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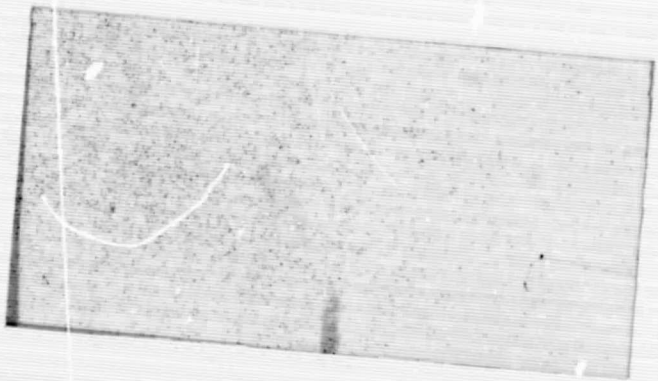
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Operation of a Three-Frequency Riometer System on the NASA 711 Aircraft During the 1969 Auroral Expedition

Contract No. NASw-1966

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CONTENTS

Section		Page
	Figures	ii
	Tables	iii
I	Introduction	1
II	Instrumentation	4
III	Data Acquisition	7
IV	Results and Discussion	10
	Acknowledgments	16

FIGURES

Figure		Page
1	Absorption event of 26 November (Flight 3)	17
2	Absorption event of 27 November (Flight 4)	18
3	Absorption event of 29 November (Flight 5)	19
4	Absorption event of 3 December (Flight 6)	20
5	Absorption event of 11 December (Flight 11)	21
6	Absorption event of 13 December (Flight 12)	22
7	Absorption event of 16 December (Flight 14)	23

TABLES

Section		Page
II	Measured Antenna Impedances	5
III	Absorption Events Observed during 1969 Auroral Expedition	10
IV	Heights of Absorbing Regions	15

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 or X-rays, 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.

Aircraft-based multifrequency absorption measurements can provide data on some phenomena which would be difficult to acquire by means of one or a few ground stations. The proposal for including a three-frequency riometer system for making measurements of the ionospheric absorption of cosmic noise aboard the NASA 711 aircraft during the 1969 auroral expedition was motivated primarily by the following 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) The aircraft mobility permits extensive coordination with satellites (OGO VI, ATS-E, OV1-18) equipped with particle detectors. Simultaneous measurements of precipitating particle fluxes and multifrequency absorption can provide estimates of D-region effective recombination coefficients.

3) 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.

4) An aircraft-based program could make possible the acquisition of data pertinent to the large scale morphology of absorption events, possible variations in the heights of the absorbing regions during breakup and pre-breakup phases of auroras, and dawn-dusk effects on absorption in constant and accelerated local time conditions.

The feasibility of making absorption measurements from an aircraft was established during the 1968 auroral expedition. The basic instrumentation, data acquisition techniques, and results of that expedition are discussed fully in the final report relating to that program [LMSC/N-83-69-1]. During the 1969 expedition seven absorption events were observed. Most of these were associated with the breakup phase of the aurora. Satellite coordinations occurred while two of the events were in progress. Slight absorption was encountered during one of the midday aurora flights. No PCA events occurred during the expedition; however, 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 instrumentation modifications instituted for the 1969 Auroral Expedition. Section III contains the data

acquisition procedure and a discussion of the new noise problems encountered. In Section IV the observed absorption events are described and correlated with all-sky camera, photometric, and satellite measurements.

II. INSTRUMENTATION

Cosmic radio noise is received by an antenna mounted on the fuselage of the NASA 711 jet aircraft. Matching networks are used to match antenna impedances 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. The matching network outputs were delivered to the riometers on RG-8U coaxial cables. Each riometer (Aerospace Research Inc., Model ARI-100c) 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 of each riometer and timing signals (provided by aircraft time code generators) are recorded by a six channel chart recorder (Brush, Model 260). A full discussion of the instrumentation philosophy, including choice of frequencies, principles of riometry, aircraft antenna characteristics and problems, etc., is contained in an earlier report [LMSC/N-83-69-1] to which reference may be made. In this section attention will be focussed on improvements and modifications of the equipment made after conclusion of the 1968 auroral expedition.

An antenna similar to that used during the 1968 expedition was employed for the 1969 expedition. It was, however, shortened from 11 feet to 8 feet and moved along the fuselage to a position somewhat forward of the wings. It was mounted on window plates about 20° off the vertical and spaced about 10 inches from the fuselage. The new antenna length was $\leq \frac{1}{2}$ wavelength at all

frequencies which calculations indicated should result in modest zenithal gain at 20, 30, and 60 MHz. Although a formal antenna pattern measurement program was not undertaken, variations in the received cosmic noise level were observed while the aircraft was rotated on the ground and when the aircraft made 180° course changes in flight. At all frequencies, these variations were ≤ 10% which is consistent with the major lobes of the beam being directed above the aircraft.

Unless considerable engineering effort is expended a jet aircraft antenna is constrained to be fairly close to the fuselage. At the frequencies used in the absorption experiment the ten inch spacing results in a very low antenna radiation resistance and consequently rather poor efficiency. The measured real and imaginary parts of the antenna impedance are tabulated below.

Table I

Frequency (MHz)	Impedance (ohms) R	X
20	3.1	-197
30	2.2	- 48
60	6.4	-580

The matching networks tune out the reactive components and transform the R values to 50 Ω. When such large transformations are required the networks tend to become somewhat lossy. The networks used in the 1968 expedition permitted either the simultaneous reception of 20 and 30 MHz or the reception of 60 MHz alone. For the 1969 expedition new networks were constructed which allowed simultaneous acquisition of absorption data at all three frequencies.

The final adjustments of the networks were performed in flight prior to the expedition. The VSWR at the three frequencies were of the order of 1.2 and the isolation between channels was greater than 10 db.

The relatively low antenna efficiency and lossy matching networks resulted in a system sensitivity of the order of 0.4 db which may be compared with .1 - .2 db sensitivity attainable in a well-designed ground installation. However within the context of the overall experimental goals (and the lack of a well-defined quiet day curve) such a sensitivity is very reasonable.

The entire system was checked out during a pre-expedition flight and was found to perform adequately, although low level noise from the aircraft 440 Hz generators was noted. This problem was eliminated by adding capacitive filter networks to the riometer inputs.

III. DATA ACQUISITION

Simultaneous absorption data at 20, 30, and 60 MHz were acquired for each flight of the 1969 Auroral Expedition. 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 10 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.

Interference problems, with the exception of a local noise source discussed below, were similar to those encountered during the 1968 expedition. Precipitation static occasionally obscured the cosmic noise signals during ascent or descent in overcast conditions, but was not a problem at cruising altitude. Sources of man-made noise were always present at some frequencies 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. During some periods, particularly over towns and near airports, broadband noise prevented data acquisition at one or more frequencies.

One peculiar local source of interference was noted about the midpoint of the expedition. The signal level at both 20 and 30 MHz was observed to

increase slightly about 30 seconds after takeoff and decrease slightly shortly before landing. The noise producing this variation was eventually found to result from operation of the aircraft autopilot system and was probably due to dirty servomechanisms in the aft section of the aircraft. The detection and isolation of the effect were delayed because usual procedure involved operating the riometer system only after the aircraft had left the generally noisy environment of an airport. Ground-based measurements had been observed to be slightly different than those obtained at altitude but the differences were attributed to the somewhat different antenna impedances existing on the ground. Utilization of the autopilot system was desirable from the point of view of the other experimenters in that it provided increased stability in aircraft attitude. As the noise effect was usually less than 20% of the cosmic noise level, and could to first order be removed by a suitable correction factor, it was not deemed necessary to institute an autopilot repair procedure. The effect was monitored as completely as possible after its detection and was found to vary somewhat, both during flight and from flight to flight, but was usually in the range 10 - 20%, and occasionally as high as 25% ($\sim$ 1 db). The absorption measurements at 20 and 30 MHz were corrected for this noise source. Fortunately, at 60 MHz, where the absorption is very small, no discernible effect was observed due to the autopilot.

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. The overall accuracy of

the absorption measurements, including effects due to system sensitivity, lack of well-defined quiet day curves, and the correction factor discussed above, is estimated to be $\pm$ 0.4 db.

IV. RESULTS AND DISCUSSION

The auroral absorption events observed during the 1969 auroral expedition are listed in Table II. Included in the table are the corrected values of the maximum absorption at the three frequencies.

Table II

Flight	Date	U.T.	Maximum Absorption (db) 20 MHz	30 MHz	60 MHz
3	26 Nov.	0510-0630	1.5	0.8	0.2
4	27 Nov.	0433-0520	3.0	1.3	0.5
5	29 Nov.	0629-0716	1.9	1.0	---
6	3 Dec.	1001-1024	2.9	1.4	0.6
11	11 Dec.	2145-2204	4.1	2.0	0.5
12	13 Dec.	0718-0750	0.8	0.3	---
14	16 Dec.	0712-0802	4.2	2.5	0.5

Blanks in the 60 MHz column in Table II indicate that the data at that frequency were excessively noisy, generally to the extent of equipment saturation.

The chart records for the absorption events are shown in Figs. 1-7, located at the end of this report. In the figures absorption increases toward the bottom of the page and all dates and times are U.T. The auroral conditions existing during each event, briefly described below, have been inferred from a variety of sources including visual observations, all-sky camera reports, photometric measurements at several wavelengths (supplied by R. H. Eather), and satellite measurements of precipitating particle fluxes.

26 November

At about 0500 several arcs were observed which gradually increased in intensity to an estimated 15 kR in λ 5577. At 0544 a strong surge was evident on the all-sky camera records. Rapidly moving forms with red lower borders, signifying the onset of an auroral break-up, were apparent to the west of the aircraft about 0555. Zenithal λ 5577 intensities were in the range 2-4 kR, and the λ 6300/λ 4278 ratio was low, varying in bright regions between 0.2 and 0.4, indicating the precipitating electrons were quite energetic. Maximum absorption occurred in the period 0510-0600, with some absorption persisting until landing. At 0538 the aircraft passed over Churchill and the absorption at 30 MHz measured at that time agreed to within 0.5 db of that measured on the Churchill riometer indicating the aircraft instrumentation was functioning properly.

27 November

This event was stronger than, but morphologically similar to, the event of 26 November. A surge and considerable zenithal activity occurred about 0450 with a λ 5577 intensity of 14 kR. The absorption peaked about 0500 and was absent after 0515. Very little λ 6300 was observed indicating the bulk of the precipitating electrons possessed energies greater than 5 kev. The Lockheed experiment aboard the ATS-E satellite registered the onset of a substorm about 0430, in good temporal agreement with the absorption event observed from the aircraft. At the time the aircraft intercepted the nominal conjugate point of the satellite, near 0522, the absorption event was ending; however, the substorm, as defined by the particle detectors, was still in progress, and, in fact, lasted several more hours. Further analysis of these

data may help unravel the complex interrelationships between the particles observed at synchronous altitude and those responsible for absorption in the D-region. The Churchill riometer recorded slight absorption between 0440 and 0550.

29 November

This absorption event commenced about 0630 with considerable activity observed in several regions of the sky. Zenithal intensities in λ 5577 were in the 15-25 kR range during the period 0655-0710 with the λ 6300/λ 4278 ratio indicating a fairly hard electron energy spectrum. Absorption at Churchill maximized at 0640 and occurred in reduced amount during the period 0655-0720. For most of the flight the aircraft was flying a grid pattern around the nominal conjugate point of the ATS satellite. The ATS particle experiment detected a substorm beginning about 0600 which lasted approximately 10 hours. Three surges in the period 0609-0650 were recorded by the all-sky camera.

3 December

A rather abrupt absorption event began about 1000 near College, Alaska. Although only weak emissions ($\sim$ 300 R of λ 5577) due to fairly soft electron fluxes were measured photometrically and little luminosity was evident in the sky, the occurrence of absorption was substantiated by the College riometer records which showed about 2 db absorption at 30 MHz near 1020. This rather peculiar observation may be explicable in terms of a discontinuous electron energy spectrum containing only very soft and very hard components.

11 December

This relatively strong absorption event occurred as part of an auroral substorm. A surge at about 2134 was accompanied by bright arcs of about 10 kR intensity in λ 5577. At 2150, the period of peak absorption, the forms exhibited considerable motion and possessed pink lower borders. Between 2150 and 2205 the absorption decreased, primarily as a result of the softening of the electron energy spectrum evidenced by the change in the value of the ratio of λ 6300 to λ 4278 from about 0.3 to 5.

13 December

Very weak, but probably real, cosmic noise absorption was encountered on the first of the midday aurora flights. The absorption commenced at an invariant latitude of about 70° and ended about 74°. A zone of hard electron precipitation on the equatorward side of the statistical auroral oval has been observed with particle measuring experiments on satellites. The photometric observations were consistent with a weak but relatively hard electron flux which gradually became softer as the aircraft progressed poleward. At invariant latitudes 70°, 72°, and 74° the values of the ratio λ 6300/λ 4278 were respectively 0.1, 0.4, and 0.6.

16 December

The explosive phase of an auroral substorm began about 0715 and produced the strongest absorption measured during the expedition. Zenithal intensities of λ 5577 reached 16 kR at 0730 and considerable activity was observed throughout the rest of the flight. The absorption of 30 MHz galactic noise was 2.5 db at 0725 at which time forms were observed with pink lower borders and λ 5577 intensities estimated at 30 kR. A prolonged surge

was in progress during the period 0718-0744. The Churchill riometer recorded one absorption peak near 0730, agreeing with the airborne measurements, and a maximum absorption of about 6 db at 30 MHz near 0830 after the aircraft had landed. This was the largest absorption recorded at the Churchill station during the expedition.

Multifrequency absorption measurements permit estimates to be made of the height range of the absorbing region. 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 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. Using a standard electron collision frequency profile and assuming that the absorption is uniform across the antenna beam (perhaps unrealistic for the case of the low gain antenna used in this experiment) the value of the exponent, n, in the measured dependence of absorption upon frequency, $A \sim f^{-n}$, can be related to the approximate height of the absorbing layer. The results for the aircraft observations are shown in Table III. Only the absorption values at 20 and 30 MHz have been employed in these estimates since the small values at 60 MHz are dominated by the measurement uncertainty of $\pm$ 0.4 db.

Table III

Date	Frequency Exponent n	Height of Peak of Absorbing Layer
26 Nov.	1.6	60-70 km
27 Nov.	2.0	> 80 km
29 Nov.	1.6	60-70 km
3 Dec.	1.8	70-80 km
11 Dec.	1.7	65-75 km
13 Dec.	2.4	> 80 km
16 Dec.	1.3	< 60 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 view of the experimental uncertainties the above results should probably be construed only as indicators of the relative hardness of the electron energy spectrum. For example, the electrons responsible for the absorption peaks of the events of 26 November, 29 November, and 16 December appear to have been more energetic than those at the peaks of other events. As expected, a gross correlation thus exists between the exponent n and the photometrically measured λ 6300/λ 4278 ratio although the usual caveat concerning the comparison of narrow field-of-view photometric measurements with very wide beam absorption measurements must be remembered. Finally, the exponents of Table III were calculated at the absorption maxima and certainly vary during the course of an event.

In summary, most of the absorption events observed during the 1969 auroral expedition were associated with the occurrence of an auroral substorm during the explosive phase of which the electron energy spectrum hardens.

Absorption generally coincided with low values of the λ 6300/λ 4278 ratio. Slight absorption was detected somewhat equatorward of the auroral oval during a midday auroral flight confirming some results obtained with satellites. On two occasions absorption data were obtained near the time the aircraft intercepted the field line on which the ATS-E satellite was located. When the data from the particle experiments aboard that satellite are fully analyzed, a detailed correlation with the absorption data may prove fruitful in establishing the fate of particles detected at synchronous altitude. Also, electron density profiles could be generated from the multifrequency absorption measurements which, in conjunction with ion production rates derived from the particle fluxes measured on the satellite, may be used to estimate effective recombination coefficients which are important for increased understanding of D-region processes.

ACKNOWLEDGMENTS

The personnel associated with the NASA 711 aircraft were extremely helpful and cooperative, both in the air and on the ground, during all phases of the experiment. Especial appreciation is due Dr. M. Bader and Mr. L. Haughney of the NASA Airborne Science Office for successfully coping with the numerous major and minor problems intrinsic in carrying out a long term multi-experiment scientific program at high latitudes.

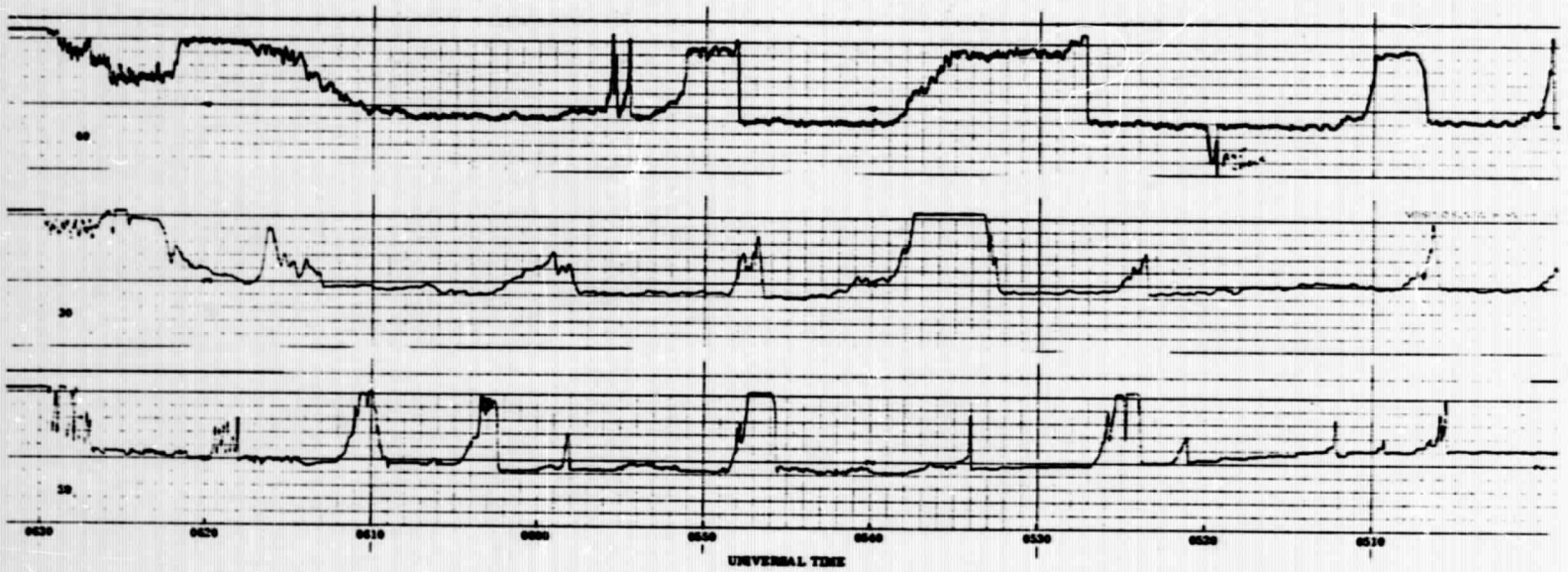


Fig. 1 Absorptiocn event of 26 November (Flight 3) at 20, 30 and 60 MHz

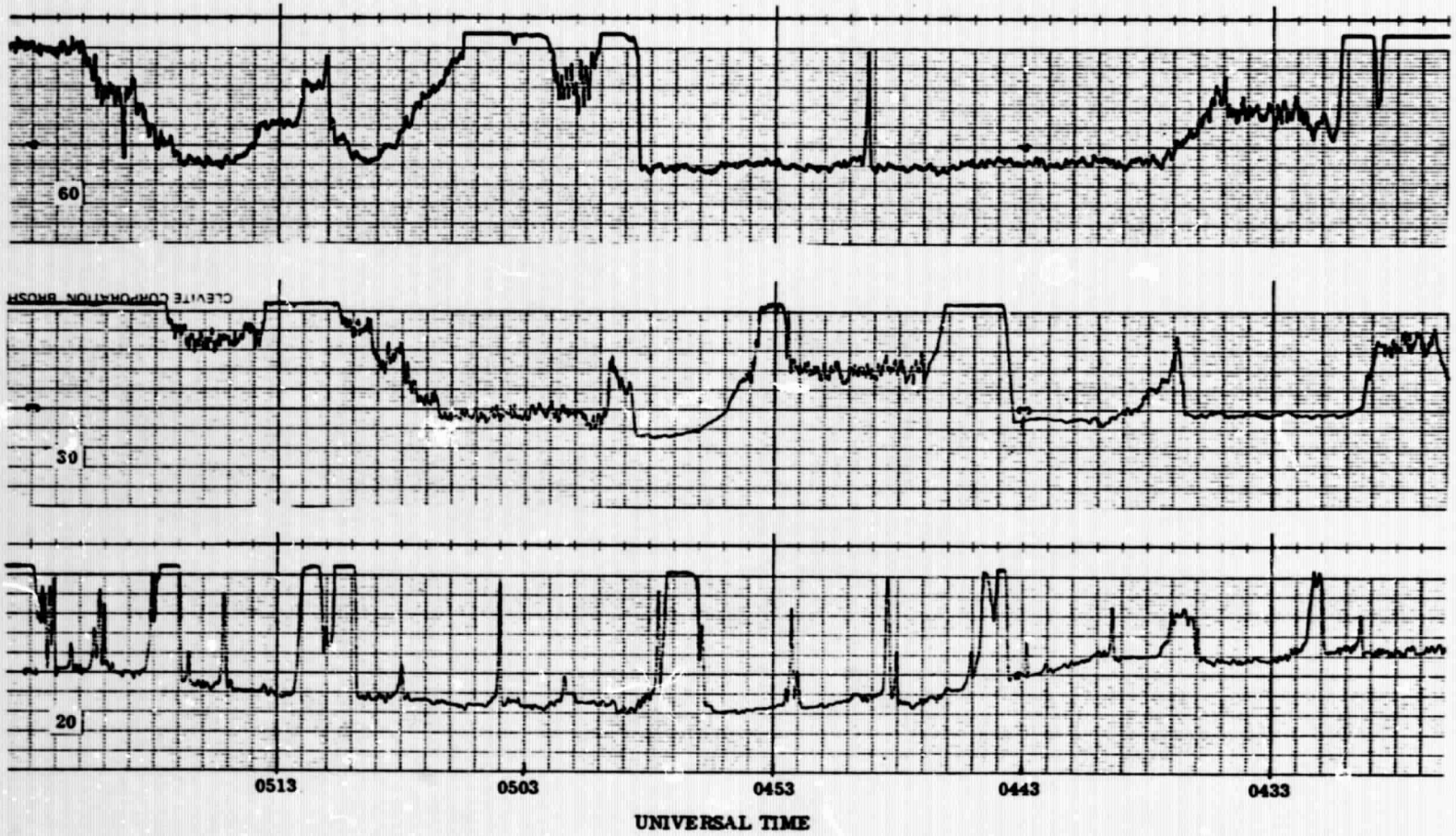


Fig. 2 Absorption event of 27 November (Flight 4) at 20, 30 and 60 MHz

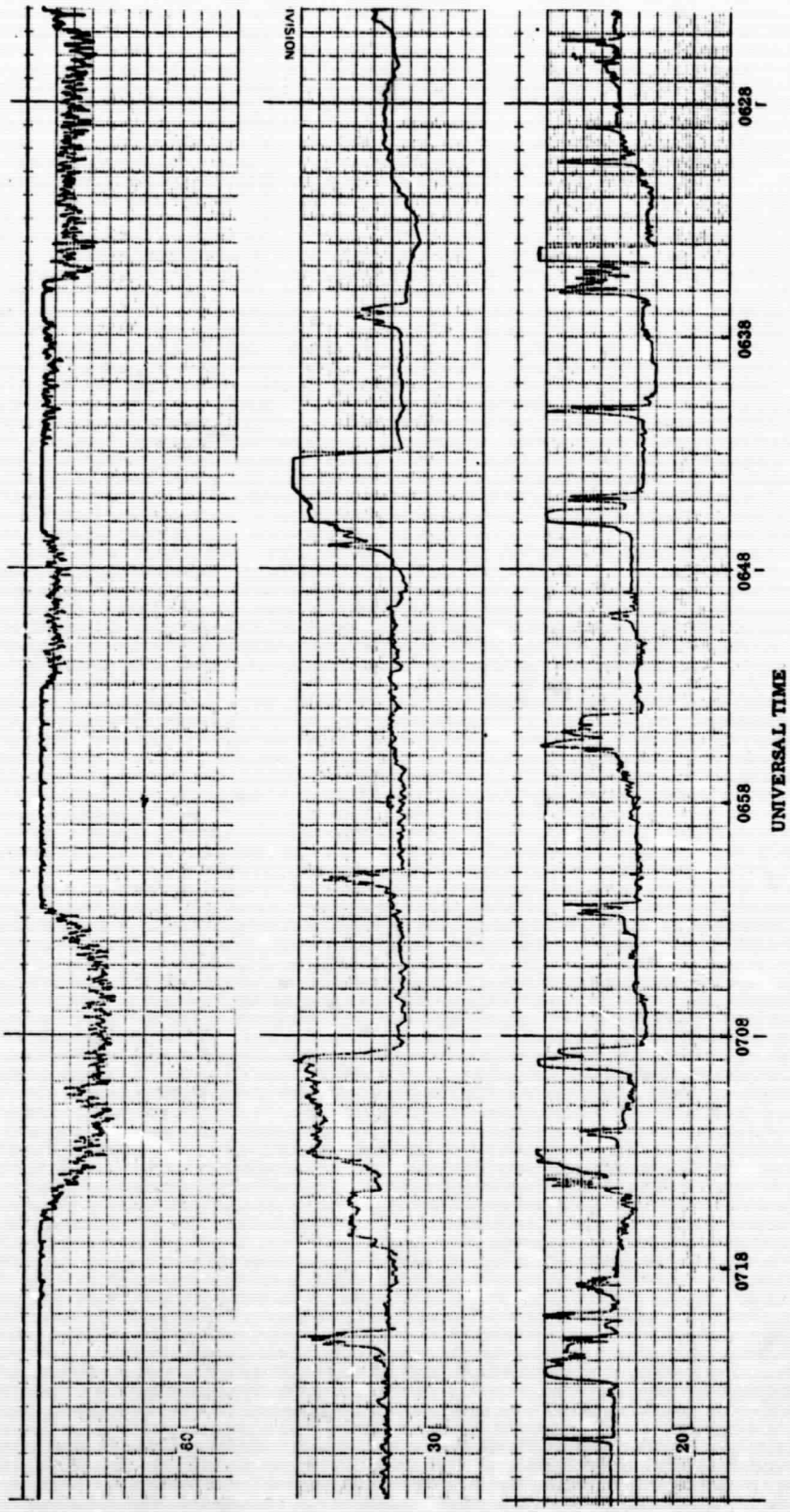


Fig. 3 Absorption event of 29 November (Flight 5) at 20, 30 and 60 MHz

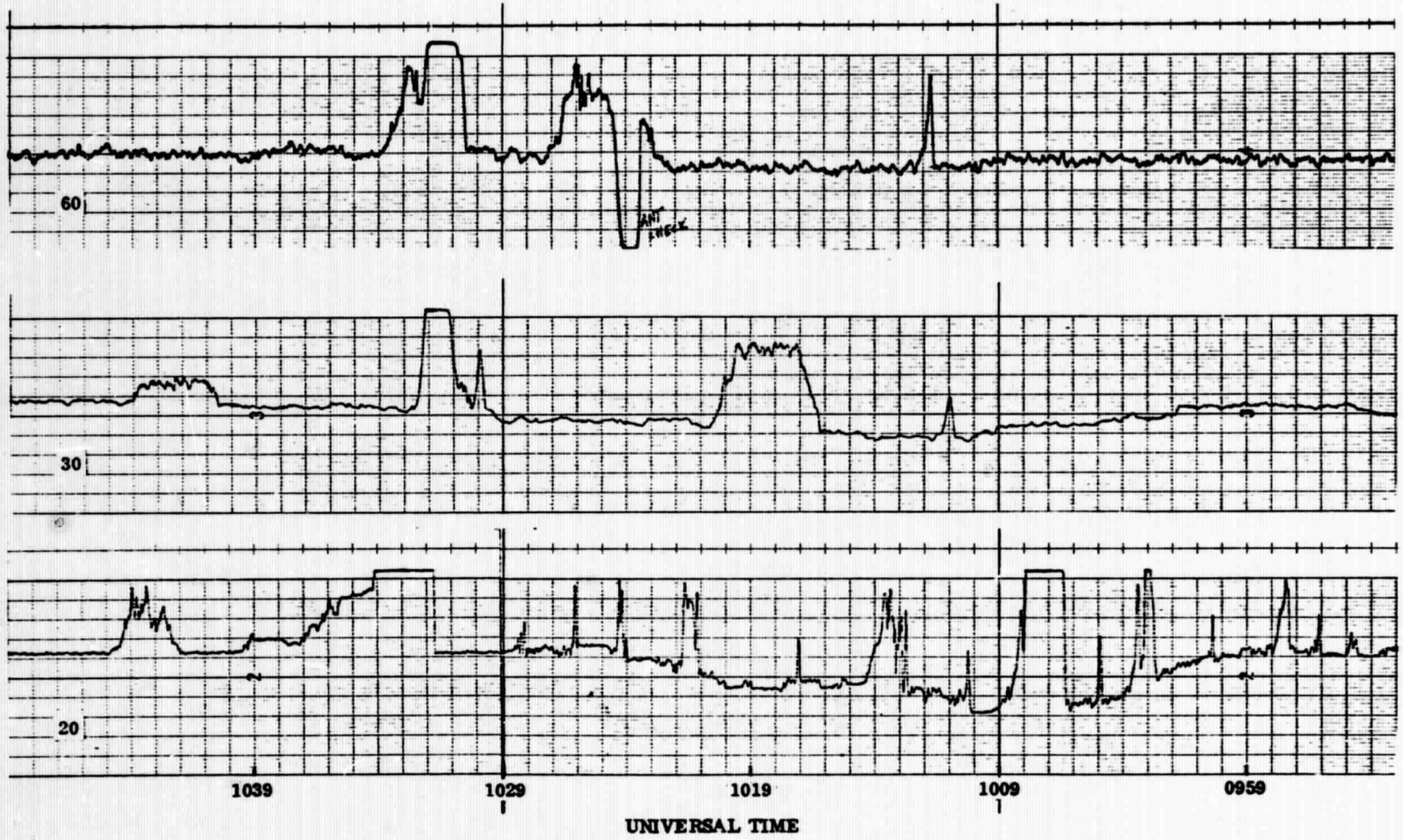


Fig. 4 Absorption event of 3 December (Flight 6) at 20, 30 and 60 MHz

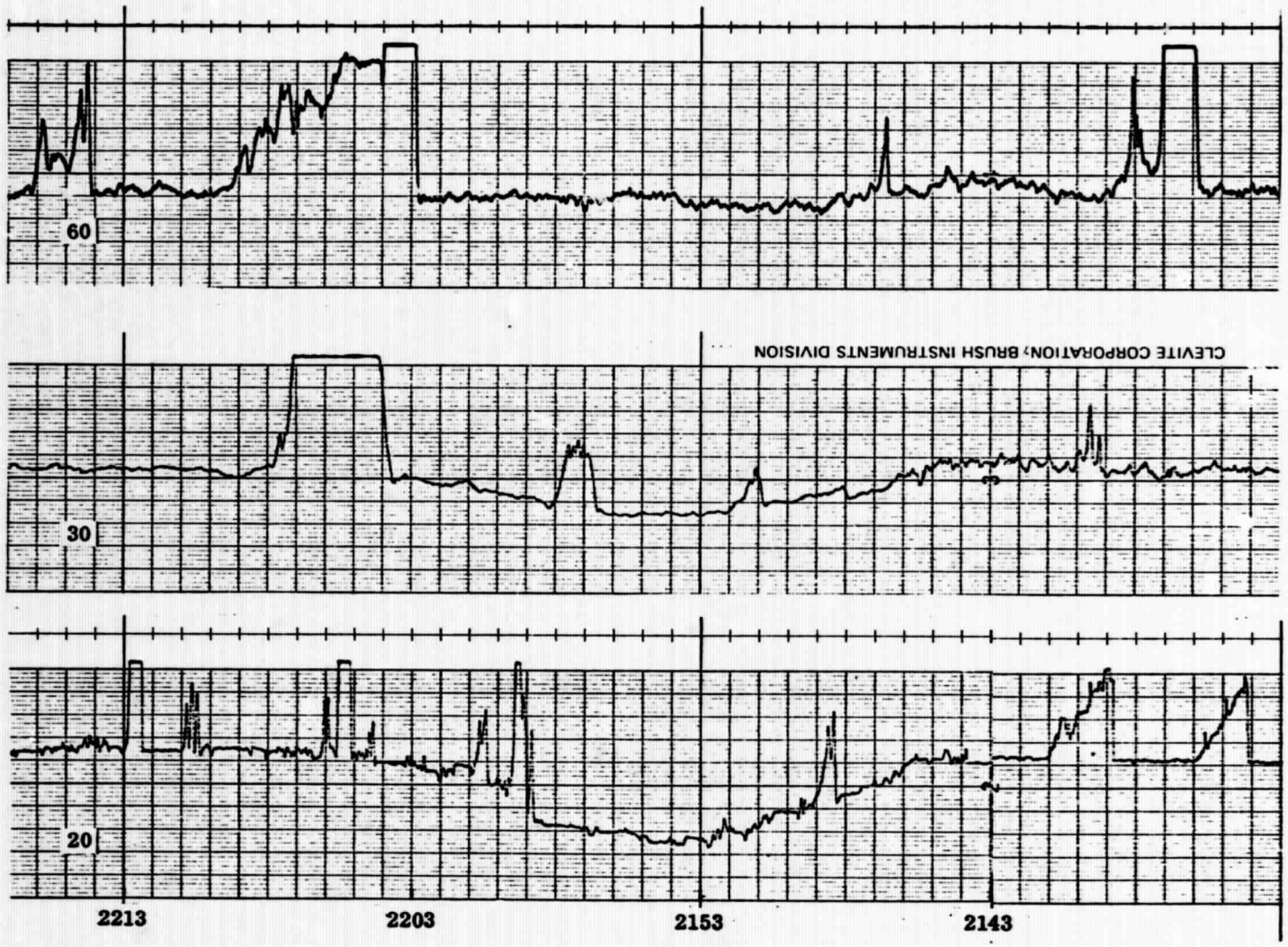


Fig. 5 Absorption event of 11 December (Flight 11) at 20, 30 and 60 MHz

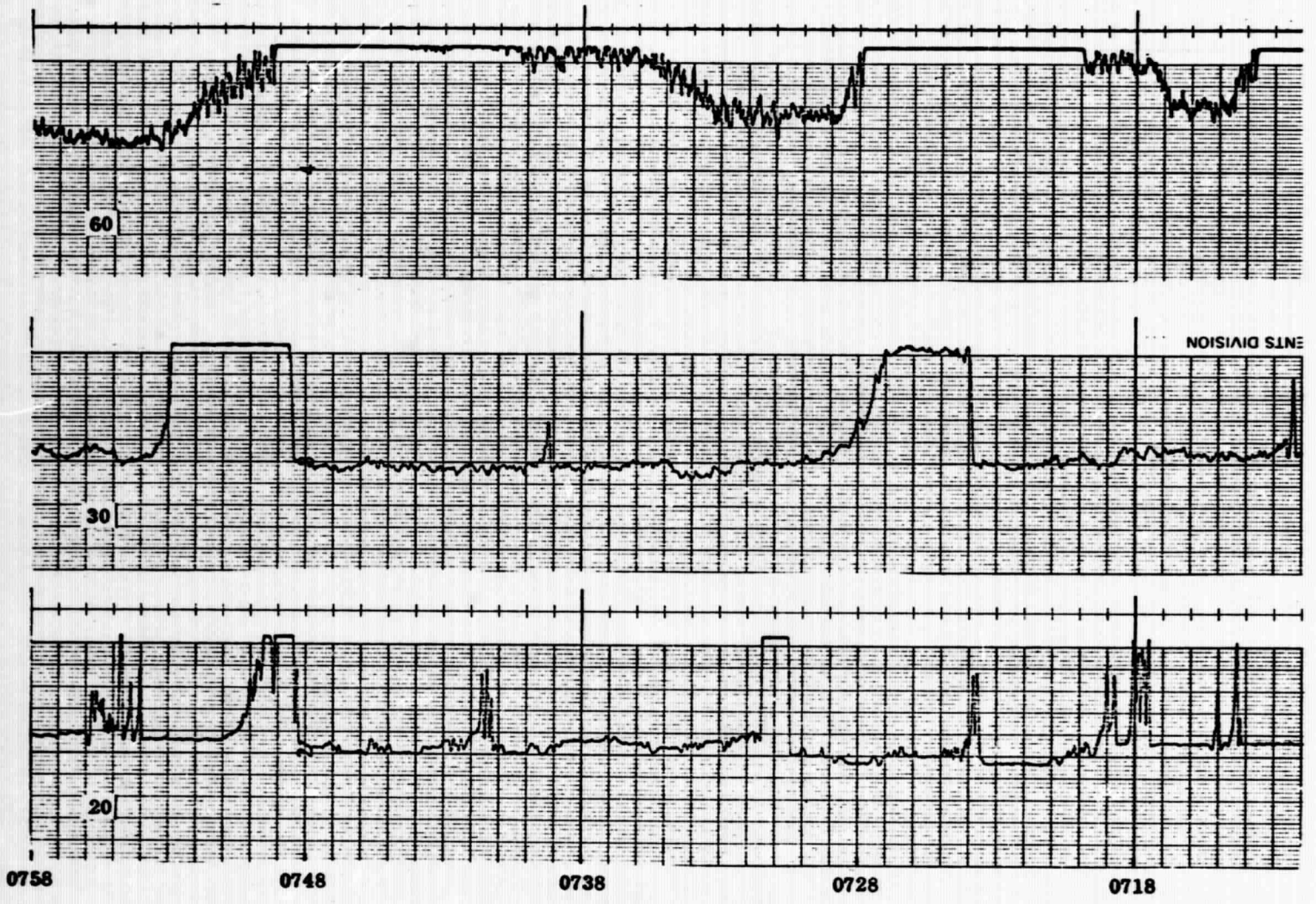


Fig. 6 Absorption event of 13 December (Flight 12) at 20, 30 and 60 MHz

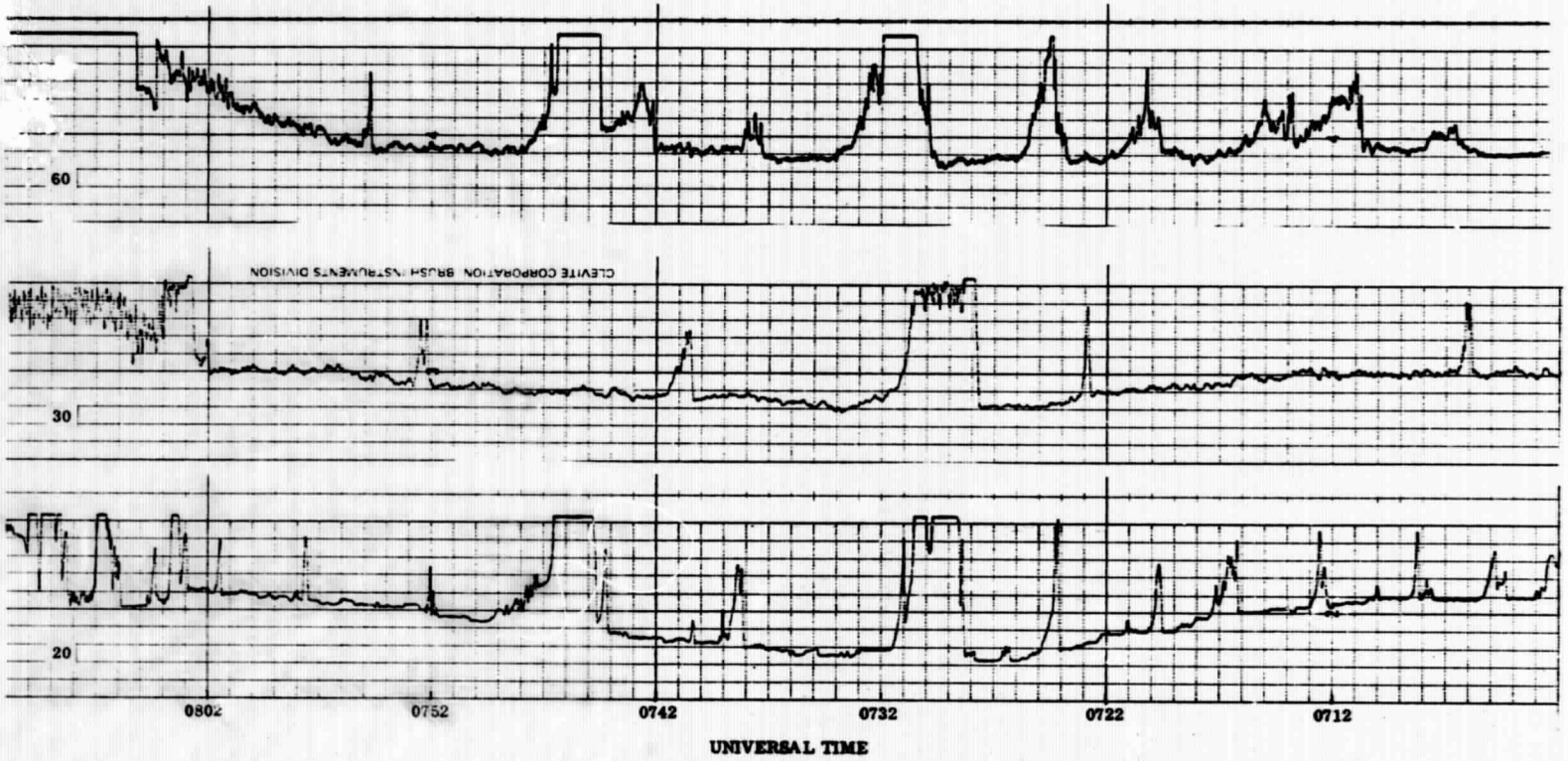


Fig. 7 Absorption event of 16 December (Flight 14) at 20, 30 and 60 MHz