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RADIO ASTRONOMY EXPLORER-1 DATA DISPLAYS

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I. INTRODUCTION

The first Radio Astronomy Explorer spacecraft was placed in a 6000 km circular orbit on July 4, 1968. Since shortly after launch, RAE-1 has continuously observed low frequency (0.2 - 9.2 MHz) radio noise emanating from the sun, the earth's magnetosphere, the galaxy and beyond. A summary of the observations made by RAE-1 during its first two years in orbit is given by Alexander (1970).

The scientist has access to the RAE-1 data primarily in the form of computer generated microfilm plots. However, due to the very large volume of data involved, only a limited number of plots can be produced on a production basis. These plots have been designed to present a maximum amount of useful information per frame.

It is quite important that all users of the RAE-1 data understand precisely what each plot displays. This document describes the RAE-1 data displays and explains or defines all variables pertinent to their interpretation.

II. RAE-1 INSTRUMENTATION

RAE-1 is equipped with a variety of antennas and receivers as well as probes to measure antenna characteristics and the ambient electron density. Most striking in appearance are two V-shaped antennas, each leg extending 750 feet in length. The V antennas are oppositely directed forming a huge X in space. Splitting the obtuse angles of the X and lying in the same plane, is a 120 foot dipole antenna. Gravity-gradient stabilization of the spacecraft allows one V antenna to always scan the celestial sphere, while the other scans the lower magnetosphere. The radius vector from the geocenter to the spacecraft bisects the V's to within three degrees at all times.

Attached to each of the three antennas are Ryle-Vonberg radiometers operating at nine discrete frequencies between 0.45 and 9.18 MHz. The R-V receivers step through the nine frequencies, sampling twice on each frequency, in slightly more than 69 seconds. In addition, each R-V sample actually consists of four course and one fine sample, providing a total of 270 samples from the R-V systems every 69 seconds.

The lower V antenna also drives a fast sampling radiometer operating at eight frequencies between 0.25 and 3.93 MHz. This radiometer, known as burst receiver-one (BR-1), samples at each frequency twice per second.

Another fast sampling radiometer known as BR-2 is attached to the dipole antenna. BR-2 samples at six frequencies twice per second. Also, one channel of the BR-2 receiver sweeps through 32 frequencies every eight seconds.

Approximately every ten minutes, the electrical characteristics of the antennas are measured by an impedance probe on the V antennas and a capacitance probe on the dipole. At the same time, the ambient thermal electron density is measured by an electron trap.

The RAE-1 spacecraft operates continuously at these rates, and thus makes over 10^9 measurements per year. When time of measurement, spacecraft performance parameters, and various spacecraft coordinates are added, RAE-1 produces data at the remarkable rate of 4×10^{11} bits per year!

III. DATA DISPLAYS

Each of the receiving systems and probes, with the exception of the electron trap, has a display associated with it. A full orbit (about 3.75 hours) of data is displayed for both the Ryle-Vonberg and BR receivers. Ten minute spans of data are displayed for BR-2 and the 32 frequency receiver. Plots containing six hours of data are displayed for the impedance and capacitance probe. A full day of RAE-1 data - 10^9 bits - can be displayed in about 1200 frames of microfilm.

A. COORDINATE SYSTEMS

Common to all RAE-1 data displays are certain coordinates which are either listed or graphically illustrated. These coordinates are the pointing directions of the V antennas. They are derived from spacecraft positions as determined by the Brouwer general perturbation routine described by Kaiser (1968). Spacecraft positions as compared with GSFC Refined World Maps vary by no more than $\pm$ 0.3^{o} in sub-satellite position and $\pm$ 2 km. in height.

The RAE-1 geocentric right ascension and declination are defined as equal to the pointing direction of the upper V antenna; and, the sub-satellite latitude and longitude are defined as the pointing direction of the lower V antenna. These assumptions are valid to well within $\pm$ 3^{o}, according to Blanchard (1969). Right ascension is always listed on the plots in hours, declination in degrees. Local mean time and geomagnetic latitude are used for the lower V direction, and are listed in hours and degrees respectively.

The ordinate of most receiver plots is given as temperature. This temperature is derived from the calibration process and is not antenna temperature. The spacecrafts receivers actually measure intensity relative to some noise source, and this noise source is expressed as a reference temperature. Relative changes in calibration temperatures are the same as antenna temperatures changes, $\Delta T_{cal} = \Delta T_A$.

B. RYLE-VONBERG RECEIVER DISPLAY

Figure 1 shows a typical display of Ryle-Vonberg receiver data. All three antenna systems are shown as indicated at the right edge of the frame for the frequency listed in the upper left hand corner. The abscissa is marked every ten minutes in Greenwich mean time, and labeled every hour. The actual span of data plotted is listed at the top of the frame in a YYMMDD HHMMSS format. Every half hour of GMT, the pointing positions of the V antennas are listed directly below the appropriate abscissa value.

The ordinate is logarithmic and shows five decades of calibration temperature with each decade marked at the 1, 2, 4, 6, and 8 levels. All receiver values in excess of 10^{10} degrees are plotted as 10^{10}, and all values less than 10^5 are set to 10^5.

Out of the possible five Ryle-Vonberg values available at a given time (4 course, 1 fine), only the third course value is plotted. Course value 3 has proven to be the most reliable in practice.

A complete orbit of data would consist of nine frames of microfilm, one for each operating frequency.

C. FULL ORBIT BURST RECEIVER DISPLAYS

Figures 2 and 3 show an average example of a full orbit of burst receiver data. This display is always

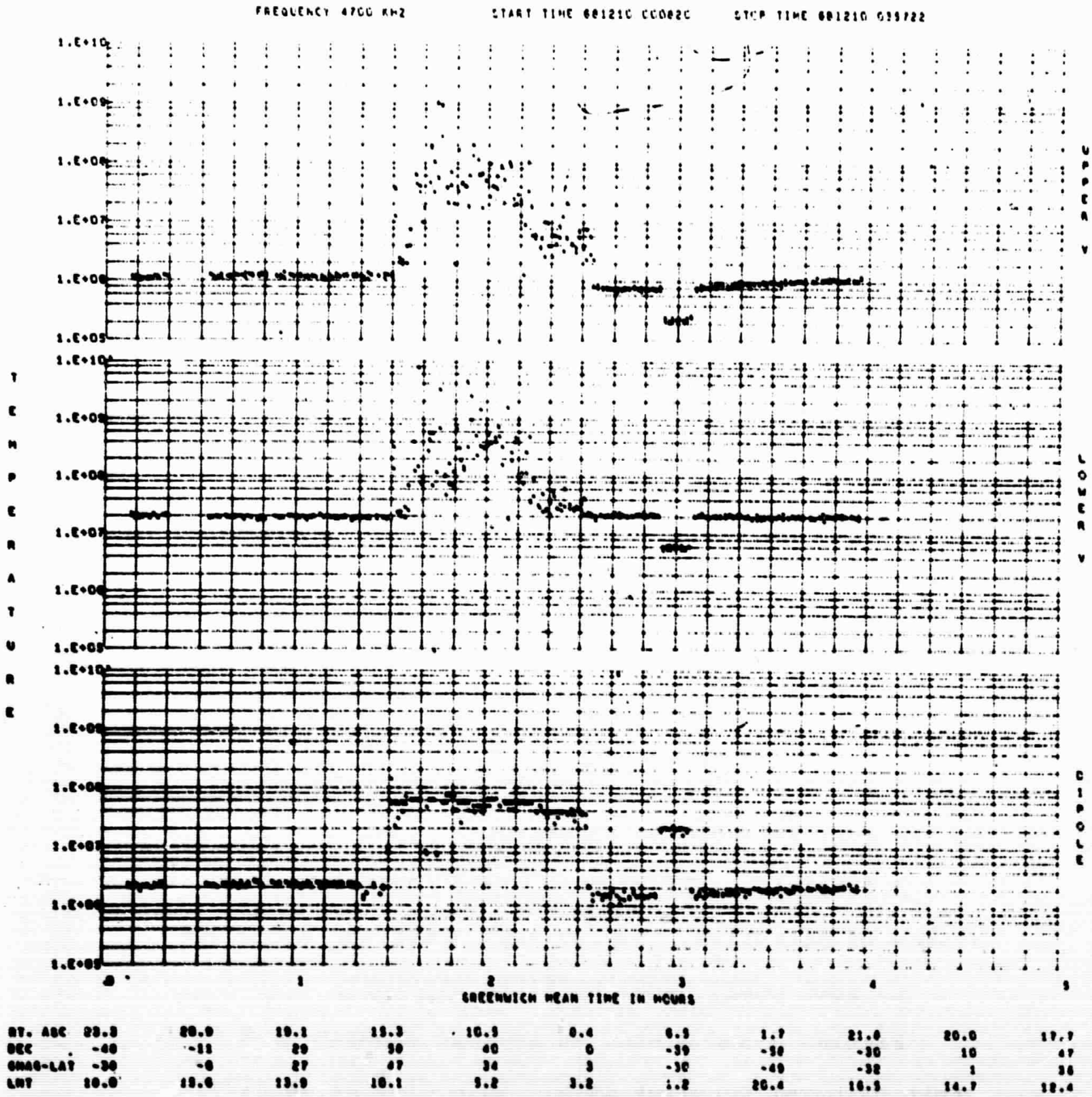

Figure 1 - Ryle-Vonberg Receiver Display.

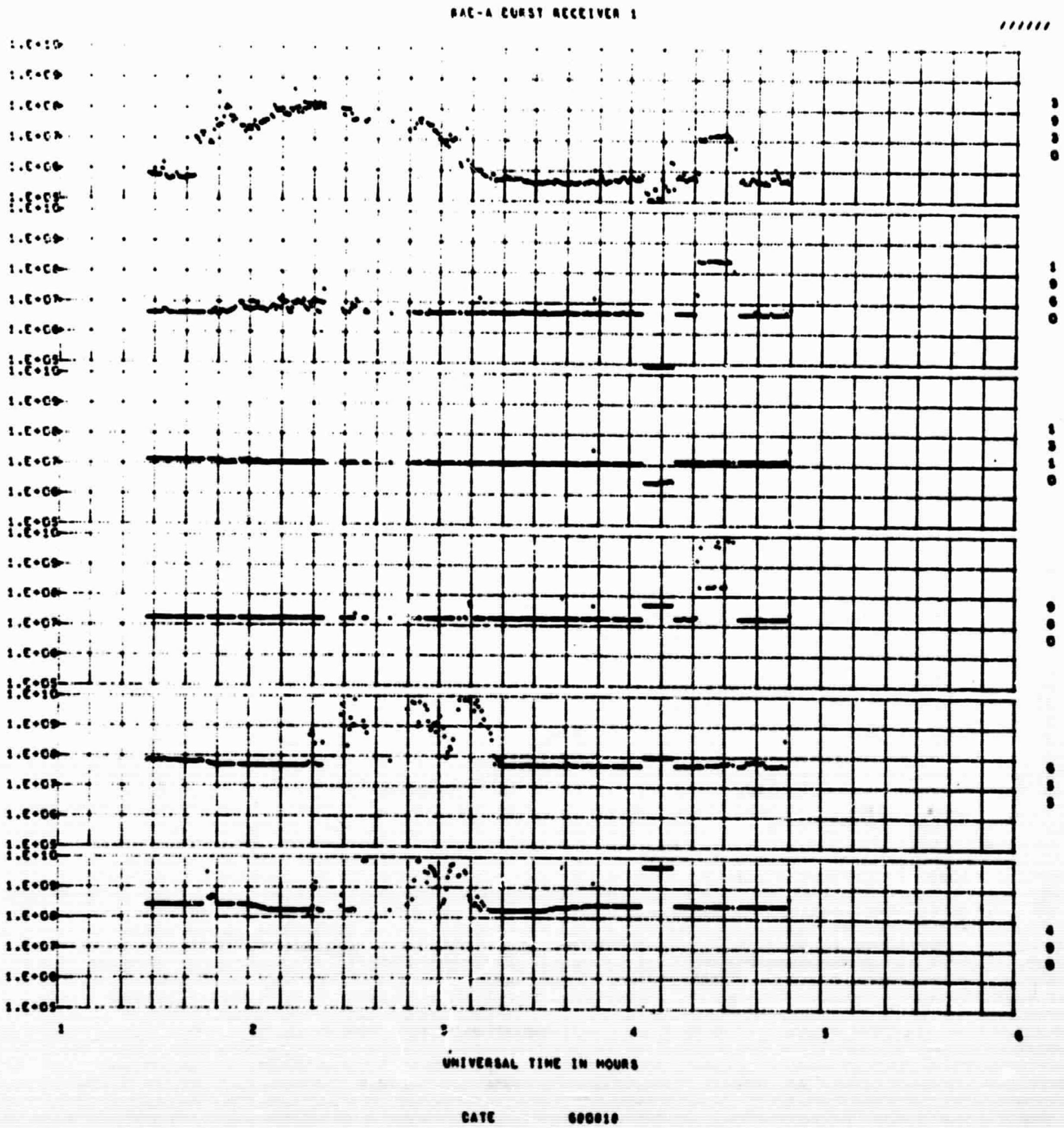

Figure 2 - Full Orbit Burst Receiver Display - Frame 1

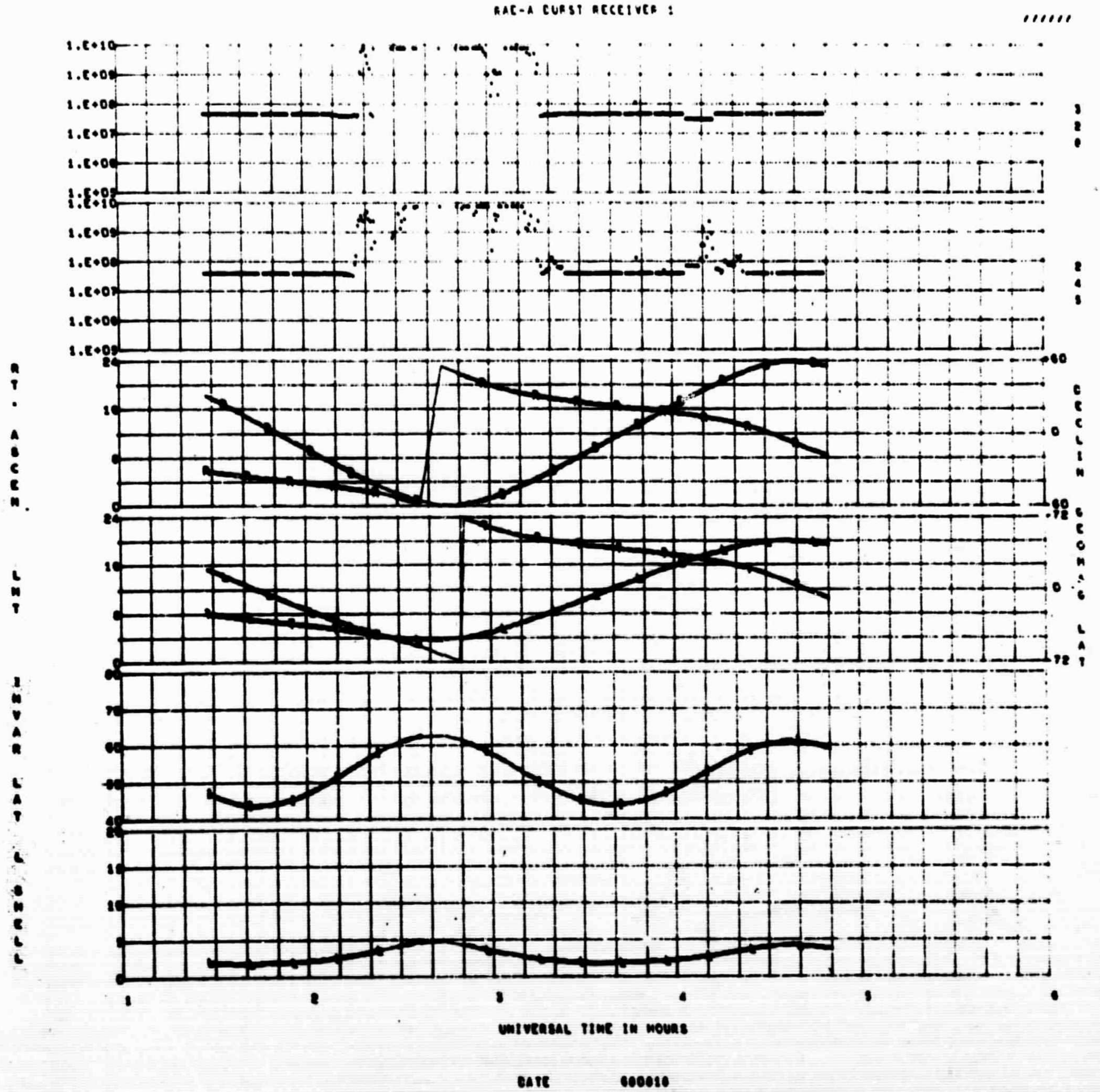

Figure 3 - Full Orbit Burst Receiver Display - Frame 2

two frames. The particular receiver is indicated at the top of each frame. The observing frequency in kilohertz is indicated at the right of each framelet. When BR-2 is displayed, the top two framelets of the second frame are blank.

The abscissa is marked every ten minutes of Greenwich Mean Time, and labeled every hour. The date is at the bottom of each frame in YYMMDD format, and corresponds to the beginning of the frame.

The ordinate of the receiver data is logarithmic and shows five decades of calibration temperature marked once per decade. All values greater than 10^{10} degrees are plotted as 10^{10}, and all values less than 10^5 degrees are set to 10^5.

The bottom four framelets of frame two show various coordinates as a function of GMT. The third framelet from the top shows the satellite geocentric right ascension and declination. Right ascension is read in hours using the left-hand ordinate, and is the plotted curve marked with "R". Declination in degrees is read from the right-hand ordinate, and is the plotted curve marked with "D". Similarly, the next framelet shows sub-satellite local time in hours and geomagnetic latitude in degrees. The local time curve is marked

"T", and the geomagnetic latitude curve with "L". The bottom two framelets show a dipole representation of invariant latitude in degrees and the "L" shell parameter in earth radii described by McIlwain (1961). Each data point plotted represents an arithmetic average of 32 seconds of data, thus reducing a full orbit of data from 28,000 to 450 samples per frequency. Although this procedure can occasionally give an unrealistic value, the usefulness of the full orbit burst receiver plots for over-all views of the data is not seriously hampered.

D. TEN MINUTE DISPLAYS

1. Burst Receiver Two

Figure 4 shows one frame of a four frame set of displays of burst receiver two data. Each framelet is always 11 minutes long with lines every 20 seconds. The start of the frame is indicated at the top. The frequency in kilohertz is listed in the upper right hand corner of each framelet. The spacecraft positions at the time of the first data point are shown at the bottom of the frame.

The ordinate can be either linear or logarithmic (see upper right hand corner of frame). A standard set of four frames consists of two logarithmic

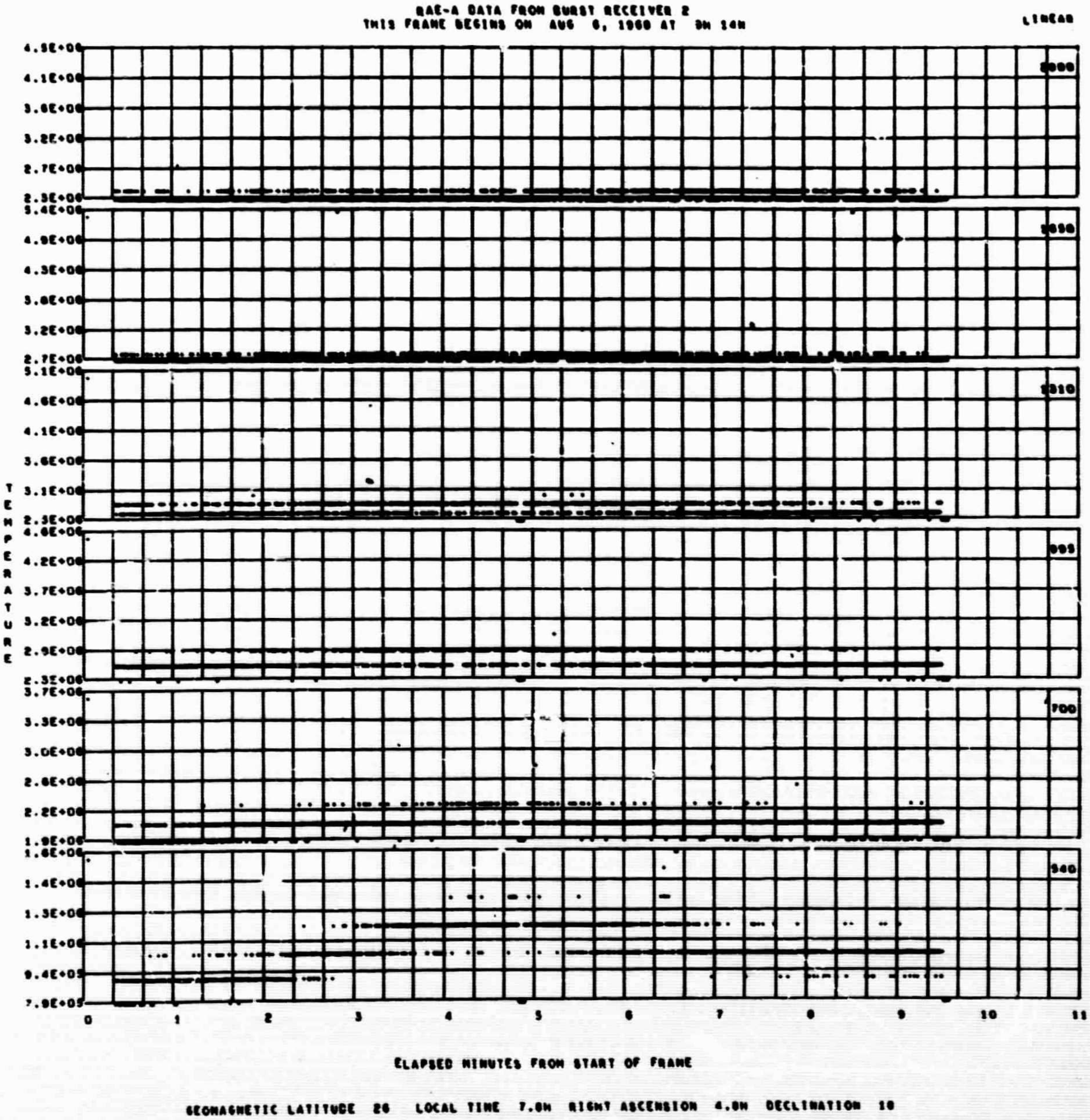

Figure 4 - Ten Minute Display - Burst Receiver 2

plots displaying 6 decades and 3 decades of dynamic range, and two linear plots showing a factor of 20 and a factor of 2 in dynamic range based on the minimum temperature in the framelet. In the linear mode, all ordinate lines are labeled, and, in the log mode, the integral decades are labeled.

The data plotted consists of all samples taken between antenna impedance-capacitance measurement periods. However, in the digital burst receiver data, this period can be recognized only by a 38 second gap between samples. The processing program will consider any gap of 38 seconds or greater as the end of a frame.

2. Swept Frequency Burst Receiver

Figure 5 shows one frame of a three frame set of data from the 32 frequency receiver. Contours of equal intensity referenced to the galactic background are plotted against time in minutes on the abscissa and frequency number on the ordinate. The frequency number is complimented on the right by an actual frequency scale in MHz (logarithmic). The galactic background reference expressed in T_{cal} as scaled from Alexander et al. (1970) is shown in table 1.

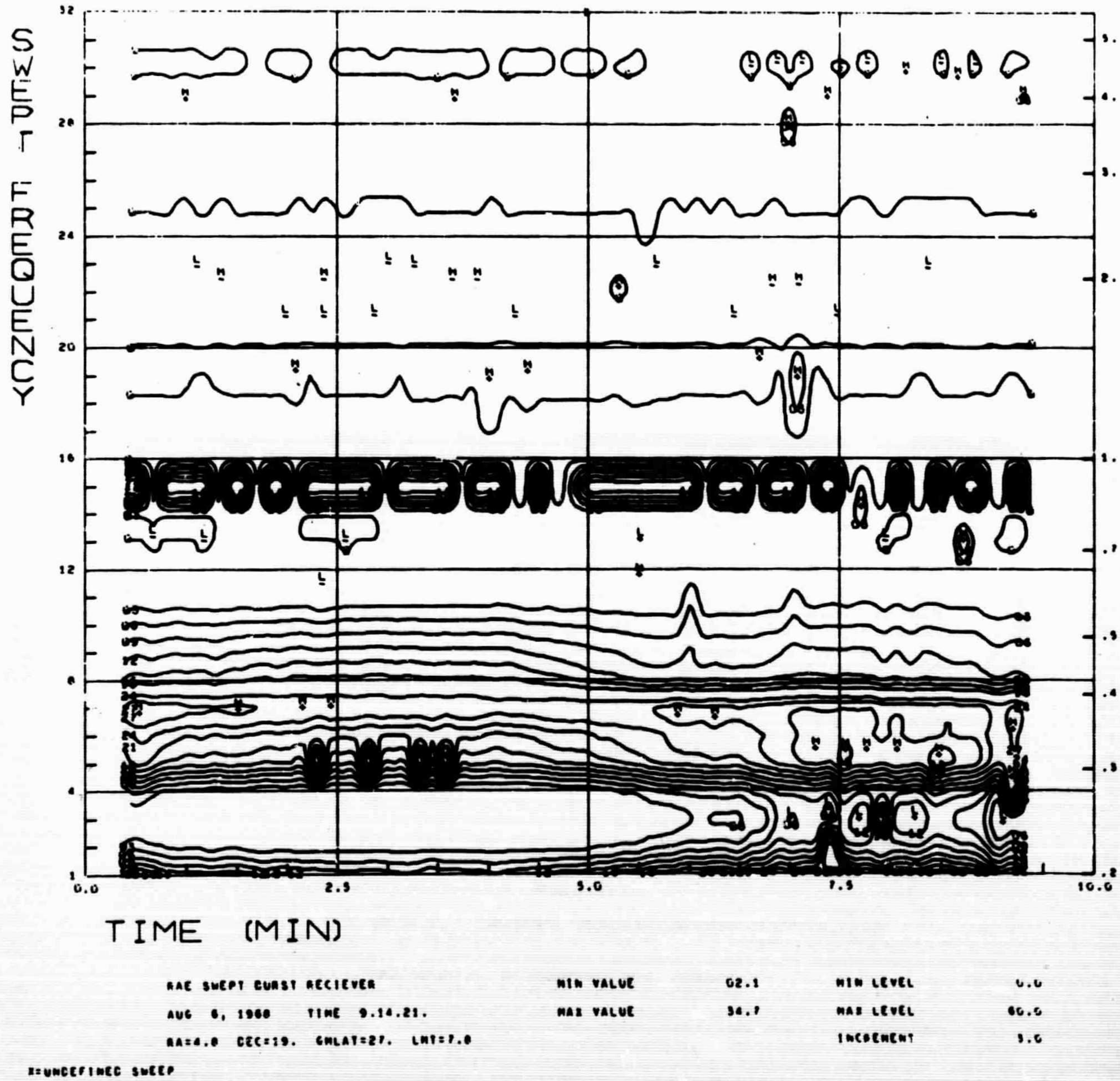

Figure 5 - Ten Minute Display - Swept Frequency Burst Receiver.

FREQUENCY NUMBER	FREQUENCY (KILOHERTZ)	GALACTIC BALKGROUND TEMPERATURE (db above 1^{o}K)
1	202	66
2	220	67
3	246	70
4	274	70
5	311	65
6	346	68
7	369	62
8	414	65
9	463	63
10	505	61
11	570	61
12	635	62
13	726	63
14	817	63
15	891	64
16	996	64
17	1107	64
18	1197	64
19	1342	65
20	1472	65
21	1665	65
22	1837	64
23	1944	64
24	2133	64
25	2703	63
26	2934	63
27	3320	62
28	3635	62
29	4139	61
30	4540	61
31	4941	61
32	5410	60

TABLE 1

GALACTIC BACKGROUND TEMPERATURES (T_{cal})

USED IN CONTOUR DISPLAY

An error in the on-board programmer of RAE-1 has caused frequencies 9, 10, 17, 18, 25, and 26 to be inoperative. The frequencies are interpolated from surrounding frequencies for display purposes.

The date and time of the first data point are shown at the lower left along with satellite position. The plotted frame always starts on the minute. At the lower right, the min and max level show that a frame containing 0 to 60 db of dynamic range plotted in 3 db contour intervals was requested. A standard three frame set consists of 0-60 db at 3 db, 0-20 db at 1 db, and 0-10 db at 0.5 db. At the bottom center of each frame, the actual minimum and maximum values in the frame are listed in decibels. The individual contour lines are labeled in decibels.

The ordinate has been tilted to account for the eight second delay needed by the receiver to sweep through 32 frequencies. Occasionally an X is plotted along the top edge of the grid. This indicates a missing eight second of digital data. Contour lines are interpolated across. Relative high and low centers are marked with H or L for added convenience.

E. Probe Displays

1. Impedance Probe

Figure 6 shows one frame from a four frame

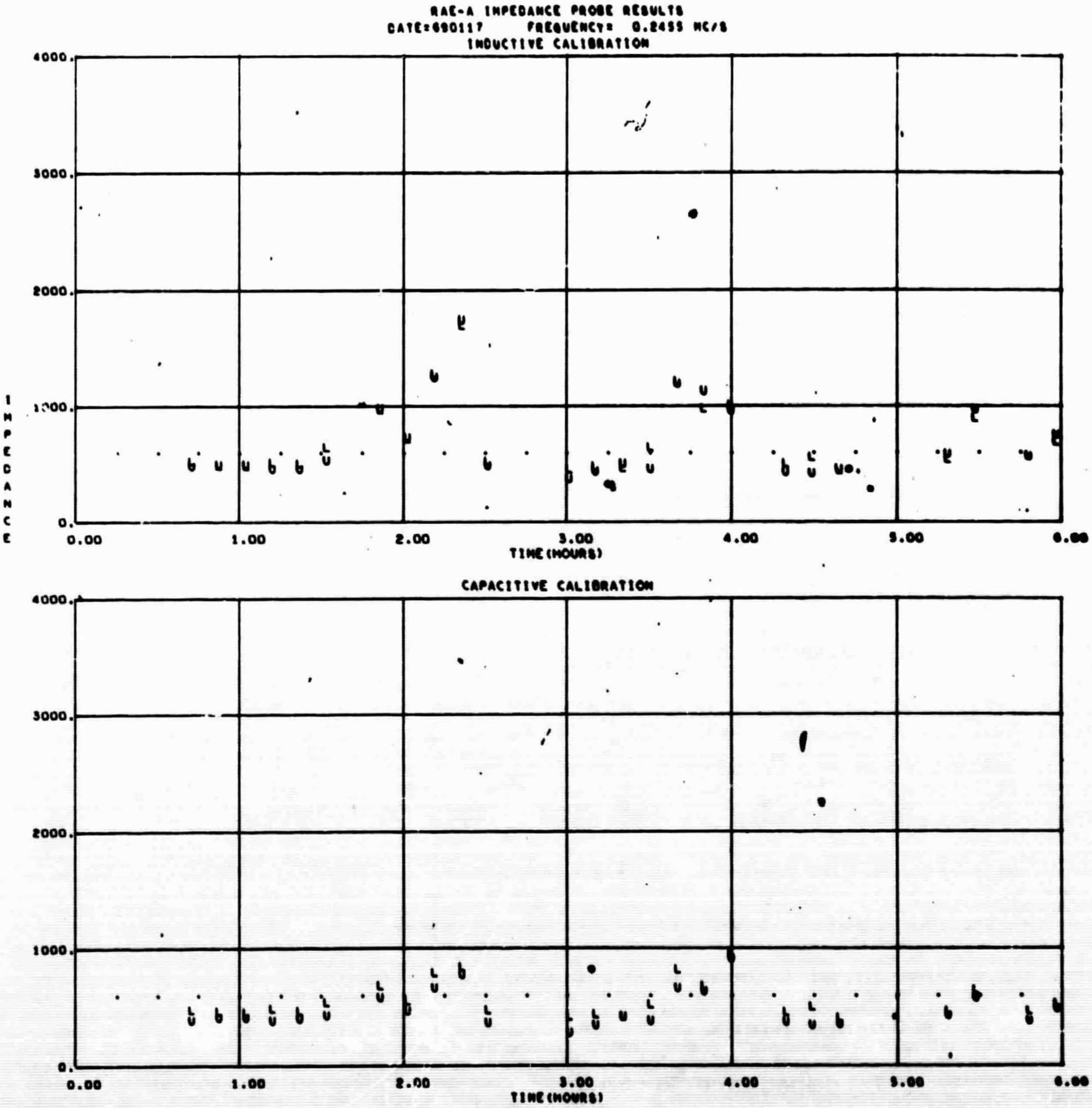

Figure 6 - Impedance Probe Display

set of impedance probe displays. The date in YYMMDD format, and the observing frequency are listed at the top of the frame. The abscissa of each framelet is Greenwich meantime, and the ordinate in this example is ohms. The other three frames forming a set have ordinates of phase angle in degrees, resistance in ohms, and reactance in ohms.

Two framelets in each frame arise from the lack of sign of the phase measurement made by RAE-1. Thus, two possibilities exist for impedance. The resulting impedance values are plotted as a "U" for upper V measurements and as an "L" for the lower V.

2. Capacitance Probe

Figures 7 and 8 show a two frame capacitance probe display. The second frame shows a listing of each measurement with time and satellite position indicated. The capacitance values are taken from the high frequency measurement made by RAE-1. The electron density and plasma frequency values are calculated from the expression:

$$C/C_o = 1-X$$

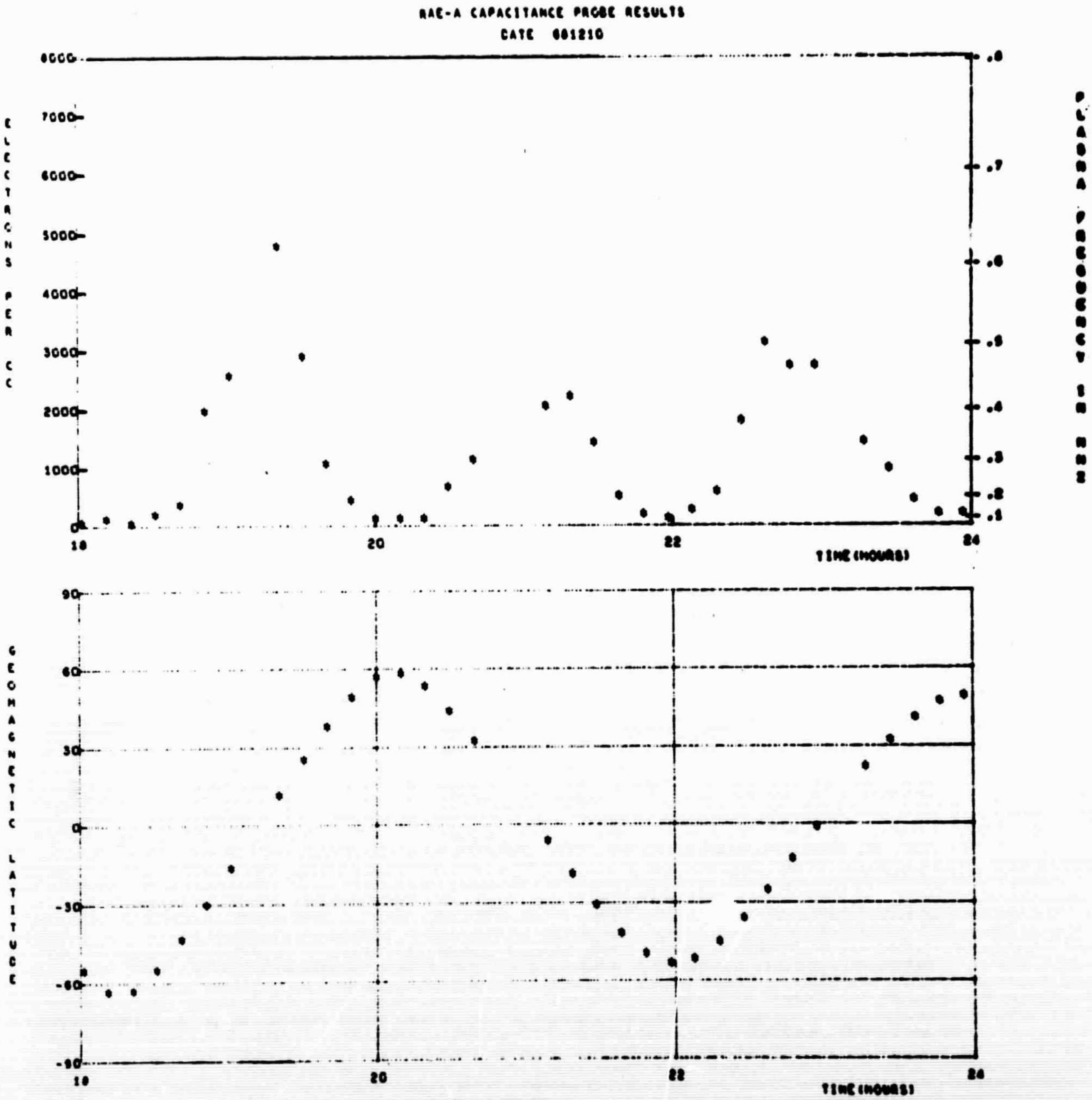

Figure 7 - Capacitance Probe Display - Frame 1

RAE-A CAPACITANCE PROBE

GMT		LMT	GEOMAGNETIC			ELECTRON	PLASMA
YYMMDD	HHMMSS	HHMMSS	LATITUDE	LONGITUDE	CAPACITANCE	DENSITY	FREQUENCY
			DEGREES	DEGREES	PFD	PER CC	KHZ
681210	180138	004640	-55.55	167.63	155.00	6.07E 01	69.89
681210	181129	232950	-63.14	137.19	153.73	1.38E 02	105.37
681210	182121	214120	-62.86	99.28	155.00	6.07E 01	69.89
681210	183112	194134	-55.02	69.65	152.46	2.15E 02	131.58
681210	184103	180739	-43.37	50.55	149.95	3.70E 02	172.52
681210	185054	170318	-30.15	37.03	124.61	1.98E 03	399.12
681210	190046	161711	-16.30	26.04	116.59	2.58E 03	456.11
681210	192028	150730	11.71	5.88	86.53	4.80E 03	621.52
681210	193020	143428	25.29	354.67	112.11	2.92E 03	484.68
681210	194011	135727	38.02	341.07	138.84	1.07E 03	293.29
681210	195002	130827	49.43	322.11	148.69	4.47E 02	189.80
681210	195954	120207	56.96	296.29	153.73	1.38E 02	105.37
681210	200945	102526	58.53	264.29	153.73	1.38E 02	105.37
681210	201936	082446	53.50	234.96	153.73	1.38E 02	105.37
681210	202928	063830	44.06	213.31	144.96	6.82E 02	234.36
681210	203919	052401	32.42	197.29	137.63	1.14E 03	303.41
681210	210853	031837	-6.34	161.38	123.45	2.06E 03	407.49
681210	211844	024553	-19.09	149.34	121.15	2.23E 03	424.14
681210	212835	021038	-31.06	135.57	132.83	1.44E 03	340.20
681210	213827	012753	-41.61	118.61	147.45	5.25E 02	205.69
681210	214818	003007	-49.55	96.85	152.46	2.15E 02	131.58
681210	215809	230540	-53.26	70.02	153.73	1.38E 02	105.37
681210	220801	211043	-51.59	42.12	151.20	2.92E 02	153.40
681210	221752	191458	-45.26	18.28	146.20	6.04E 02	220.48
681210	222743	174902	-35.95	359.44	126.94	1.82E 03	382.38
681210	223734	165015	-25.05	344.14	108.78	3.15E 03	503.66
681210	224726	160710	-13.39	330.85	114.34	2.75E 03	470.90
681210	225717	153143	-1.41	318.38	114.34	2.75E 03	470.90
681210	231700	142552	21.88	292.41	132.83	1.44E 03	340.20
681210	232651	134643	32.35	277.06	140.06	9.92E 02	282.69
681210	233642	125629	41.13	258.69	148.69	4.47E 02	189.80
681210	234634	114434	47.16	236.36	152.46	2.15E 02	131.58
681210	235625	100052	49.20	210.91	152.46	2.15E 02	131.58

Figure 8 - Capacitance Probe Display - Frame 2

where C is the measured capacitance, C_o is the free space capacitance (defined as 156 pfd), and X is the ratio of plasma frequency squared to observing frequency squared. The assumptions validating this equation are discussed by Stone et al (1966).

The top framelet of the first frame shows an ordinate of electron density (linear) on the left and plasma frequency (logarithmic) on the right. The bottom framelet has geomagnetic latitude as an ordinate. Both have Greenwich mean-time on the abscissa for the date indicated in YYMMDD format at the top of the frame. The data listed in frame 2 is plotted in frame 1.

IV. FURTHER USE OF RAE-1 DATA DISPLAYS

It is unlikely that new data displays of production importance will be developed for the RAE-1 project. However, the possibility of major improvements to these existing displays is not ruled out. Present plans call for use of these or very similar displays on the upcoming IMP-I GSFC radio astronomy project and the RAE-B project. Most further development of data displays will be aimed at these projects and not at the RAE-1 project.

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