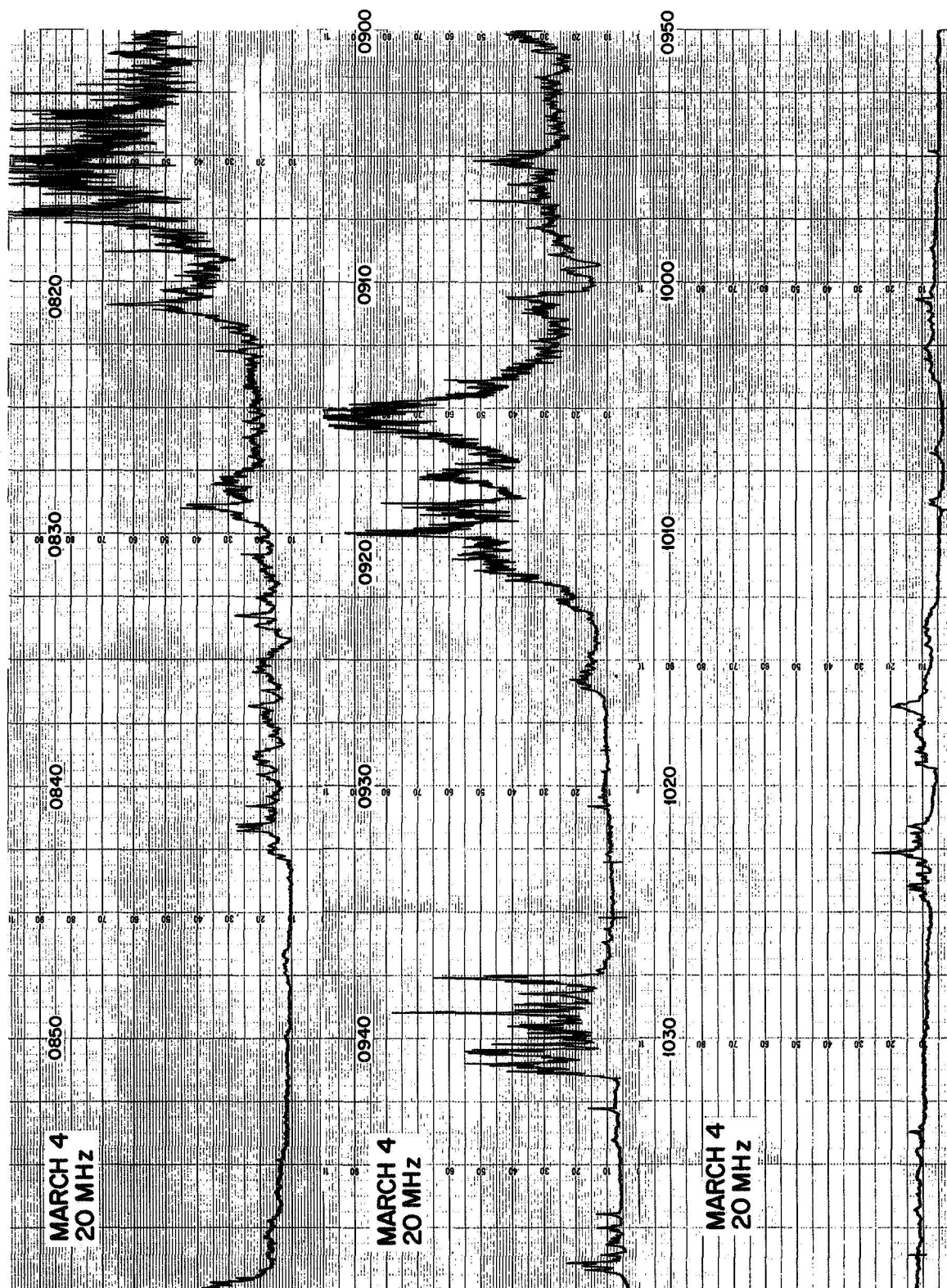


Fig. 9 Absorption events of 4 March

the working frequency. Clearly at high altitudes, when $\nu \ll \omega$, the absorption varies approximately as the inverse square of the working frequency, while at low altitudes, when $\nu \gg \omega$, the absorption is independent of frequency. Assuming an electron collision frequency profile and that the absorption is uniform across the antenna beam, which is perhaps unrealistic in the case of the aircraft antenna, the measured value of the exponent $n[A \sim f^{-n}]$ can be used to estimate the height of the absorbing layer [Lerfald et al., J. Geophys. Res. 69, 2857 (1964)]. The results for the aircraft observations are shown in Table III.

Table III

<u>Date</u>	<u>Freq. Exponent n</u>	<u>Height of Peak of Absorbing Layer</u>
January 30	2.0	> 80 km
February 1	1.5	60-70 km
February 27	1.8	70-80 km
February 29	1.7	65-75 km

Since the absorption is a function of both the electron density and the collision frequency, the above heights do not represent the electron density maxima, but do indicate enhanced electron densities and hence the presence of energetic particles at altitudes considerably below the peaks in luminosity.

In conclusion, almost all of the absorption events observed during the 1968 auroral expedition were associated with the occurrence of an auroral substorm. This is consistent with other observations [Pilkington

et al., Planetary and Space Science 16, 815 (1968); Bailey, Reviews of Geophysics 6, 289 (1968)] that the electron energy spectrum hardens during breakup. Gross correlation between absorption and zenithal luminosity was frequently apparent, but it should be emphasized that detailed correlation should not be expected due to the large difference between the fields of view of the photometers and the antenna beamwidth. No absorption was measured outside the auroral oval or at points of coordination with OGO IV. As data become available from other experimenters (particularly all-sky camera photographs), it is anticipated that selected events may be studied more fully. Of particular interest are the events of March 3 as two westward travelling surges were encountered. The riometer data in conjunction with photometer data may help to delineate the mechanism involved in such surges.

Acknowledgments

The contributions of Mr. George Joki of the Lockheed Palo Alto Research Laboratory in many areas are gratefully acknowledged. Mr. Earl Petersen of the NASA Airborne Science Office made possible data acquisition during the second session of the expedition. The NASA 711 personnel, both on the ground and in the air, were extremely helpful and cooperative during all phases of the experiment. Finally, our thanks go to Dr. M. Bader and Mr. L. Haughney of the NASA Airborne Science Office for successfully solving the staggering problems, long-term and day-to-day, encountered in making the expedition a productive scientific effort.