X-724-65-466

NASA TM X-55343

ANALYSIS OF US—USSR COMMUNICATIONS EXPERIMENTS CONDUCTED BETWEEN JODRELL BANK OBSERVATORY (UK) AND ZIMENKI OBSERVATORY (USSR) VIA THE ECHO II SATELLITE

FACILITY FORM 602

N66-11235 (ACCESSION NUMBER)	(THRU)
202 (PAGES)	1 (CODE)
(NASA CR OR TMX OR AD NUMBER)	07 (CATEGORY)

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 5.00

Microfiche (MF) 1.25

ff 653 July 65

JANUARY 1965

NASA

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

ANALYSIS OF US-USSR COMMUNICATIONS EXPERIMENTS CONDUCTED BETWEEN JODRELL BANK OBSERVATORY (UK) AND ZIMENKI OBSERVATORY (USSR) VIA THE ECHO II SATELLITE

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This report will be released ONLY with the approval of the Project Manager

January 1965

Goddard Space Flight Center
Greenbelt, Maryland

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I. INTRODUCTION

1.0 GENERAL

Communication experiments have been conducted via the Echo II satellite, between the University of Manchester at Jodrell Bank (U.K.) and the Gorky State University at Zimenki (USSR).

These experiments were conducted in accordance with an agreement between the USSR Academy of Sciences and NASA (USA); and by agreement between representatives of the USSR Academy of Sciences and Gorky State University and representatives of NASA and of the British Communications Ministry and Jodrell Bank Observatory. Management of the experiment program within the USA was provided by NASA Headquarters. The Echo Project Office at Goddard Space Flight Center did not participate in this management.

In the conduct of the experiments, the British Jodrell Bank facility was the transmitting station and the Soviet Gorky State University facility in Zimenki was the receiving station. The experiment period extended from 21 February to 8 March 1964.

The purpose of this report is three-fold. First, to present a combined report of these communication experiments, conducted with the Echo II satellite; second, to provide a project analysis of the experiments; and third, to compare these experiments with those presently being conducted between certain U. S. ground facilities under the direction of the Goddard Space Flight Center, Greenbelt, Maryland.

2.0 EXPERIMENT OBJECTIVES

The purpose of these experiments was primarily to provide an opportunity for joint experimentation in the field of communication satellites. The Echo II lends itself admirably to this type of experimentation because it does not require either special or complex ground equipment.

As stated in the Bilateral Space Agreement between the USSR and NASA, the passive Echo II satellite experiments were to consist primarily of measuring the quality of transmission over the Echo II satellite circuit between the USSR and the UK for the following types of transmissions:

a. Unmodulated carrier

b. Single frequency modulation

c. Telegraphy

d. Facsimile

e. Voice

3.0 IMPLEMENTATION PLAN

3.1 EXPERIMENT FACILITIES

The Jodrell Bank facility served as the transmitting end of the link, utilizing a 1-kw transmitter at a frequency of 162.4 mc, with a steerable 250-foot diameter parabolic reflector antenna. Pointing of the antenna was accomplished by programmed autotrack based on predictions from GSFC except in the cases of revolutions 389 and 450. On those passes, the antenna was manually positioned to point at positions in space through which the satellite was expected to travel.

A steerable 15-meter (49 foot) diameter parabolic reflector antenna and associated receiving equipment were used to receive the 162.4 mc signals at Zimenki. In addition to receiving the 162.4 mc signals from Jodrell Bank, the system also received and recorded the telemetry beacon signals from the satellite at 136 mc. In both cases, the variation in the received frequency due to doppler was compensated for by manual tuning.

A digital drive tape and an antenna programmer were used to point the Zimenki antenna for reception. The data points were furnished by the Astro-Council of the USSR Academy of Sciences in intervals of 15 seconds. These were checked from time to time with predictions furnished by the Goddard Space Flight Center. A computer was used to interpolate between the data points in order to generate the drive tape. Apparently, on occasions, the 15 second data points were also used directly for manual positioning of the antenna.

A more complete description of these two facilities is contained in Section II of this report.

3.2 DESCRIPTION OF PLANNED EXPERIMENTS

As indicated in Section 1.0, five types of experiments were to be conducted:

a. Unmodulated carrier

b. Single frequency modulation

c. Telegraphy

d. Facsimile

e. Voice

The following outlines the proposed schedule for tests 1 through 22 which was agreed upon shortly before tests began:

SESSION	TEST
1 thru 4	Unmodulated carrier interrupted every 2 seconds for 1/10 sec (ICW).
5 and 6	400 cycle tone.
7 thru 10	Test teletype message, repeated for duration of session.
11 and 12	Clear teletype message from US, repeated.
13	Voice message from US.
14	Repeat test of session 13.
15	Voice message from UK.
16	Repeat test of session 13.
17	Facsimile CCITT pattern.
18	Repeat test of session 17.
19	Facsimile photograph from UK.

SESSION	TEST
20	Repeat test of session 19.
21	Facsimile photograph from UK.
22	Repeat test of session 21.

II. DISCUSSION OF EXPERIMENTS

1.0 GENERAL

The experiments began on February 21, 1964, and continued through March 8, 1964. Thirty four tests ("communication sessions") were conducted via the Echo II satellite. Ten sessions were conducted via the moon for comparative and system check purposes. Table II-1 summarizes the tests performed.

Section 3.0 has been written from the English translation of the Russian report. Although some of the wording has been changed to make easier reading and some terms have been changed to those in more common use in this country, every effort has been made to avoid changing the original meaning.

2.0 TRANSMISSION AT JODRELL BANK

The UK provided a brief summary report regarding their operations at Jodrell Bank. It was pointed out that their transmitter was not designed to stand for any length of time without drive. Consequently Morse Code, accomplished by keying the carrier, could not be transmitted as slowly as would have been desirable, since the drive was arranged to come on automatically after a break of approximately 0.5 second. As indicated later in this report, this caused some difficulty for the Russians.

The power as stated by the British was, "measured on a power meter in the output line from the transmitter." A 3 db loss in power could be expected when the tracking error in either azimuth or elevation reached 1°.

A brief description of the Jodrell Bank transmission is given below:

1. Interrupted CW (ICW). A break of approximately 0.1 second occurred every 2 seconds.

2. 400 cps tone

3. TTY. Carrier modulation

TABLE II-1.
SUMMARY FOR JODRELL-ZIMENKI EXPERIMENTS VIA ECHO II AND THE MOON

PASS NO.	DATE	TIME START	TIME FINISH	TYPE OF TRANSMISSION	MODU-LATION	XMTR POWER	MAX. EL. ANGLE* JODRELL	MAX. EL. ANGLE* ZIMENKI	REMARKS
362	21/2/64	2258	2310	1 CW 1/10 sec every 2 sec		1 kw	8°	77.5°	
363	22/2/64	0048	0107	1 CW		1 kw	40°	28.5°	
370	22/2/64	1315	1325	1 CW		1 kw	7°	78°	TX 3 kc of freq. Reset for next run.
M1	22/2/64	1330	1440	1 CW		1 kw			via moon
375	22/2/64	2235	2245	1 CW		1 kw	6.5°	55°	
384	23/2/64	1437	1452	1 CW		1 kw	35°	32°	
M2	23/2/64	1500	1600	1 CW 1500-1530. 400 cps tone 1530-1600	50%	1 kw			via moon
388	23/2/64	2210	2219	1 CW		1 kw	5.5°	48.5°	pass time corrected by −30 seconds.
389	24/2/64	0000	0016	1 CW		1 kw			fixed position.
397	24/2/64	1412	1427	1 CW		1 kw	27°	40°	
402	24/2/64	2335	2351	400 cps tone	50%	1 kw	17°	62°	
410	25/2/64	1349	1402	400 cps tone	50%	980 w	21°	47°	
415	25/2/64	2311	2325	CW until 2312, then TTY		980 w	14°	54°	
423	26/2/64	1324	1338	CW until 1325, then TTY		980 w	16.5°	54°	via Relay II and Echo II
M3	26/2/64	1610		TTY		950 w			via moon
428	26/2/64	2247	2259	Time expanded speech A	90%	870 w	11.5°	84°	spoken in English by male.
429	27/2/64	0037	0054	Time expanded speech A	100%	850 w	40°	23°	English
436	27/2/64	1301	1313	400 cps	100%	850 w	12°	69.5°	
441	27/2/64	2222	2234	Time expanded speech B	90%	830 w	9.5°	65°	spoken in Russian by woman.
442	28/2/64	0011	0029	Time expanded speech B	100%	860 w	33°	28°	in Russian.
449	28/2/64	1238	1248	Time expanded speech B	100%	850 w	9°	54°	in Russian.
450	28/2/64	1433		1 CW		850 w	33°	16°	fixed point.
M5	28/2/64	2100	2140	Facsimile, International test card	50%	840 w			via moon
454	28/2/64	2157	2209	Facsimile, International test card	50%	840 w	7.5°	70.5°	
455	28/29/2/64	2348	0004	Facsimile. Picture 1.	70%	850 w	27°	34°	
462	29/2/64	1214	1223	Facsimile. Picture 2.	100%	870 w	6°	22°	
463	29/2/64	1400	1415	Facsimile. Picture 2.	100%	870 w	38°	39°	lost elevation axis after 1406
468	29/2/64	2322	2339	Facsimile. Picture 2.	100%	870 w	22.5°	41°	
M6	29/2/64	2345	0010	Facsimile. Picture 2.	100%	875 w			via moon
476	1/3/64	1335	1350	Facsimile. Picture 3.	90%	850 w	29.5°	39°	
M7	1/3/64	2200	2230	TTY		700 w			via moon. Fault in TX feed system.
489	2/3/64	1311	1325	Unmodulated CW		900 w	23°	45°	TX repaired.
494	2/3/64	2234	2249	Facsimile. Picture 3.	100%	930 w	15.5°	64°	
M8	2/3/64	2252	2330	TTY		930 w			via moon
502	3/3/64	1247	1300	Morse code carrier modulated.		1 kw	-	-	
507	3/3/64	2208	2222	Morse code carrier modulated.		1 kw	13°	80.5°	
502	3/3/64	1247	1300	Morse code carrier modulated.		1 kw	13°	80.5°	
M9	3/4/3/64	2345	0030	1st half of period morse on carrier. 2nd half morse on 980 cps subcarrier.	100%	1 kw			via moon
541	6/3/64	1137		Fault occurred in feed to one dipole			7°	81°	
555	7/3/64	1257	1271	Slow morse carrier modulation.		1 kw	32°	33°	Aerial now linear polarized.
559	7/3/64	2028	2042	Slow morse carrier modulation.		1 kw	6°	55°	Aerial now linear polarized.
560	7/3/64	2220	2234	Facsimile. Picture 4.	100%	1 kw	20.5°	72°	Aerial now linear polarized.
M10	8/3/64	0630	0700	CW		1 kw			via moon
568	8/3/64	1233	1247	Facsimile. Picture 4.	100%	1 kw			

*Approximate within 1° of actual

4. Speech. This was recorded and transmitted at 1/8 speed for bandwidth compression.

5. Facsimile. A frequency-modulated subcarrier was used according to the standard practice; 1500 cps = white; 2300 cps = black.

6. Morse, carrier keying.

7. Morse, 980 cps audio tone keying.

Modulations 1, 3, and 6 were provided by keying the drive before feeding it to the transmitter. Modulations 2, 4, 5, and 7 were applied to the audio modulator of the transmitter.

Figures II-1 through II-4 are copies of pictures used in the facsimile tests. The texts of the recorded speech, TTY, and Morse messages are given below:

1. TTY Transmission A. A simple repeated sequence of the alphabet and numerals:

ABCDE	FGHIJ	KLMNO	PQRST	UVWXY	01234	56789
ABCDE	FGHIJ	KLMNO	PQRST	UVWXY	01234	56789
ABCDE	FGHIJ	KLMNO	PQRST	UVWXY	01234	56789
ABCDE	FGHIJ	KLMNO	PQRST	UVWXY	01234	56789
ABCDE	FGHIJ	KLMNO	PQRST	UVWXY	01234	56789

2. TTY Transmission C.

   To Dr. Getmantsov and Colleagues at Zimenki

   We at Jodrell Bank take this opportunity of sending our warm greetings to you via the moon. We hope that this cooperative experiment may lead to closer links in the future between the astronomers and scientists of our countries. With best regards. Lovell, Davies, Thomson, and the staff of Jodrell Bank.

3. Voice A.

   "Jodrell Bank calling Zimenki via Echo II satellite."

4. Voice B. Spoken by a Russian-born woman member of the Department of Russian Studies in the University: "Jodrell

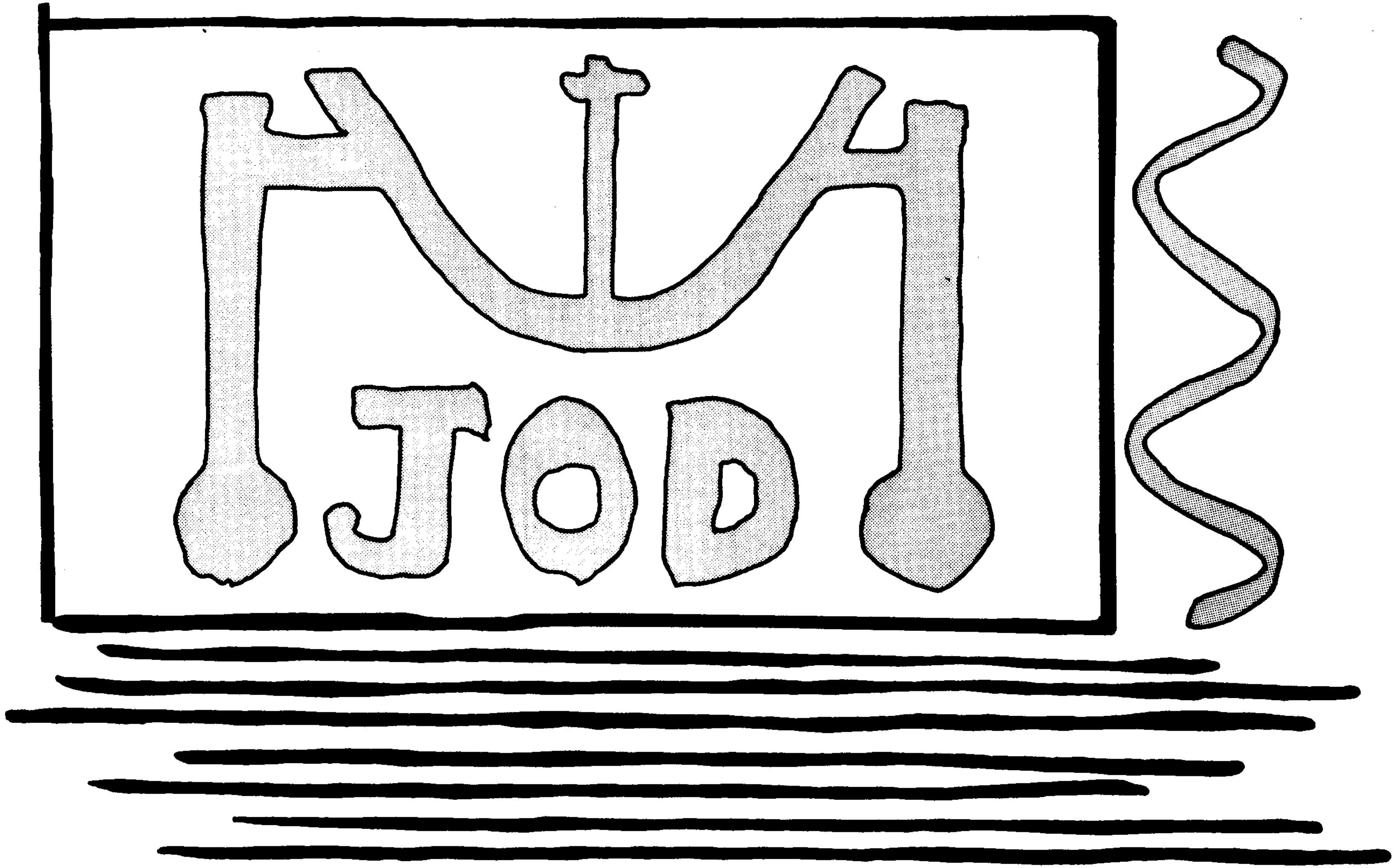

Figure II-1. Original Picture Used in Facsimile Tests

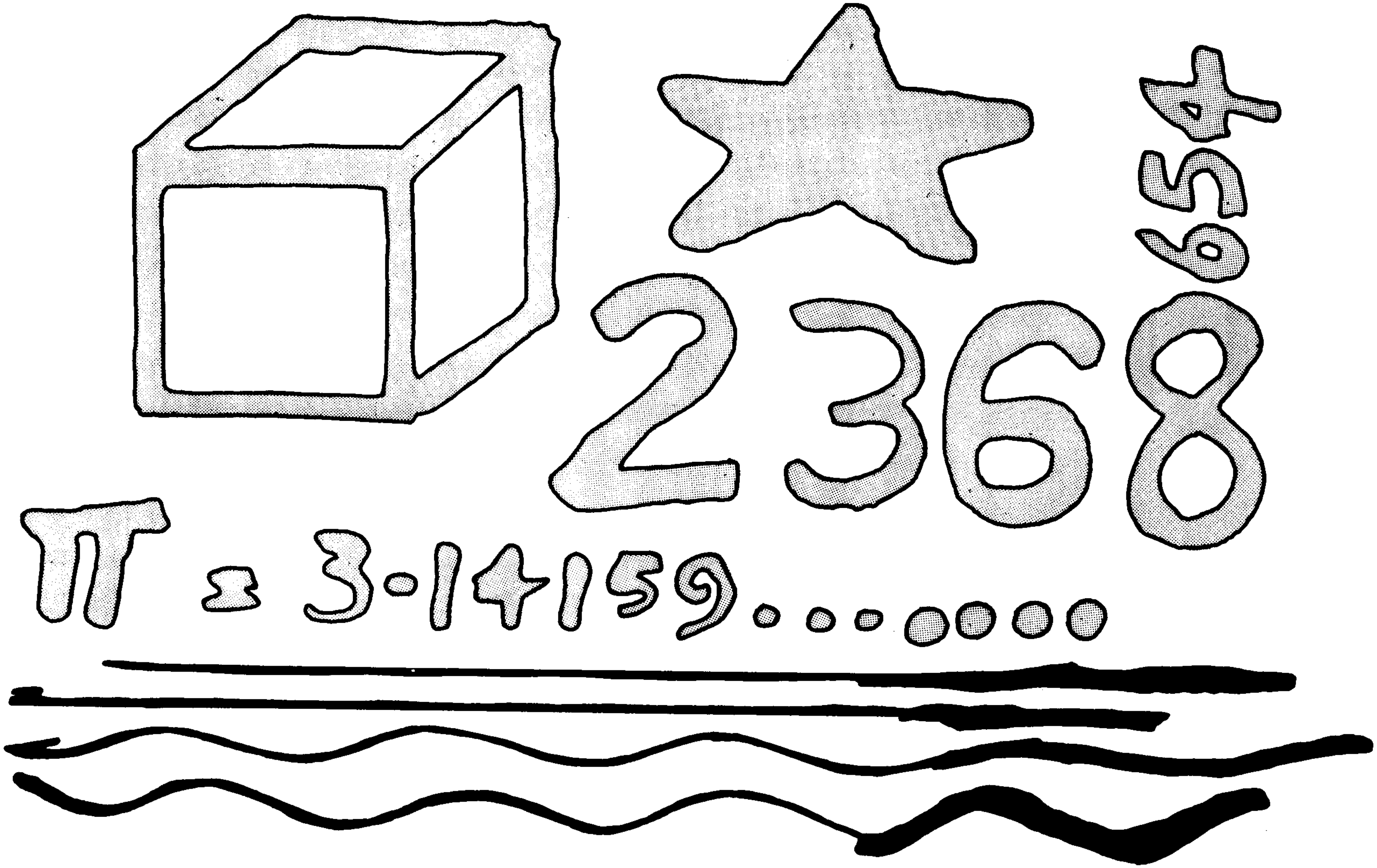

Figure II-2. Original Picture Used in Facsimile Tests

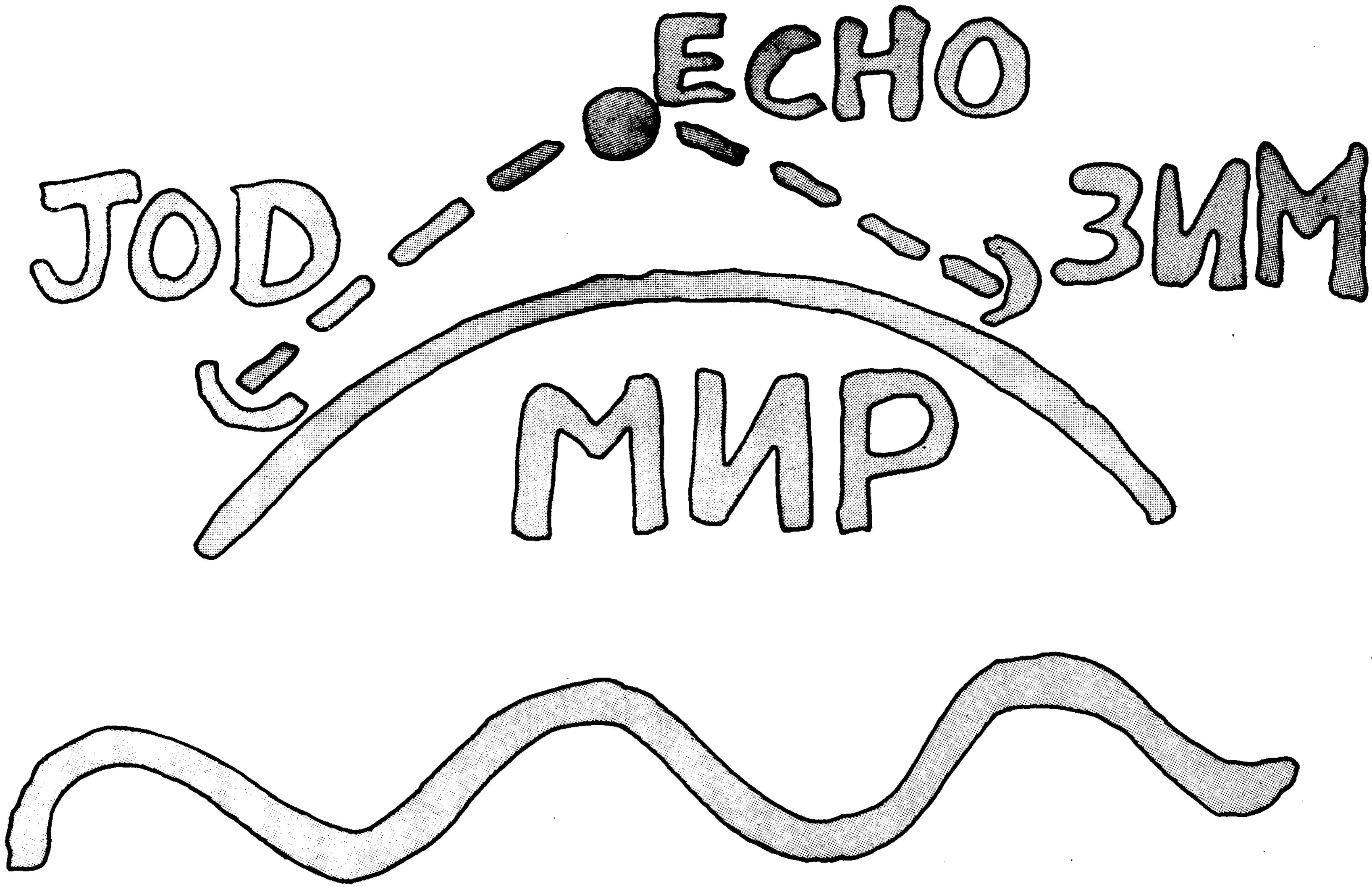

Figure II-3. Original Picture Used in Facsimile Tests

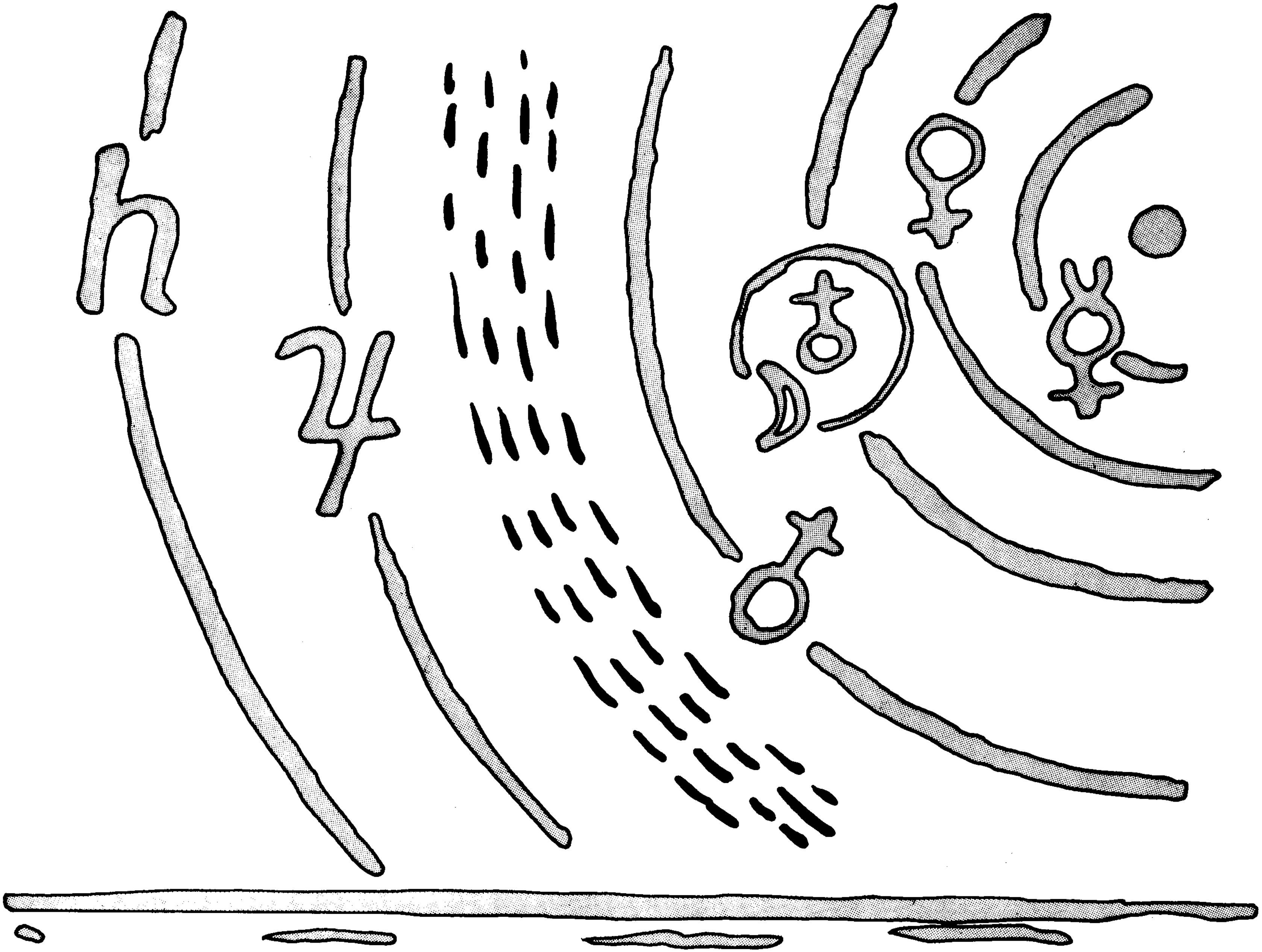

Figure II-4. Original Picture Used in Facsimile Tests

Bank zovet Zimenki. Privet nashin Russkim kollegam ot Daview i vce shtata Jodress Bank."

5. Morse Message A.

   Jodrell Bank calling Zimenki

   Greetings to our Russian colleagues from Davies and the staff at Jodrell Bank.

6. Morse Message B

   Jodrell Bank transmitting to Zimenki on 162 point 4 mc via Echo II satellite. Power, 1 kilowatt. Gain, 40 decibels.

   Time 2036
   2038

3.0 RECEPTION AT THE ZIMENKI FACILITY

3.1 DESCRIPTION OF RECEIVING SYSTEM

The antenna used by the Zimenki facility was a 50 foot parabolic mirror with a focal distance of 17.4 feet. The irradiator, installed at the focal point of the mirror, consisted of two lattice-type folded dipoles. These were located approximately 18 inches above a flat round metal reflector about 5 feet in diameter. (See Figure II-5). A cable with a quarter wave electrical length was used to connect the local oscillator and the converter in order to achieve a phase displacement of $\pi/2$ between the local oscillator signal and the RF signal in the converter. The irradiator was connected so that it received left-handed polarization. The polarization of received signal refers to its polarization prior to its reflection from the parabolic mirror. The width of the antenna directivity pattern between the half power points at a frequency of 162.4 mc was measured using the radio radiation of the sun and the discrete source Cassiopeia A. It proved to be close to the estimated value of 9°. The coefficient of the area used on the receiving antenna was calculated to be close to 0.5. The power level of the side lobes of the receiving directivity pattern was determined to be about 30%. The efficiency ratio of the feeder that connected the converter to the antenna proved to be around 0.8 according to the measurements made.

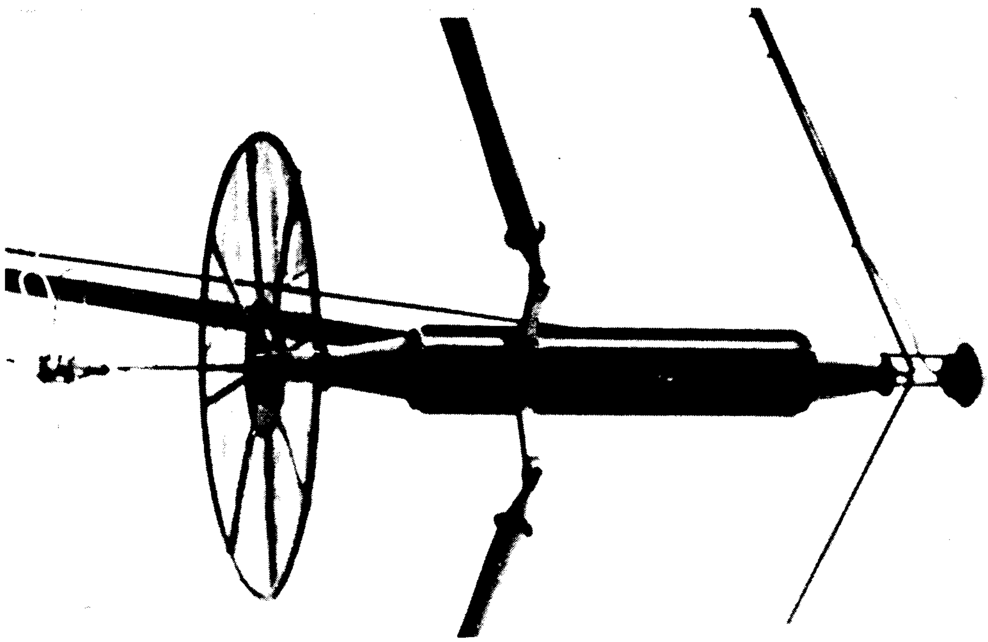

Figure II-5

A block diagram of the receiving system configuration is shown in Figure II-6. An overall view of the radio receiving equipment is presented in Figure II-7. The signal, received by the radio antenna at a frequency of 162.4 mc, was fed to the converter which was mounted directly on the antenna. The converter included an RF amplifier, a mixer and an amplifier for the first intermediate frequency of 17.6 mc (see Figure II-8). The local oscillator signal at a frequency of 180.000 mc was fed to the converter's mixer from an oscillator which was stabilized by thermostatically controlled quartz. The converter's RF amplifier had a pass band of ±0.7 mc at the nominal frequency of 162.4 mc. The overall amplification factor of the converter with respect to voltage was 300. The noise figure of the converter (RF amplifier) at 162.4 mc is approximately 2.6.

The first intermediate frequency signal of 17.6 mc was fed from the converter to the equipment room by means of an RF cable. (Figure II-9). There it was fed to a main communications rack which included two professional tunable radio receivers along with low frequency equipment for amplifying and processing the telegraph messages. The RF signal was simultaneously fed through two cathode followers to both of the tunable receivers on the rack. These receivers were used to amplify the first intermediate frequency. With the aid of the tunable radio receivers, tuning to the incoming signal was accomplished as well

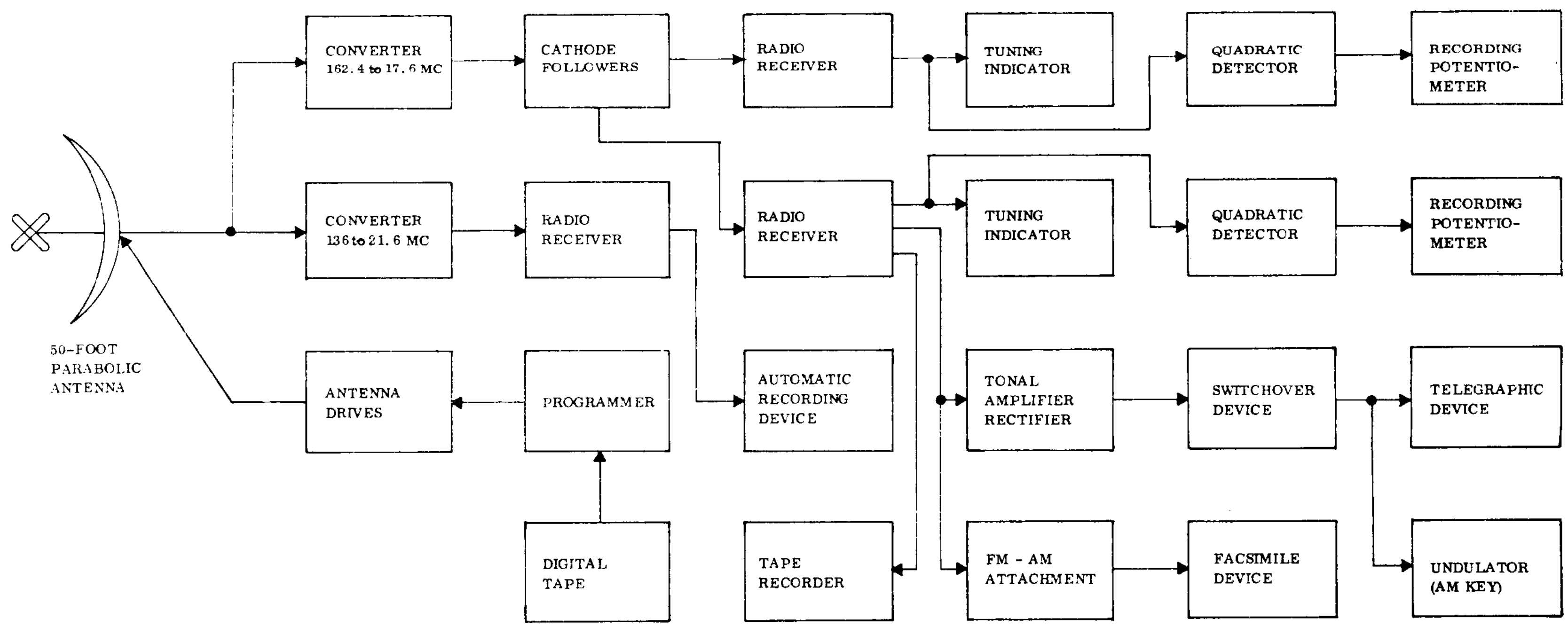

Figure II-6. Receiving System Configuration at Zimenki

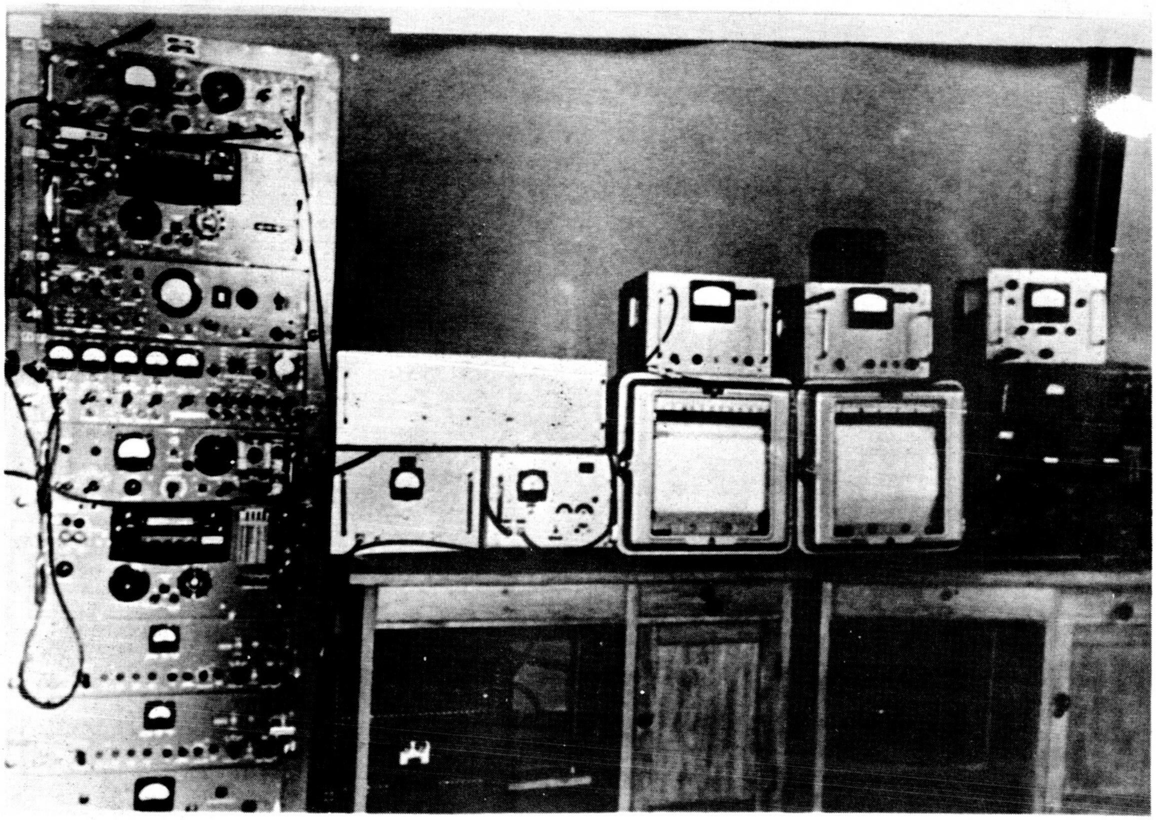

Figure II-7

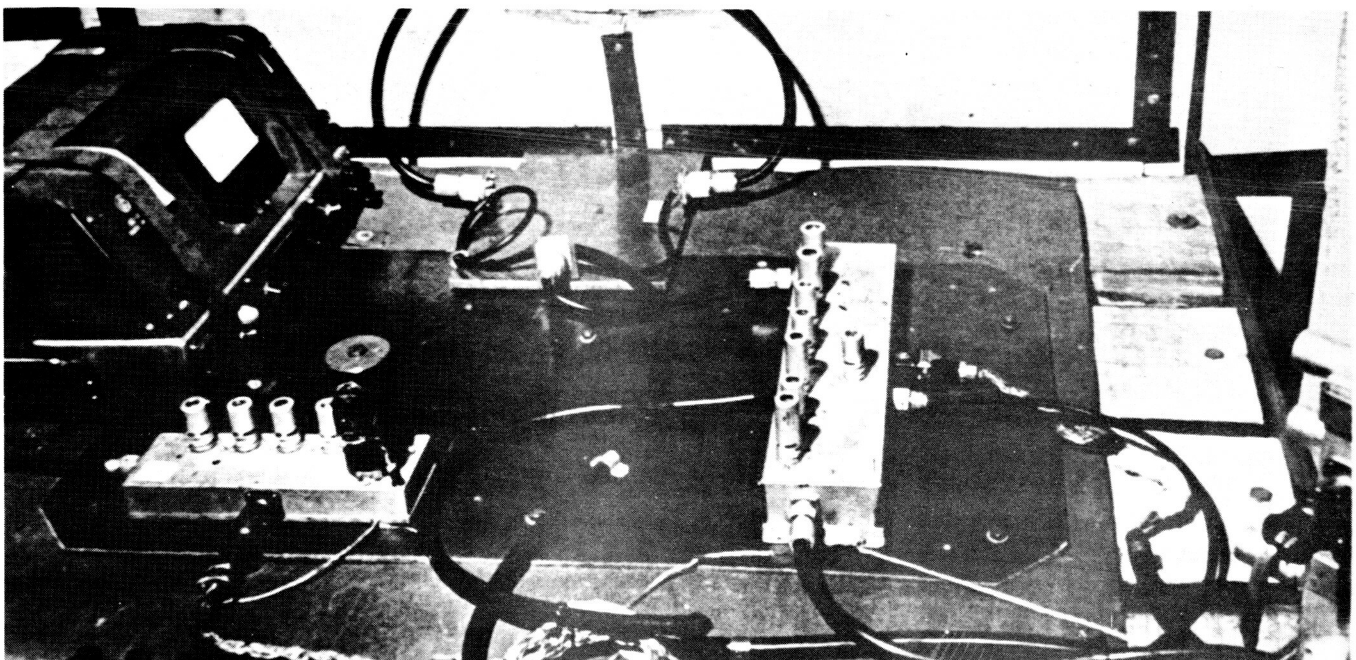

Figure II-8

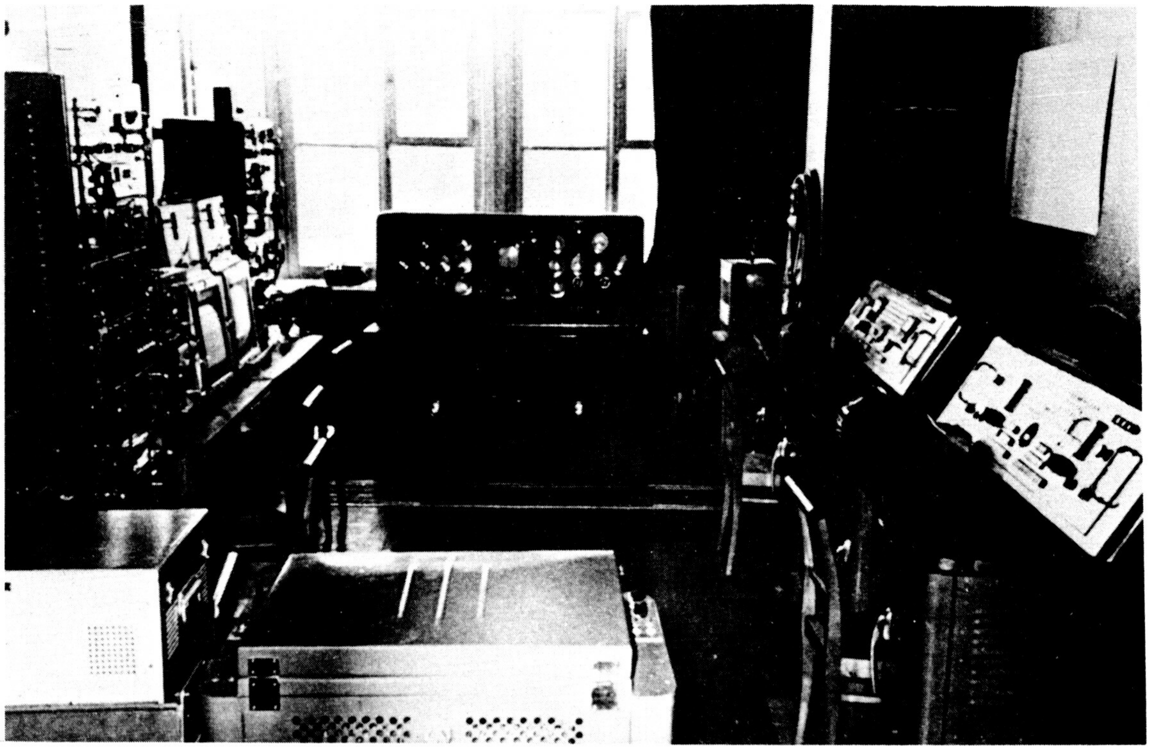

Figure II-9

as tracking the variation in frequency due to the doppler effect. Telephone and telegraph reception of the signal could be accomplished at various values for the pass band of the receivers.

The wide-band radio receivers, used to amplify the 17.6 mc signal that enters from the converter, permitted reading of the signal frequency to within a 1 kc error. The indicator, connected to the output of the receiver's intermediate frequency amplifier, was used to show the difference between the frequency of the incoming signal and the receiver's tuning frequency. Its use permitted tracking of the incoming signal during the communication sessions through the Echo II with an error of not more than 50 cps.

From the intermediate frequency amplifiers of the tunable receivers, the signal was fed to a low frequency unit consisting of a square law detector and a d. c. balancing amplifier. An electronic automatically recording potentiometer which registered the signal level on a moving paper tape was connected to the output. At the same time the signal was fed from the detector output, which followed the intermediate frequency amplifier of the tunable receivers, to a tape recorder. The unit, which indicated the difference in the frequency of the incoming signal and the tuned frequency of the radio receiver, together with the low frequency unit, were connected in parallel to the output of the intermediate frequency amplifier of the tunable receivers.

In addition to receiving the basic signal at a frequency of 162.4 mc, the antenna array permitted simultaneous reception of the Echo II radio telemetry beacons at frequencies of approximately 136 mc. The beacon signals were fed to a converter, similar in arrangement to the converter for the 162.4 mc frequency. The signal from the converter, with the intermediate frequency of 21.6 mc, was fed to a tunable receiver. It was then recorded by an automatically registering galvanometer connected to the receiver's output. A system of matching sections of coaxial cable was used to decouple the 162.4 mc converter from the 136 mc converter. This resulted in the converter for the 136 mc frequency having negligible effect on the main converter's reception of the signal on 162.4 mc.

Since the system of dipoles mounted in the focus of the receiving mirror was adjusted to the frequency of 162.4 mc, the signal entering the 136 mc converter was considerably weaker. In addition, the coaxial matching sections for decoupling the 162.4 mc converter from the 136 mc converter shunted the 136 mc converter, which weakened the 136 mc signals. Nevertheless, the resulting signal level at the frequency of 136 mc was quite adequate for reliable reception.

The terminal telegraphic equipment included the following devices; a tonal amplifier-rectifier for converting the AM signals into dipole dc signals, a converter device for changing the dc dipole signals to single pole and a terminal telegraphic printout device.

The terminal equipment for the facsimile reception consisted of an attachment to convert the FM signals to AM signals and a device which recorded the signals on facsimile paper.

An undulator was used to record the telegraph signals in Morse Code.

A tape recorder, used to record decelerated speech, received the output of the detector which was connected to the output of the wide-band radio receiver's intermediate frequency amplifier. It had a frequency response characteristic, which was essentially flat from 30 cps to 10 kc. The terminal telegraphic and facsimile equipment had parameters corresponding to the standards of the CCIT (Comite Consultatif International Telephonique).

Figure II-10 illustrates the relation of the readings of the output recording device (i.e. of the automatically recording potentiometer) to the square of the voltage value at the output of the low frequency unit. This relation, which is very nearly linear, shows that the recorder readings were proportional to the power of the incoming signal with the exception of a small sector corresponding to the initial values of the recorder readings.

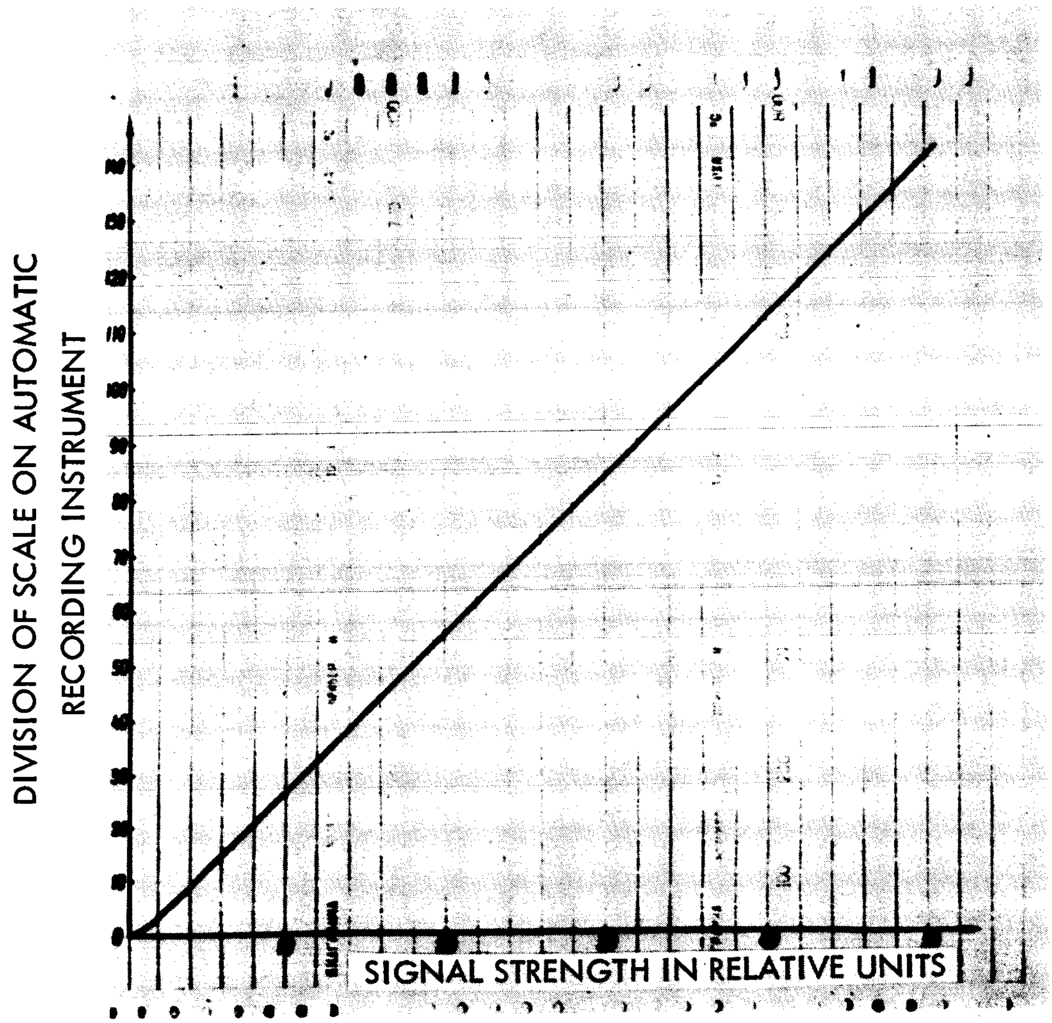

Figure II-10

3.2 METHOD OF MEASUREMENTS

3.2.1 Calculating the Ephemerides of Echo II

A computer was used to calculate the ephemerides of Echo II from the orbital elements that were sent daily from the astronomical council of the USSR Academy of Sciences to the Zimenki Observatory. The orbital elements were received in the "Sator" form, that had been adopted at the 11th conference of the International Astronomical Union in August 1961. These were compared with the orbital elements being received from Washington during the test.

Two methods of calculating the ephemerides were used:

1. Numerical integration of the differential equations for the satellite's motion. This method is described in detail in the report by E. L. Akim and T. M. Eneyev (Reference 1). The motion equations were integrated according to the Runge-Kutta method and including Merson's modification that dealt with automatic pitch selection so as to assure the assigned accuracy of the calculations (Reference 2). The error in each integration step did not exceed 10^{-10} km. The integral error in calculations in a three day period did not exceed 0.1° of the satellite's topocentric coordinates.

2. The analytical method described in the report by A. S. Sochilina (Reference 3). The program based on this method was used for comparison with the results of the first program and for auxiliary calculations.

Both programs furnished the topocentric coordinates of the satellite every 15 seconds during the satellite's period of visibility at Zimenki. These data were sometimes used directly for the manual control of the antenna. For programmed control of the antenna, a punched film drive tape was used. The data points on the drive tape were derived by interpolating these data points (for 15 second intervals) by the use of a special computer program.

The ephemerides obtained with the aid of the computer were monitored by the following procedures:

1. Measurement of the signal levels of the beacon transmitters on Echo II in the sessions which preceded the communication sessions. This was done by successively setting the receiving

antenna to several fixed positions, corresponding to various points on the trajectory of the satellite.

2. The ephemerides obtained from NASA prior to the start of the experiment on the communication sessions from 21 to 28 February were compared with those used for aiming the receiving antenna at the satellite. A time displacement of as much as 40 seconds was found.

3. The stationary setting of the receiving and transmitting antennas for the assigned (with reference to time) point of the orbit of Echo II. The test was accomplished twice.

4. The control ephemerides sent by the Astro Council of the USSR Academy of Sciences to Zimenki Observatory.

5. The optical observations which were conducted at Zimenki from 16 February to 6 March each evening during the sessions that preceeded the communication sessions through the Echo II. The observations were not conducted on several days when bad weather obstructed optical visibility. The optical observations were conducted with the aid of the two AT-1 tubes according to the method described in Reference 4. The error involved in fixing the position of the Echo II with the aid of optical observations did not exceed 0.2° of an arc.

During the communication sessions conducted through the Echo II, pointing of the receiving antenna was accomplished, essentially automatically, by use of the program control system. The deviation of the actual direction of the electrical axis of the antenna from the assigned program during the session did not exceed 3 angular minutes. When manual control of the antenna was used, the corresponding error was appreciable but still was not over 15 minutes of arc.

An analysis of the ephemerides used for aiming the antenna at the Echo II, taking into account the corrections as determined from the optical observations of the satellite at Zimenki showed that the deviation of the antenna's electrical axis from the optical axis of the Echo II during all the communication sessions did not exceed one degree of arc. Based on the pattern of the receiving antenna, the drop in strength of the incoming signal due to the actual error in pointing the antenna on the Echo II should not have exceeded 0.1 to 0.2 db.

3.2.2 Checking the Polarization of the Incoming Signal

The lattice-type folded dipoles that were installed at the focal point of the receiving mirror could be switched in such a way as to enable the antenna to receive either a clockwise or counterclockwise polarized signal. The switching of the dipoles could be accomplished in the course of several minutes. The type of polarization of the signal being received was checked with the aid of an auxiliary (spiral) antenna set up about 328 feet from the antenna and at a height of 85.5 feet above the earth's surface. In this way, the effect of the earth on the nature of the polarization of the signal being picked up by the antenna was almost fully eliminated. When connections of these lattice-type dipoles were switched from clockwise to counterclockwise circular polarization, the strength of the incoming signal varied by 20 db. At the same time, the level of the signal from the discrete source of radio radiation (Cassiopeia A.) in relation to the characteristic noises of the receiving equipment was practically uniform for various connections of the lattice-type dipole radiators. On the basis of these tests, it can be stated that the receiving antenna should detect only the circularly polarized radiation of one sign. During the communication sessions conducted through the Echo II, the lattice type dipoles mounted in the mirror's focus were switched in such a way that the antenna picked up a circularly polarized wave with a left sign of rotation of vectors of the electromagnetic field. The sign of rotation refers to the wave prior to its reflection from the surface of a parabolic mirror.

3.2.3 Calibration of the Receiving Equipment

Thirty minutes before each communication session the entire radio receiving channel was calibrated using the radio radiation from a discrete source, Cassiopeia A as a standard. The antenna was sighted each time first on the North Star and then on Cassiopeia A.

A sample of the 1 March 1964 recording of the radio radiation, emanating from the region of the North Star and Cassiopeia A at a 10 kc pass band width of the receiver is presented in Figure II-11. As a criterion of the stability of the noise characteristics of the radio receiving channel the following was determined: The ratio $(P_2 - P_1)/P_1$ of the excess in the strength of radio radiation coming from the Cassiopeia region over the strength of radio radiation arriving from the region of the North Star to the total strength of the characteristic noises of the equipment and the strength of radio radiation from the region of the

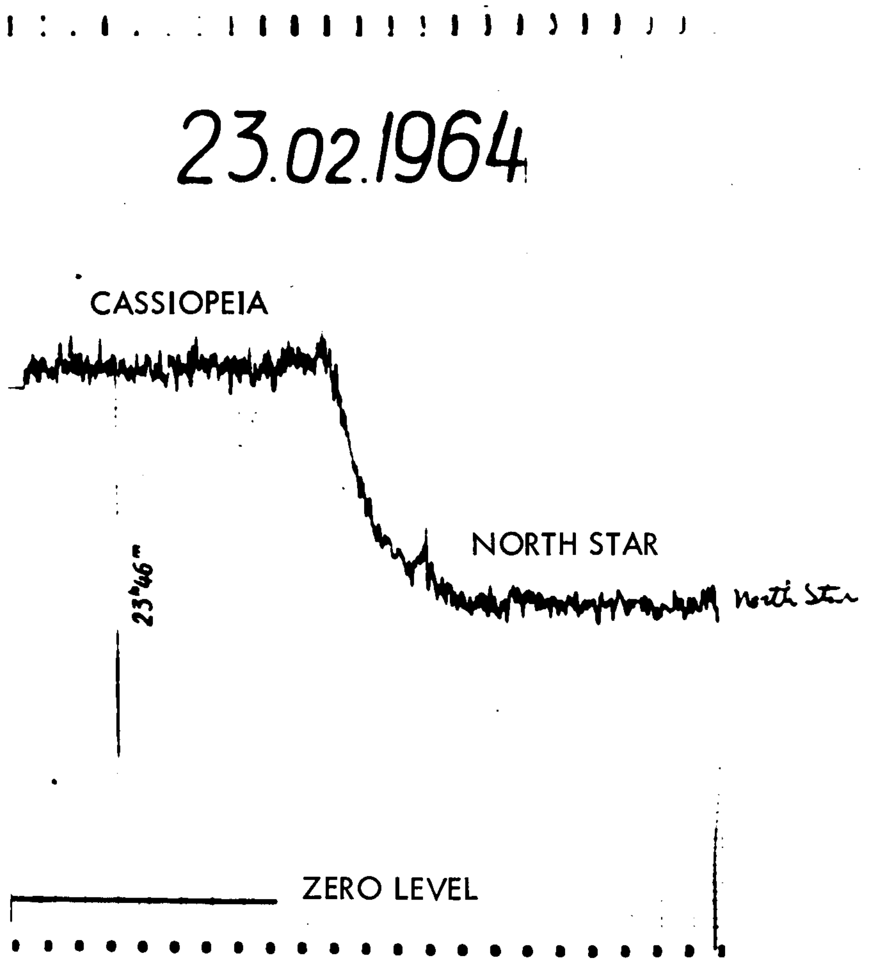

Figure II-11

North Star. For the sample of recording shown in Figure II-11, this ratio equals 0.69. In the various communication sessions this ratio changed somewhat, but the changes did not exceed 0.65, ± 10% of the average value.

A similar calibration was also conducted on sessions through the moon when they did not follow directly after a communication session through the Echo II.

3.2.4 Timing Markers

Minute time markers, derived from a chronometer, were fed automatically to the signal level recording device during the communication sessions. The chronometer readings which were only approximate, were corrected to obtain the true time. In the expression $t = T - a$, which is entered on the signal level recordings, t is the true time, T is the chronometer reading and a is the applied correction.

3.3 SIGNAL LEVEL EXPERIMENTS

The methods used by the Soviets and by the Echo Project at Goddard Space Flight Center for computing receiver signal strength are outlined in Appendix A. Photocopies of the original recordings of the signal levels for all the communication sessions conducted through the Echo II are included in Appendix B, Figures B-1 through B-33. In several cases, the contrast of the original recordings was inadequate to obtain satisfactory photocopies. As a result the originals of these recordings were touched up with India ink prior to photographing. The accuracy of the original recordings was fully retained.

The date and the universal time (UT) of the sessions are shown in the photocopies. The time correction for the contact chronometer which was necessary for determining the true time, was also entered on each photocopy. As a rule scales were drawn in at the beginning and end of a session to facilitate the determination of signal to noise ratio in db. The values entered on the scales were calculated using the formula $P_S/P_N = 10 \log S - S_N/S_N$, where S = the total strength of the signal and noise, while S_N = the noise level taking into account the deviation of the characteristics of the detector of the low frequency unit from quadratic. The lower horizontal marker of the decibel scale fixes the recording level of the automatically recording galvanometer in the absence of a signal and noise at the detector input. The noise level on which the decibel scale was based, was determined during the portion of the recording which occurred before the start and after the completion of reception of the signal. Since during a session the noise level changed somewhat mainly because of variations in the level of the cosmic radio radiation, the decibel scales at the beginning and end of the sessions differed slightly in a number of cases. In the sessions on Feb. 22, 1964, at 0048 hrs UT, Feb. 23, 1964 at 1438 hrs UT, and Feb. 29, 1964 at 1401 hrs UT, sectors can be seen during which the noise intensity increased appreciably. These sectors correspond to the passage of the directivity pattern of the receiving antenna through the Milky Way. On certain photocopies, the vertical arrows indicate the beginning and the end of the time interval during which the operator noted the presence of a signal by ear. On several of the photocopies the theoretical curves for the signal level with respect to time have also been drawn. On these photocopies a correction of +8 db must be applied to these curves.

The level of the signal received during the transmissions via the Echo II underwent temporal fluctuations. Gradual changes occurred in the signal level, with a typical period of variations of 1-2 minutes. Relatively rapid fluctuations lasting for 3-10 seconds, also occurred. The relative value of the rapid fluctuations varied both from one session to another, as well as during each session. In certain sessions for a limited time period, rapid fluctuations were almost completely lacking. At the same time during the greater part of the sessions, the fluctuation level was considerable and sometimes reached 80-100%.

A comparison of the recorded signal level with the theoretical level was made in certain sectors of selected sessions where the average signal level deviated least from the computed level. The experimental values (P_s/P_N) db were determined from the decibel scales entered on the photocopies, while the computed values for P_s/P_N were determined from the known distances R and R to the Echo II satellite. The results are given in Table II-2 in which the experimental and theoretical values for the corresponding times are listed as well as the difference in decibels between the experimental and computed values for P_s/P_N. The data received from Jodrell Bank on the actual transmitted power has been taken into account.

The data in the table demonstrates that the experimental values for P_S/P_N were below the computed values by an average of about 5 db. From Table II-2 the data for the sessions in which the difference between the experimental and calculated values for P_S/P_N was greater than 6 db have been omitted. This table also does not contain data for those portions of the sessions during which telegraphic transmission was conducted. This is because the average signal level in these sessions would be somewhat lower as a result of the inertia of the automatically recording galvanometer.

The recordings of the signal level were compared with the error curves of the transmitting antenna for tracking the satellite. This comparison shows that the signal level decreased appreciably when the deviations of the antenna position from the program values were sufficiently high. It should also be noted that during passes No. 560 and 568, the transmitting antenna emitted a linearly polarized wave while the receiving antenna was connected for the reception of circularly polarized radiation. As a result, in passes No. 560 and 568, the presence of additional losses of 3 db caused by mismatch between the polarizations of the emitted and the received signal could be expected in comparison with the previous sessions when a circularly polarized wave was emitted. However, Table II-2 makes it evident that these additional losses failed to occur in these sessions.

TABLE II-2. COMPARISON OF CALCULATED SIGNAL LEVEL TO EXPERIMENTAL SIGNAL LEVEL FOR ECHO II EXPERIMENTS

PASS NO.	DATE	TIME (UT)	RECEIVER BANDWIDTH (KC)	EXPERIMENTAL VALUE P_S/P_N (DB)	COMPUTED VALUE, P_S/P_N (DB)	ADDITIONAL LOSSES (DB)
384	23 Feb 64	$14^h52^m40^s$	1	0	5.5	5.5
415	25 Feb 64	23 11 45	1	2.0	6.1	4.1
428	26 Feb 64	22 52 10	1	7.5	12.5	5.0
429	27 Feb 64	00 45 45	1	11.5	14.1	3.0
442	28 Feb 64	00 24 15	1	6.5	10.3	3.8
454	28 Feb 64	22 07 15	5	1.0	6.0	5.0
455	28 Feb 64	23 59 00	5	0	4.5	4.5
462	29 Feb 64	12 21 00	3.5	3.5	7.4	3.9
463	29 Feb 64	14 02 00	3.5	1.0	3.8	2.8
468	29 Feb 64	23 30 10	3.5	4.5	9.4	5.1
476	1 Mar 64	13 45 00	5*	3.0	7.5	4.5
560	7 Mar 64	22 26 30	5	3.5	7.5	4
568	8 Mar 64	12 35 30	5	-1	4.9	5.9

In the period from 22 February to 8 March 1964, ten sessions for transmitting signals via the moon were conducted. In Figures B-34 through B-44 photocopies of typical sectors of the original recordings of the signal for each session are shown. The mean signal level with a receiver bandwidth of 1 kc exceeded the noise level by 4 to 5 db. The signal fluctuated rapidly, with a typical period amounting to several seconds. At the minimums, the signal was almost entirely absent, whereas at the maximums, its level exceeded 10 to 12 db.

Below Table II-3 presents data concerning the average signal intensity during the transmission sessions via the moon.

TABLE II-3

No. of Session	Date	Time Hrs–Mins	Band, f, kc	P_S/P_N (db)	P_S/P_N for receiver band f = 1 kc	Remarks
1	22 Feb 64	1348-1354	1	1 to 2	1 to 2	
2-a	23 Feb 64	1534-1540	1	4 to 5	4 to 5	Counter-clockwise polarization
2-b	23 Feb 64	1547-1552	1	5	5	"
3	26 Feb 64	1627-1634	1	2	2	Teletype
4	27 Feb 64	2245-2252	1	5 to 6	5 to 6	
5	28 Feb 64	2127-2134	5	-1 to 0	6 to 7	
6	29 Feb 64	2349-2355	5	-2 to -1	5 to 6	
7	1 Mar 64	2226-2232	1	-4 to -3	-4 to -3	
8	2-3 Mar 64	2359-0005	5	-3 to -2	4 to 5	
9	3 Mar 64	2349-2355	1	2 to 3	2 to 3	
10	8 Mar 64	0628-0634	1	5	5	Transmitter antenna linearly polarized

The highest signal level was recorded in sessions No. 2, 4, 5, 6, 8 and 10 when it was of the order of 5 to 6 db. In sessions No. 1, 3 and 9, the signal level was somewhat lower amounting to 1 to 3 db: An exception was session No. 7 on 1 March 1964 when the signal level was 8 to 10 db below average. During session No. 2 on Feb. 23, 1964 up to 1540 hrs UT, the receiving antenna was connected for the reception of signals with counterclockwise polarization. At 15.46.25 UT the polarization in the antenna was switched and from that time it picked up signals with clockwise polarization. Pertinent segments of the signal recording are given in Figures B-34 and B-35 and show the mean signal levels in both cases to be practically the same.

In session No. 10 on March 8 according to the report received, the transmitting antenna emitted a linearly-polarized wave, whereas the receiving antenna was connected to receive a circularly polarized wave. As a result, in session No. 10 additional 3 db losses in the signal level could be expected. There was, however, no appreciable weakening in the mean signal level during this session. These results indicate that a mismatch between the polarizations of the transmitted and the received signals could have taken place during the entire experiment. As a result there could have been unforeseen losses of 3 db in the communication lines via the Echo II and the moon.

3.4 CARRIER WAVE SINGLE TONE MODULATION TESTS

During 3 sessions of the transmissions via the Echo II, reception of a carrier wave modulated in amplitude by a 400 cps tone was conducted. The pass band of the receiver equalled 1 kc. At the detector output it was possible to install a filter with a 50 cps band pass which could be tuned to a frequency of 400 cps. This could have improved the ratio of the signal (with 400 cps frequency) to the noise significantly.

On the attached magnetic tape, there is a segment of a recording of the 400 cps tone, obtained without use of a narrow-band filter on pass No. 410 (1349-1405 hrs UT), on 25 February for the period 1356-1400 hrs UT. On the tape, time markers at 1 minute intervals were recorded. The 400 cps tone was recorded at a tape speed of 381 mm/sec (15 ips). On pass No. 402 on Feb. 24 (2336-2352 hrs UT), the 400 cps tone was also audible at receiver band width of 1 kc. During pass No. 436 on Feb. 27 (1301-1314 hrs UT), the signal level was so low that the type of modulation could not be established.

Photocopies of recordings of the signal levels of sessions with the 400 cps tone are shown in the supplement. (Figures B-9 and B-10).

3.5 DECELERATED SPEECH TRANSMISSION

During six sessions, a test was conducted using speech that was decelerated by 8 times the normal rate: (during 5 sessions via the Echo II and 1 session via the moon). The frequency pass band of the receiver during these sessions was 1 kc. Signals from the detector stage were recorded on magnetic tape then on replaying were reproduced at a speed 8 times greater than during recording. The frequency characteristic of the recording channel was essentially level over the frequency range from 30 to 10,000 cps. During the playback, the frequency band pass of the signal and noise was limited to those frequencies below 3.5 kc in order to improve the signal/noise ratio.

During the communication sessions, a meaningful text was transmitted in English and Russian. Because the signal/noise ratio was too low the speech could be understood only at the limit of intelligibility. By listening to the tape recordings (sometimes many times), it was possible to understand almost all of the transmitted messages.

On the attached tape recording, we have given a sample of the recording of a message transmitted in English during pass No. 428 via the Echo II on Feb. 26 (2247-2300 hrs UT). The speech recording has been restored, i. e., accelerated to 8 times the recorded speed. For the playback, the tape speed was 381 mm/sec. The tape also contained time markers one minute apart. The text of the message that was received is: "This is Jodrell Bank England calling Zimenki to assentor via Echo II satellite. This is Jodrell Bank calling Zimenki via Echo II satellite." A similar text was transmitted on pass No. 429 via the Echo II on 27 Feb. (0037-0054 hrs UT). On the same tape, a sample of a recording of speech transmission in session No. 4 via the moon on 27 Feb. (2240 UT) is recorded. On pass 441 via Echo II on 27 Feb. (2221-2236 hrs UT) and on pass No. 442 via Echo II on 28 Feb. (0014-0029 hrs UT) the same test used on pass No. 441 was also transmitted in Russian. Based on the results of these three sessions, it was possible to identify individual words of the transmitted text. A sample recording of this message on pass No. 442 via the Echo II is also given on the attached tape. In a segment of the tape recording of the speech during transmission via the moon in session No. 4 on 27 Feb. there is also given a recording of decelerated speech, received with receiver pass band of 6 kc. Because of the low signal/noise ratio, it is impossible to comprehend the text of the transmitted message.

At the beginning of each segment of recording of restored speech on the attached magnetic tape, appropriate explanations are given in Russian, permitting one to establish the proper sequence of the recordings.

3.6 TELEGRAPHY TRANSMISSION

During the experiments, telegraph messages were transmitted six times via the Echo II and four times via the moon. In the first sessions of the transmission, a five character code was sent at a speed of 50 bauds, while the received signals were recorded by the use of a telegraphic printout device. In the last sessions, the transmission was in Morse Code at a rate of 60-70 characters per minute. Reception was both by ear and with the aid of an undulator.

During the telegraphic sessions, the receiver frequency bandpass was 1 kc. To raise the signal/noise ratio, attempts were made to narrow the bandpass to 300-120 cps by cutting in narrow-band filters.

In Figure B-11 there is presented a photocopy of the signal level on pass No. 415 via the Echo II on 25 Feb. (2311-2325 hrs UT). During this pass groups of letters and groups of numbers were transmitted. Certain correctly received letter combinations are underlined as is shown in Figure II-12. In this session, the receiver's frequency pass band was 300 cps.

For comparison in Figure II-13 there is shown a photocopy of a segment of teletype printout recorded during communication via the moon (session No. 3 on 26 Feb. at 1610 hrs UT). Groups of letters and groups of numbers were sent during this session also. Certain correctly received combinations of transmitted letters and numbers are underscored in Figure II-13. The relative number of properly received symbols during this session is somewhat higher than in Figure II-12. During transmission via the moon, a 300 cps receiver pass band was used.

During pass No. 423 via the Echo II on 26 Feb. (1324-1338 hrs UT), the nature of the teletype printout was similar to that shown in Figure II-13. During session No. 7 via the moon on 1 March (2100 hrs UT), the received signal was below the level of characteristic noise and the teletype printed a random set of numbers and letters.

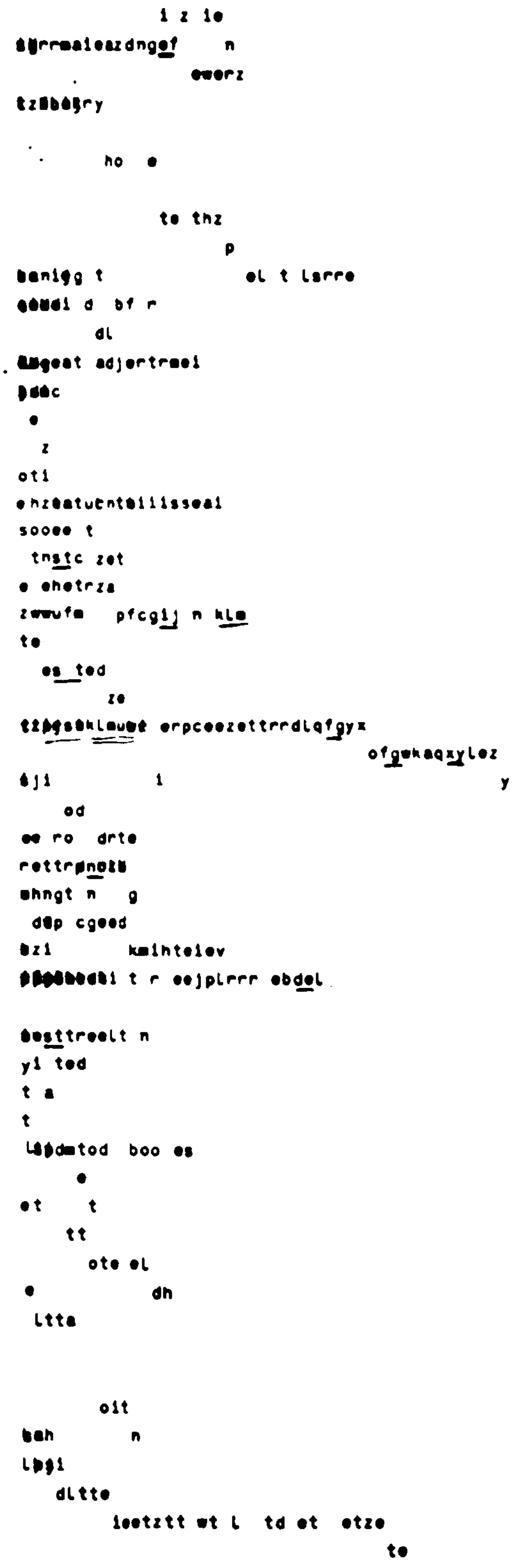

Figure II-12

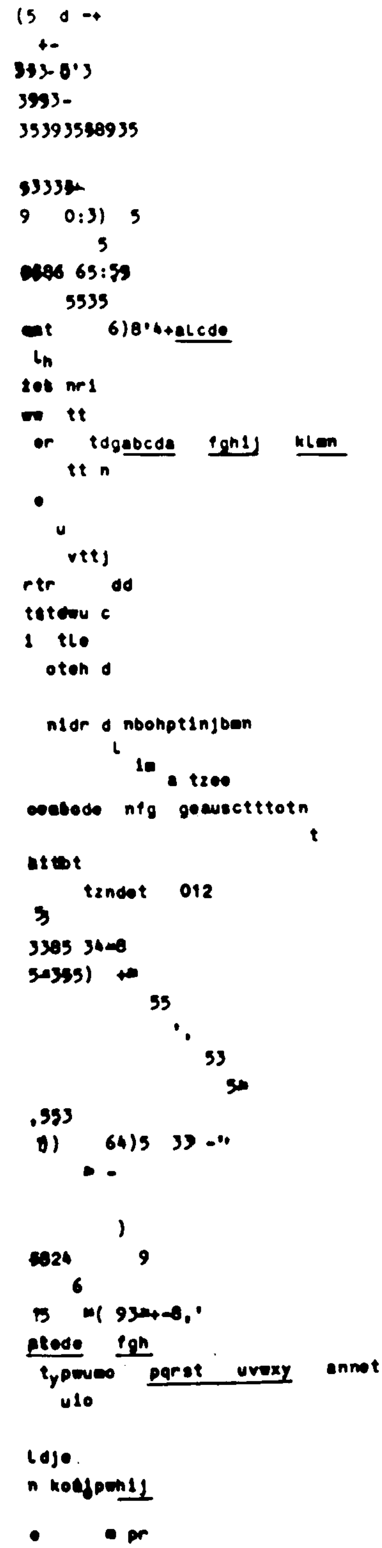

Figure II-13

In session No. 8 via the moon on 2 March (2300 hrs UT), the teletype signals were received using a narrow-band filter with band width of 120 cps. Not withstanding the relatively low level of the received signal, there were established several correct combinations of the letters in the transmitted message. A photocopy of the segment of teletype printout for the pertinent session is shown in Figure II-14.

In all the teletype sessions via the Echo II and the moon, the average signal level was insufficient for stable functioning of the teletype device, and, therefore, it printed chiefly random letters and numbers. Only at isolated periods of time when the signal level rose appreciably as a result of fading were the correct combinations of letters and individual words of the meaningful text printed on the type.

On passes No. 502 and 507 via the Echo II on 3 Mar. (1240-1300 hrs UT and 2208-2222 UT) telegraphic signals sent in Morse Code at a rate of 100 per min were received. The intelligibility of the transmitted message during reception by ear was decreased because the intervals between individual letters were too short. After repeated monitoring of a tape recording of the transmitted message, it was possible to understand all the transmitted text: "Jodrell Bank calling Zimenki Greetings to our Russian colleagues from Davies and the staff at Jodrell Bank." Oral reception and tape recording were conducted at a receiver pass band width of 1 kc. During session No. 9 via the moon on 4 Mar. (0000 hrs UT), in the first half of the session, the telegraphic signals sent in Morse Code at 100 characters per minute, were received by amplitude modulation of the carrier wave. The same text was sent as in the previous sessions.

In the second half of the session, in order to decrease the transmission speed and to space out the interval between the symbols being sent, transmission was conducted by amplitude modulation of the subcarrier frequency of 980 cps. Reception during the second half of the session was better than the first half in spite of the fact that from an engineering viewpoint, transmission using modulation of the subcarrier is less advantageous than the direct modulation of the carrier.

On pass No. 555 via the Echo II on 7 Mar. (1257-1312 hrs UT), telegraph signals transmitted in Morse Code at 60-70 characters per min were received. The width of the receiver pass band during oral reception was 1 kc. It was possible to receive immediately by ear all of the text that was repeated many times. The text was identical to the one sent in the sessions via the Echo II on 3 March. Concurrent with

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Figure II-14

the oral reception, the signal was recorded through a filter with a band width of 120 cps with the aid of an undulator. A photocopy of the recorded segment of the transmitted telegraphic report is shown in Figures II-15 and II-16.

During pass No. 559 via the Echo II on 7 Mar. (2029-2041 hrs UT) a telegraph message sent in Morse Code was received. The following message was received orally at receiver pass band width of 1 kc: "Jodrell Bank transmitting to Zimenki on 162.4 mc/s via Echo II satellite Power one kilowatt gain 40 decibels time 2036."

3.7 FACSIMILE EXPERIMENT

Photostat copies of the received facsimile images are shown in Figures II-17 to II-25. Reception of the images was accomplished using a receiver pass band width of 5 kc. In Figure II-17 a copy of an image used on pass No. 454 via the Echo II on 28 Feb. (2157-2209 hrs UT) is shown. A faint, slightly inclined broad line is perceptible. To the left of it several other finer details can be possibly seen. The horizontal lines are the minute time markers.

A photostat of the image for pass No. 455 from 28-29 Feb. (2347-0005 hrs UT) is shown in Figure II-18. The word "JOD" within the figure resembling the letter "M" (actually this was the symbolic image of the antenna), and certain finer details in the right hand part of the photo can be distinguished. The minute markers are also clearly discernible in the photostat.

In Figure II-19 a photostat of the image received on pass No. 468 via the Echo II on 29 Feb. (2322-2339 hrs UT) is shown. The portrayal of the word "MNP" framed by an arc of the circle depicting the world is relatively clear. This image was processed when the incoming signal was relatively strong. In the right part of the photo, the vertical matching band is visible.

A copy of the image received in session No. 6 during a transmission via the moon on 1 Mar. (0000 hrs UT) is shown in Figure II-20. The image is the same as those sent in the previous session via the Echo II. Since the signal was bounced off the moon which was moving very slowly a great number of details can be seen in the photo than in the session via Echo II in spite of the poor contrast of the image. The word "Echo" and to the left and right the words "JOD" and 3 NM can be seen in the upper part of the photo.

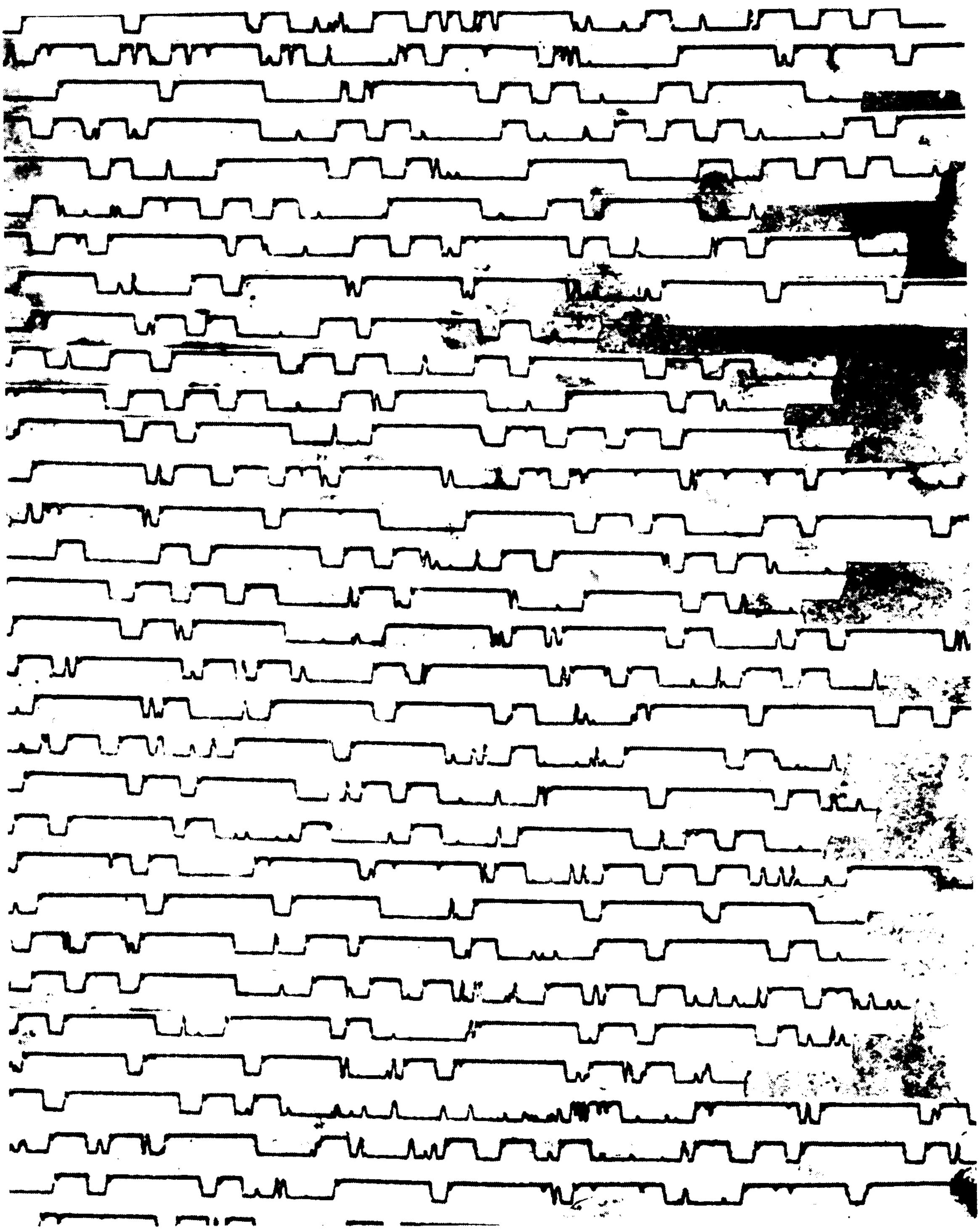

Figure II-15

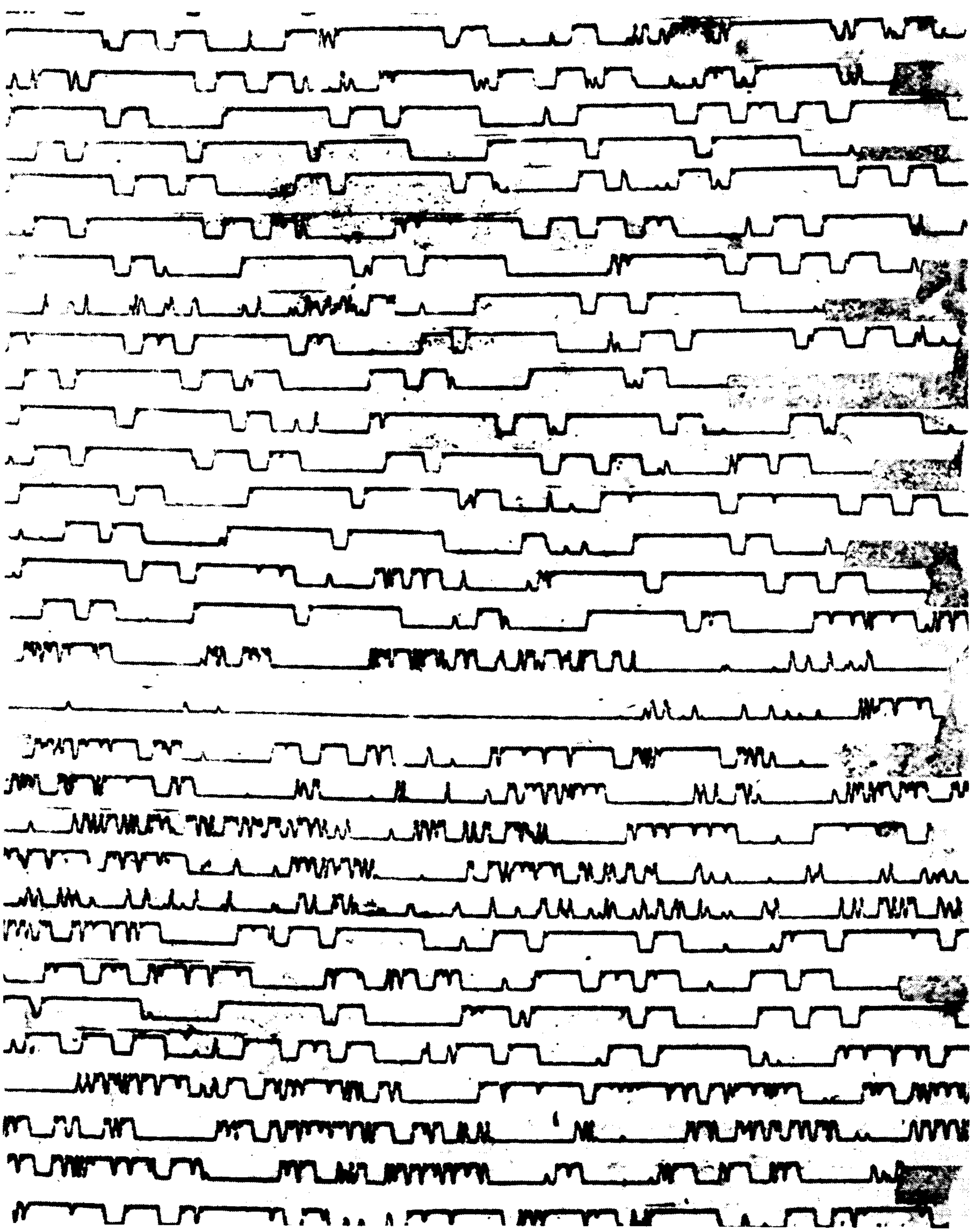

Figure II-16

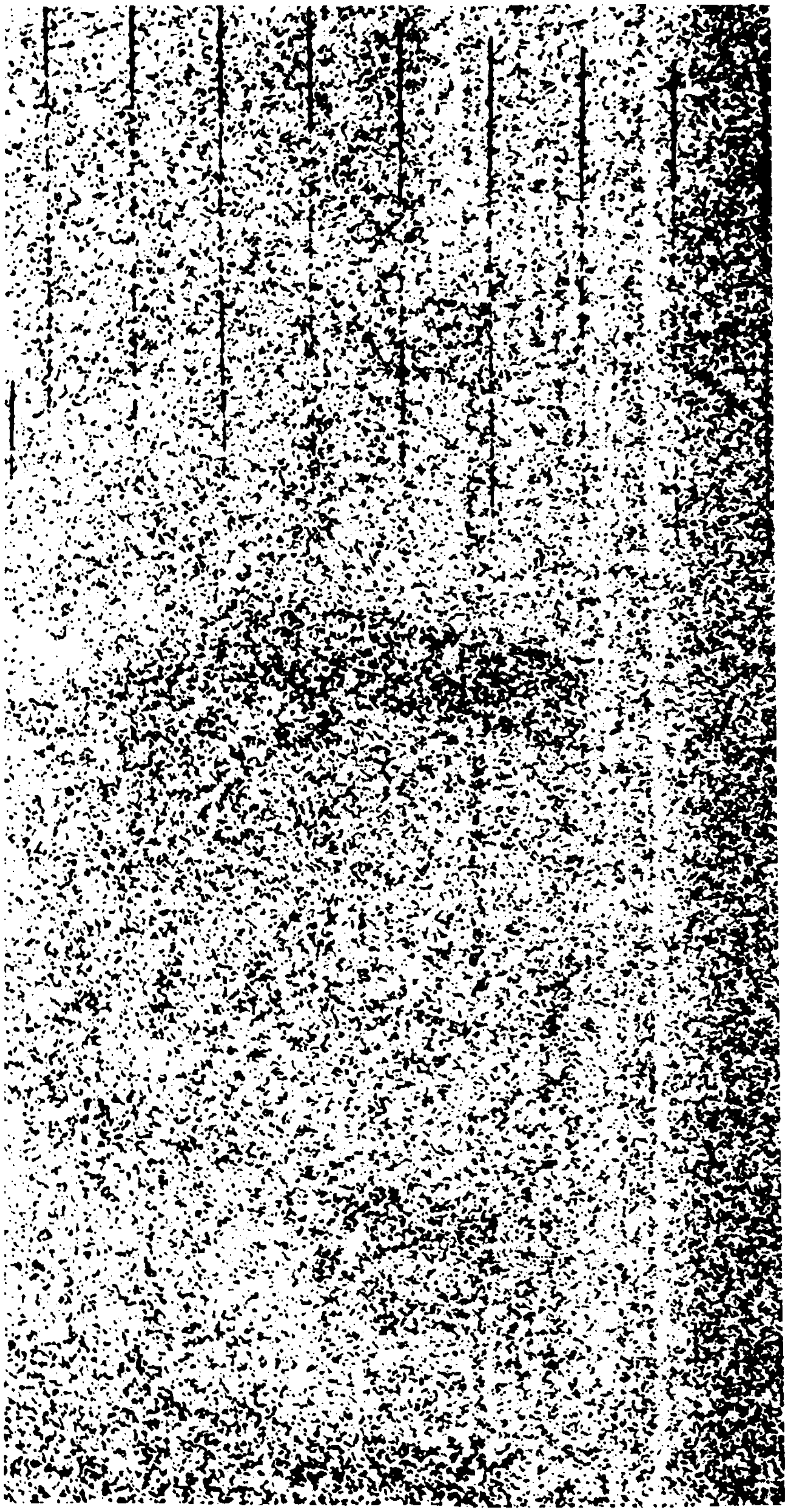

Figure II-17

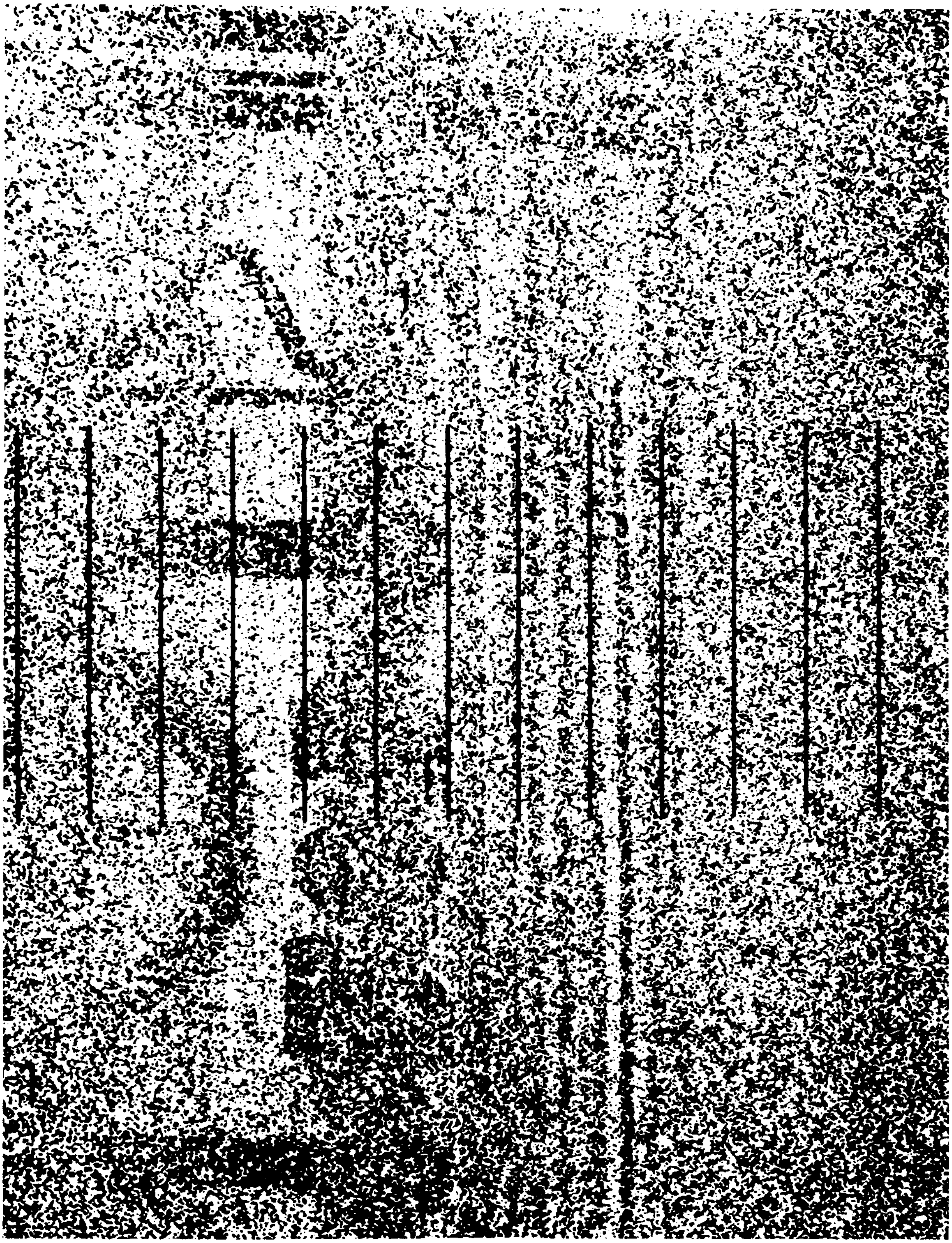

Figure II-18

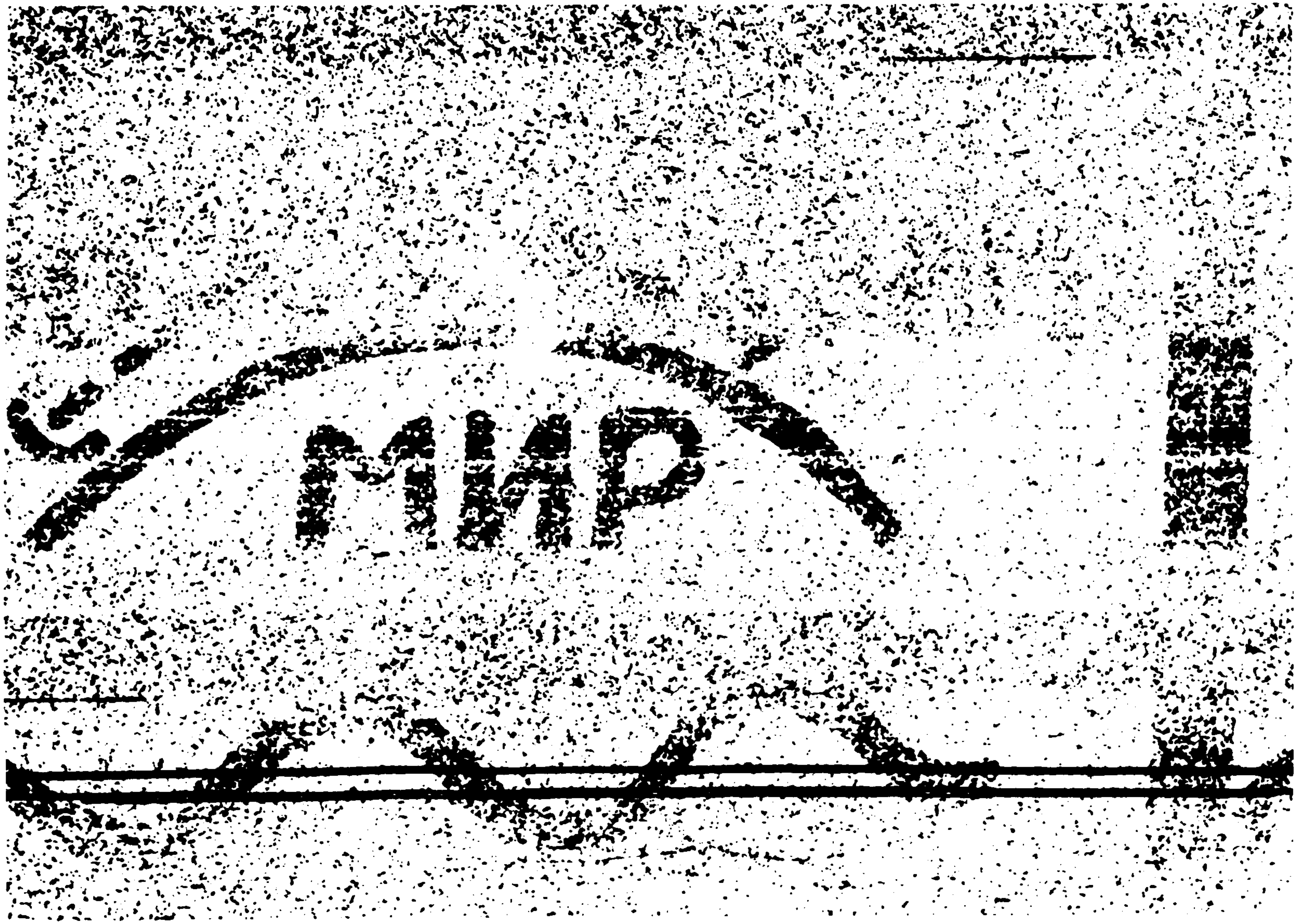

Figure II-19

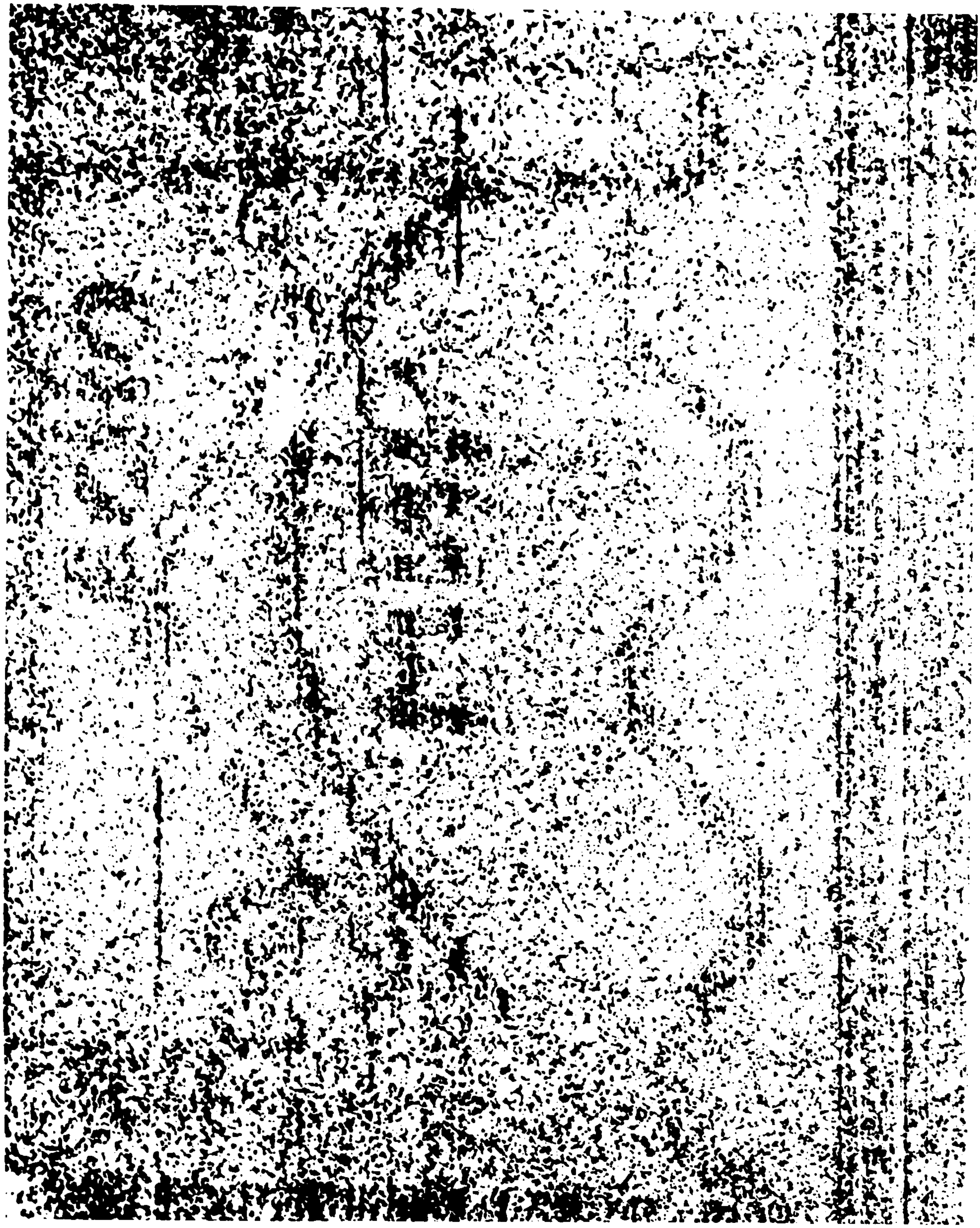

Figure II-20

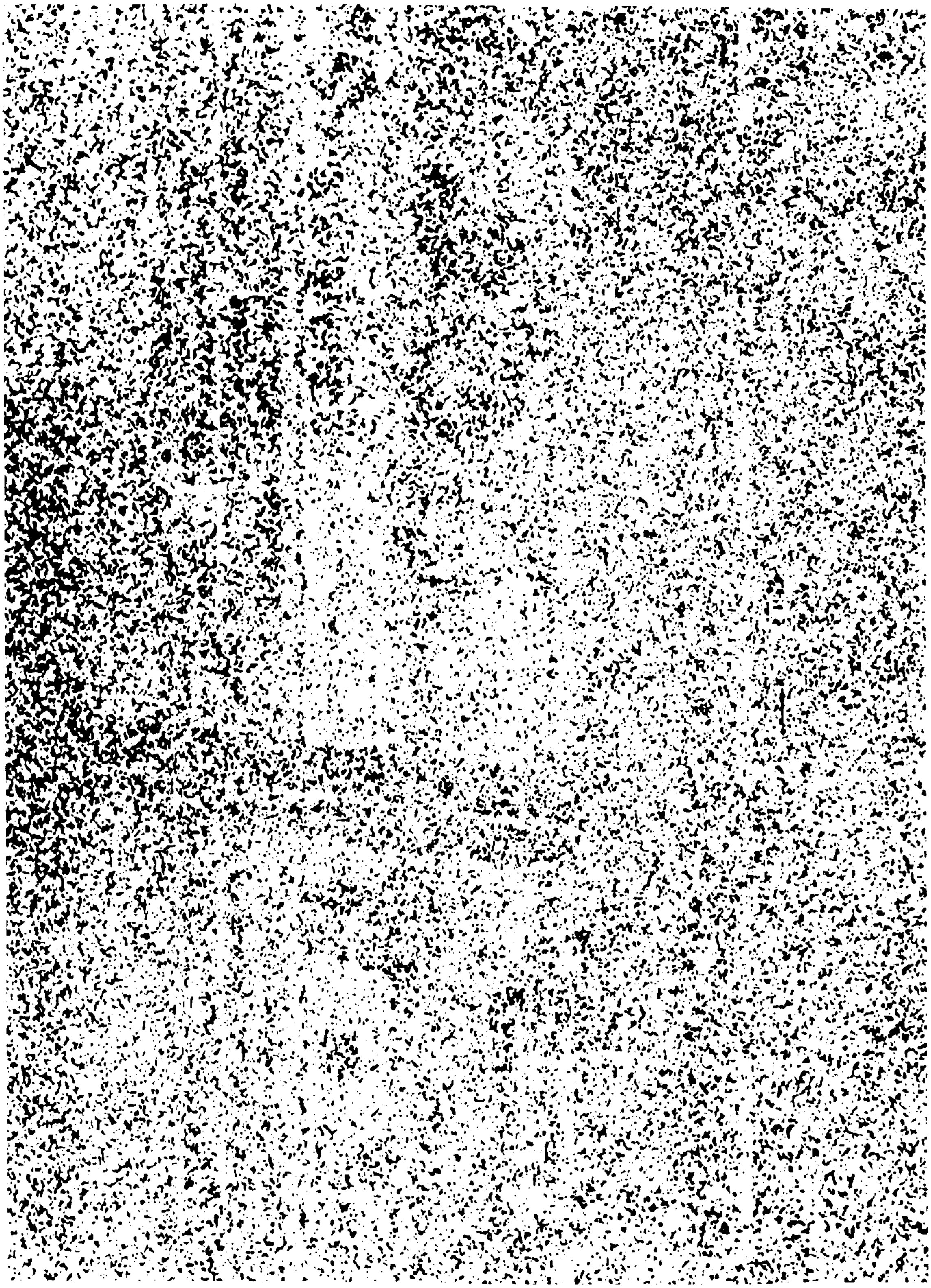

Figure II-21

Figure II-22

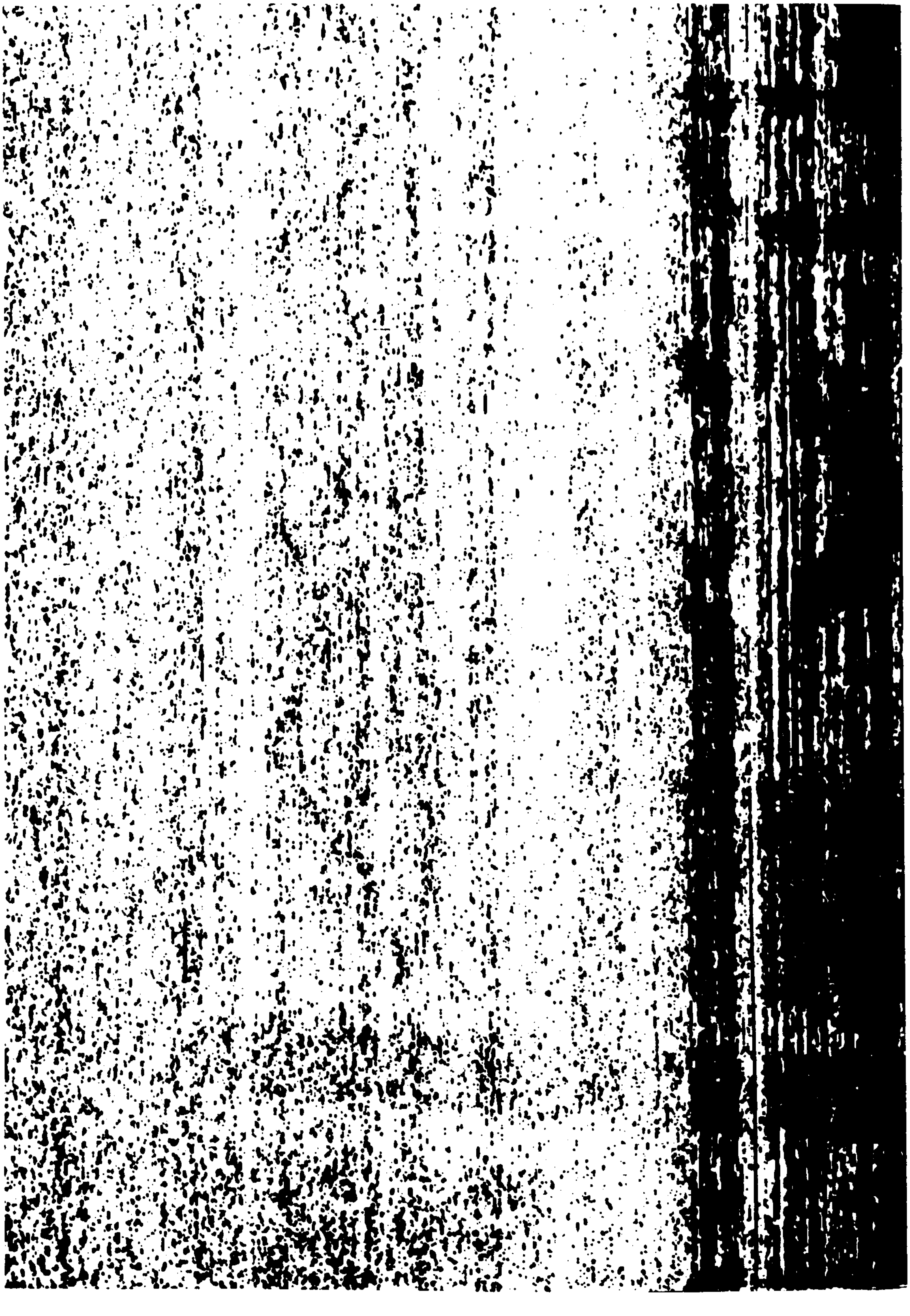

Figure II-23

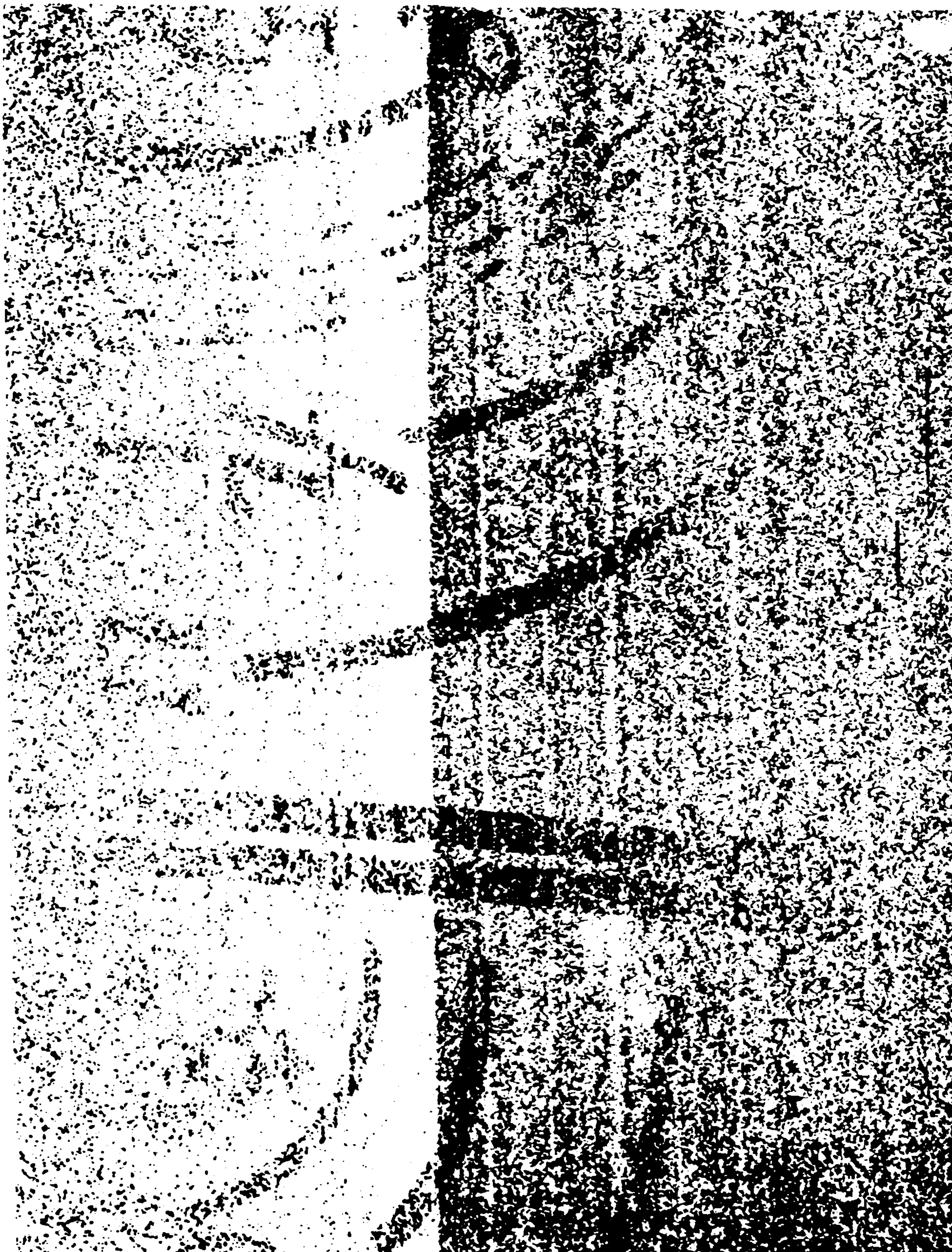

Figure II-24

Figure II-25

In Figure II-21 a copy of the image received on pass No. 476 via Echo II on 1 Mar. (1335-1350 hrs UT) is seen. To the left of the vertical (slightly inclined) matching line, the numbers 368 are barely discernible.

A photostat of the image for pass No. 494 on 2 Mar. (2234-2249 hrs UT) is seen in Figure II-22. To the right of the wide vertical matching (joining) line, the faint image of a cube and certain other details are visible.

In Figure II-23 a photostat of an image sent in session No. 8 via the moon on 2 Mar. (2340 hrs UT) is shown. Because communication with Jodrell Bank was lacking at the beginning of the session there was a delay in switching on the facsimile equipment. In the upper part of the photograph, the image is visible; in the greater part of photograph the image is absent. In all probability this is associated with the decrease in the mean signal level to zero db during the second half of the session. In this session a narrow-band filter (120 cps), tuned to the "white" frequency (1500 cps) was used during the recording.

In Figure II-24 a photostat of the image sent during pass No. 560 via the Echo II on Mar. 7 (2220-2236 hrs UT) is shown. Because of unsuccessful synchronization, the vertical joining line divides the photo-image into two parts. The distinct horizontal margin on the photographic image appeared as a result of the intentional change in the operating conditions of the facsimile receiving equipment. In the photograph, there is an image of the orbits and the symbols for the planets in the solar system, as well as dashed tracings of the orbits of the asteroid belt.

A photostat of the image sent via the Echo II on pass No. 568 on 8 Mar. (1233-1247 hrs UT) is shown in Figure II-25. The same image was sent as in the previous session via the Echo II.

During passes No. 462 and 463 via the Echo II on 29 Feb., an effort was made to obtain a facsimile image using a receiver pass band of 3.5 kc. The images were not received. The recordings of the signal levels during the transmission of the facsimile images are presented in the appropriate photostat copies (Figures B-22 and B-23).

3.8 SOVIET CONCLUSIONS

The communication experiments conducted via the Echo II demonstrated that the mean level of the incoming signal did not reach the theoretical value. However, in individual portions of certain sessions, the signal level was only 3 to 5 db below the theoretical level. Losses of 3 db in the communication line can probably be attributed to the mismatch between the polarizations of the transmitted and the received signal. If this hypothesis is correct, discrepancies in the individual portions of certain sessions do not exceed 1 to 2 db. This falls within the limit of the measurement accuracy. In light of the above considerations, it can be said that the dispersion diameter of the Echo II did not differ appreciably from that which was computed.

The signal level was subject to considerable fluctuations. The presence of relatively slow fluctuations in the signal level (with a typical period of 1 to 2 minutes) can be associated both with the extent to which the satellite's surface differed from being spherical, and with the errors involved in tracking the satellite. The rapid fluctuations in the signal level (with a typical period of 3-10 seconds) can be evoked by the presence, (roughness) on the satellite's surface. The dimensions of this roughness would be much less than the radius of the satellite. The received signal level determined the nature of the functioning of the terminal communication equipment (teletype phototelegraph, and tape recorder-during the speech transmission). Rapid and extensive fluctuations in the signal level made the operation of the teletype and the speech recording equipment particularly difficult.

BIBLIOGRAPHY

1. Akim, E. L., and Eneyev, T. M., Space Research (Kosmich. Issled.), Vol. 1, No. 1, 1963. (Translator's Note: Translation of this report available from Code ATSS-T).

2. Lance, G. N., Numerical Methods for High Speed Computers. 1960.

3. Sochilina, A. S., Bulletin of Institute on Theoretical Astronomy of USSR Acad. Sci., Vol. 8, No. 2 (95), 1961.

4. Astapovich, I. S., and Kaplan, S. A., Visual Observations of Artificial Earth Satellites (Vizual' Nyye nablyudeniya iskusstvennykh sputnikov Zemli).

III. EVALUATION OF EXPERIMENT RESULTS

1.0 GENERAL

The following analysis of the experiment results are based on data supplied by the British and the Soviets in their individual reports on the experiments. Assistance to the Echo Project Office in this analysis was provided by Mr. Abe Kampinsky of the Communications Research Branch at Goddard Space Flight Center (see Appendix D) and Collins Radio Company.

Although there is some detailed technical information lacking in certain areas (primarily in the British report) it is believed that there is adequate data to substantiate the following analysis and conclusions:

2.0 RECEIVED SIGNAL EXPERIMENTS

The signal received at Zimenki was characterized by extreme fluctuations and low signal to noise ratios. While some scintillations can be attributed to the satellite, fluctuations of the order recorded at Zimenki are somewhat in excess of those noted in any of the GSFC Project experiments, including those that were conducted at much higher frequencies where greater scintillations would be expected.

These signal fluctuations or scintillations can be attributed to one or more of the following:

a. Transmitting terminal

b. Transmission media

c. Receiving terminal

d. Satellite irregularities

The comments which follow relate these sources to the UK-USSR experiments.

2.1 TRANSMITTING TERMINAL

As previously indicated, very little information concerning the transmitting terminal at Jodrell Bank was supplied by the British. Nevertheless it can be concluded that most of the observed signal fluctuations were due to antenna pointing errors incurred at the Jodrell Bank facility.

Figure III-1 illustrates the accuracy with which the Jodrell Bank antenna was pointed relative to the predictions for pass 489, which represents an average pass. Table III-1 summarizes the relative pointing accuracy for all of the passes. The half-power beamwidth of the Jodrell Bank antenna is between 1.7° and 2.0°; i.e., a pointing error of approximately 1° results in a 3 to 4 db reduction in the received signal strength. A comparison of the recordings of the level of the incoming signal with the tracking error curves, shows that in a number of cases when the deviations of the antenna position from the programmed values were sufficiently high, the level of the signal being received decreased appreciably.

It should be emphasized that the pointing accuracies shown in Table III-1 are relative to the predicted trajectories, not to the actual trajectories of the Echo II satellite. Therefore, additional reduction in the received signal strength could have been caused by the errors between the predicted trajectories and the actual trajectories. This might account for the fact that little or no signal was received in some of the passes. There is no indication that any attempt was made to check the pointing of the Jodrell Bank antenna relative to the satellite, such as by a boresight camera. Therefore, the error between the predicted and the actual trajectories can only be estimated with the aid of calculated trajectories based upon measured data from the GSFC Minitrack Net for the passes under consideration. For illustration purposes, Figures III-2 and III-3 show the variation of error in the Echo II predictions that GSFC supplied the Collins Dallas facility for 2 different weeks during the communications experiments conducted by GSFC (See Appendix C). These predictions are made on a weekly basis. Figure III-2 illustrates the best set of predictions received to date, whereas Figure III-3 represents a "worst-case" set of predictions and is included to indicate an upper limit for the errors.

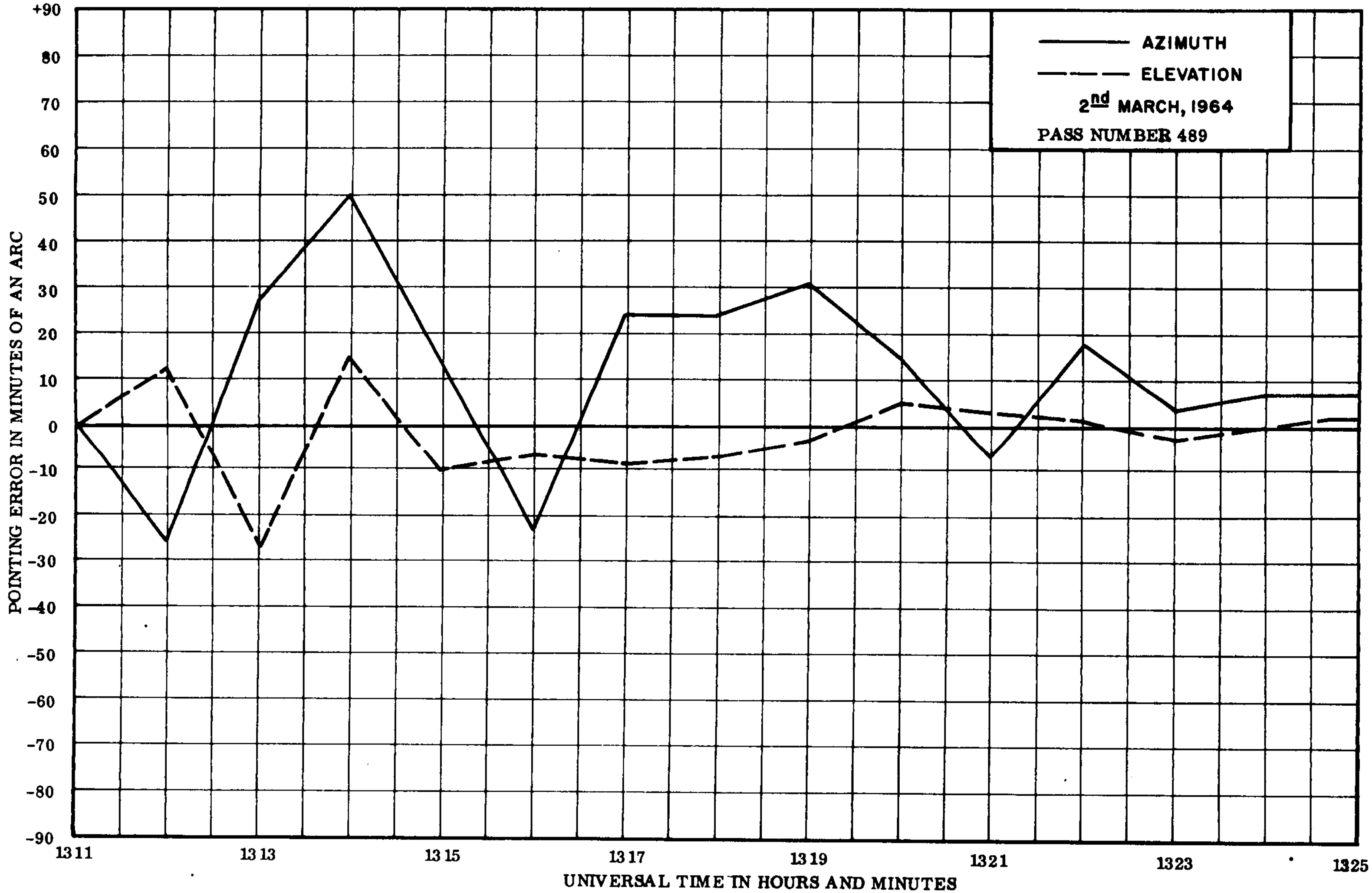

Figure III-1. Point of Jodrell Bank Antenna Relative to Predictions for Echo II Pass 489

TABLE III-1. POINTING OF JODRELL BANK ANTENNA RELATIVE TO PREDICTIONS FOR ECHO II EXPERIMENTS*

PASS NO.	AZIMUTH AVG.	AZIMUTH 66%**	AZIMUTH PEAK-TO-PEAK	ELEVATION AVG.	ELEVATION 66%**	ELEVATION PEAK-TO-PEAK
362	0.140°	0.283°	1.967°	0.023°	0.050°	0.217°
363	-0.004°	0.550°	4.233°	-0.033°	0.150°	0.633°
370	-0.055°	0.133°	0.367°	-0.012°	0.050°	0.167°
384	0.241°	0.867°	3.050°	0.098°	0.317°	1.400°
388	-0.013°	0.417°	1.750°	-0.577°	0.217°	1.683°
397	-0.561°	0.633°	2.067°	0.068°	0.250°	0.667°
402	0.118°	0.233°	1.650°	0.004°	0.067°	0.333°
410	0.178°	0.533°	2.983°	0.046°	0.067°	0.350°
415	-0.031°	0.117°	1.117°	0.018°	0.050°	0.200°
423	0.194°	0.300°	0.933°	-0.006°	0.067°	0.283°
428	-0.118°	0.233°	0.933°	0.015°	0.067°	0.233°
429	0.171°	0.217°	1.417°	0.050°	0.200°	0.717°
436	0.227°	0.117°	1.300°	0.005°	0.017°	0.100°
441	0.114°	0.100°	0.333°	0.004°	0.050°	0.267°
442	-0.088°	0.267°	1.900°	-0.009°	0.067°	0.250°
449	-0.012°	0.083°	0.467°	0.014°	0.017°	0.100°
454	0.095°	0.067°	0.600°	-0.001°	0.017°	0.083°
455	-0.009°	0.033°	0.867°	-0.014°	0.083°	0.467°
462	-0.075°	0.117°	0.333°	-0.016°	0.033°	0.200°
468	-0.264°	0.283°	2.067°	0.0133°	0.067°	0.367°
476	0.055°	0.150°	0.483°	0.022°	0.050°	0.250°
489	0.193°	0.400°	1.030°	-0.031°	0.133°	0.700°
494	-0.662°	0.667°	2.417°	0.003°	0.017°	0.117°
507	0,671°	0,283°	1,150°	0.000°	0.050°	0.250°
541	0,073°	0.200°	0.767°	-0.027°	0.067°	0.217°
555	-0.122°	0.450°	2.333°	0.182°	0.183°	1.150°
559	0.030°	0.517°	1.283°	-0.003°	0.017°	0.133°
560	0.073°	0.133°	0.617°	0.014°	0.033°	0.633°
568	-0.029°	0.300°	1.050°	0.022°	0.117°	0.517°

*Based on 1-minute sample of angular readouts during the pass.

**Sixty-six percent of the data points during the pass were less than the value shown.

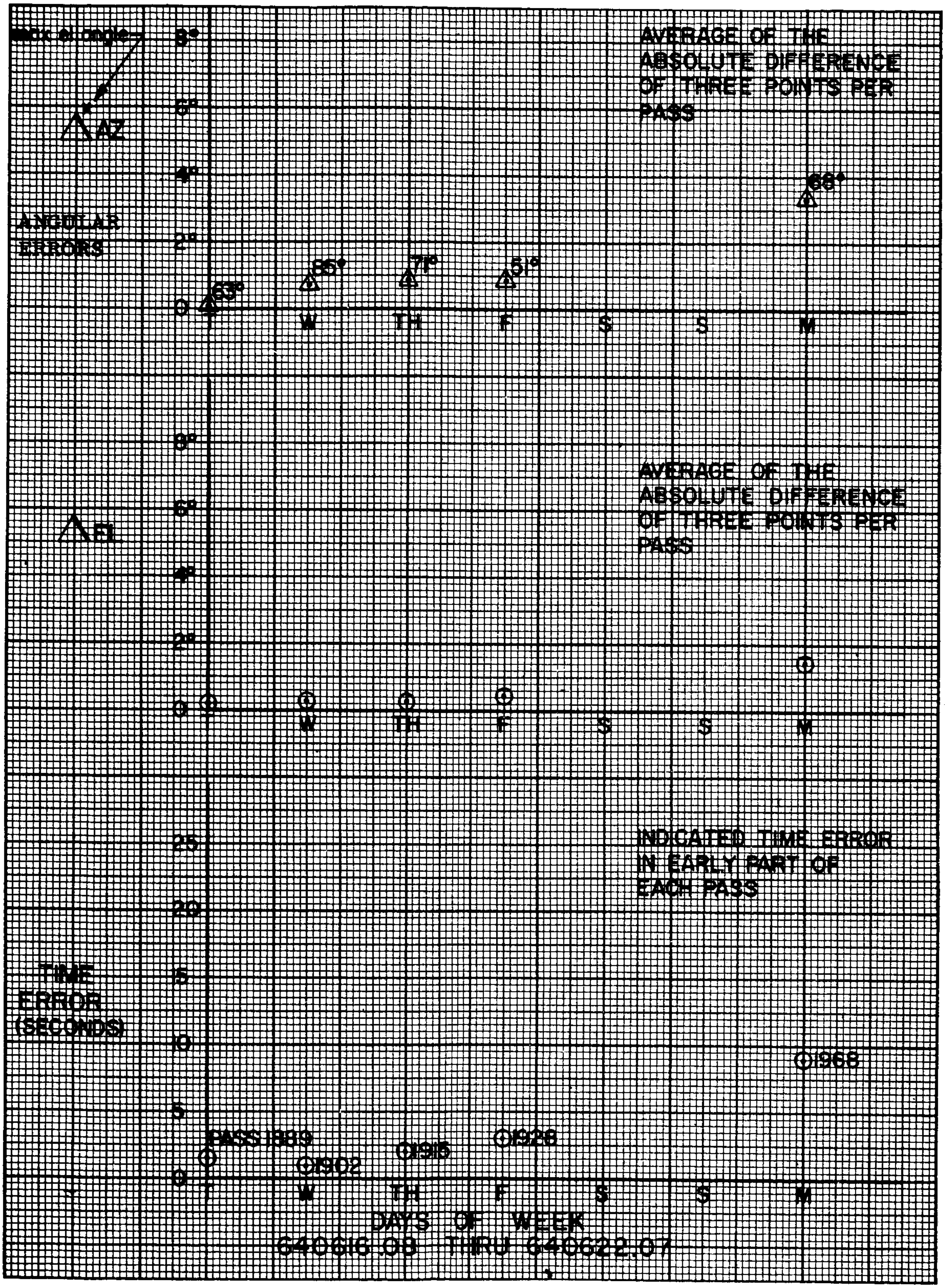

Figure III-2. Best-Case Predictions for Echo II Satellite

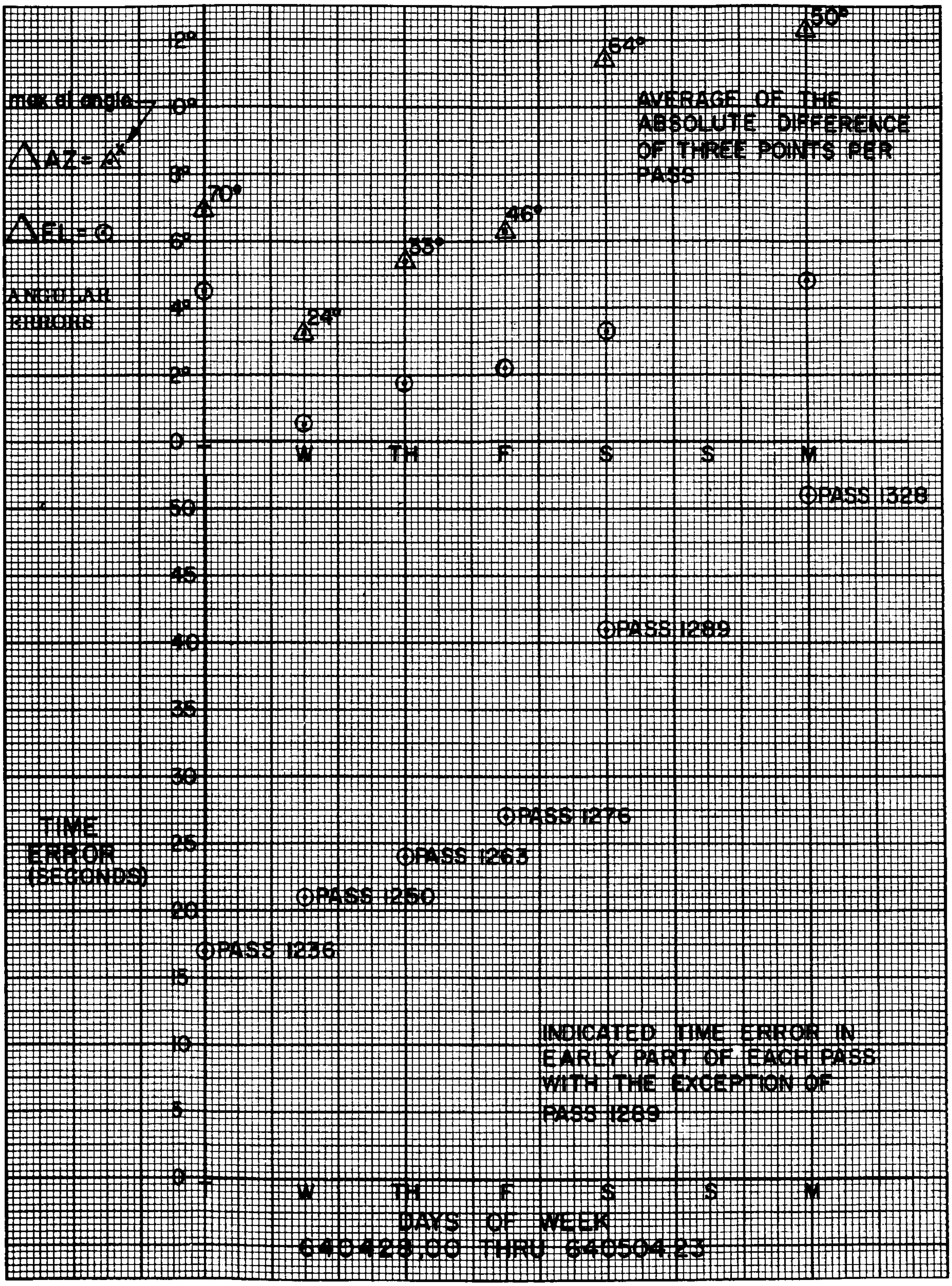

Figure III-3. Worst-Case Predictions for Echo II Satellite

The error is primarily that of time, which is typically within 3 to 6 seconds on the day after the predictions have been made. This time error gradually increases with time until 1 week after the predictions have been forecast; the time error usually has increased up to 30 seconds. Figure III-2 and III-3 also illustrate the approximate magnitude of angular error that accompanies the time errors. The actual angular error may be smaller or larger depending upon the elevation angle of the satellite relative to the tracking station.

Accurate pointing of the Collins Radio Company 60-foot antenna, which has a 1° beamwidth at 2380 mc, is achieved by radar tracking of the satellite. A boresight camera is utilized to photograph the satellite and to determine the tracking accuracy of the antenna relative to the satellite. Based upon the boresight film data, the average tracking accuracy is 0.025° rms. As a final proof, the post-facto predictions furnished by GSFC from actual pointing data from the Minitrack network agree with the Collins tracking data to within 3 to 5 seconds.

It is reasonable to assume that the difference between the predicted trajectories that GSFC furnished Jodrell Bank and the actual trajectories were of the same magnitude as those shown in Figure III-2 and III-3. If so it is possible that strict adherence to the predictions on occasion could result in failure to sufficiently illuminate the satellite. This may help to account for the signal traces in Figures B-1 through B-7. This possibility has been demonstrated by the Naval Research Laboratory (NRL), which is conducting experiments with Echo II along with Collins. Toward the end of a set of weekly predictions, the NRL 60-foot antenna, which utilizes a digital tape programmer with 2-second interval spacing between the pointing commands, is unable to receive a signal from the Echo II satellite when only predictions are used for pointing the antenna. Usually, the NRL programmed antenna pointing is supplemented by peaking on the received signal or, when conditions permit, by using a boresight telescope to determine the proper pointing bias.

Variations in the total power output, and transmitter frequency shifts can be other sources of signal fluctuations caused at the transmitter terminal. However, there is no way to technically evaluate this possibility since the only information supplied by the British regarding these parameters is as follows:

> "The power quoted is as measured on a power meter in the transmitter."

2.2 TRANSMISSION MEDIA

Refraction effects caused by the atmosphere and the ionosphere could have been another source of errors in antenna pointing at the transmitting terminal.

Figure III-4 illustrates typical refraction errors as a function of elevation angle for low elevation angles. The actual refraction error varies with the percent of humidity (an increase of approximately 1.5 times from 0 to 100 percent), number of sun spots, and time of day (typical increase of 2.7 times from nighttime to daytime). Furthermore, fluctuations during relatively short time periods often occur. The maximum elevation angle at the Jodrell Bank facility was less than 17° for at least 50% of the passes. As a result, refraction effects caused by the atmosphere and ionosphere could contribute to the scintillations.

For low elevation angles, the same refraction error considerations that apply to the transmitting antenna, apply to the receiving antenna. Although Table II-1 indicates that the elevation angles at the Zimenki facility were considerably larger than those at the Jodrell Bank facility, it should be noted that the Zimenki antenna half-power bandwidth at 162.4 mc is 9°. This can give rise to large signal fluctuations at low elevation angles because of ground reflections. This effect is much greater at low elevation angles than the refraction error effect. Significant signal fluctuations caused by ground reflections can be expected at Zimenki for elevation angles of 10° or less if the surrounding terrain is flat. If the surrounding terrain is not flat, and if there are numerous buildings, antenna arrays, etc., in the area, this situation will of course be aggravated.

It is concluded that at least some of the signal fluctuations for the lower elevation angle portions of the passes can be attributed to this cause.

2.3 RECEIVING TERMINAL

The possibility that a part of the observed signal fluctuations were caused by the receiving terminal at Zimenki was also considered. Although a drive tape and programmer system was used by the Soviets, it is doubtful that tracking errors at the receiving terminal significantly contributed to the scintillation. This is because the Zimenki facility made new predictions daily, which should have provided a higher degree of accuracy than weekly predictions. The pointing of the Zimenki antenna

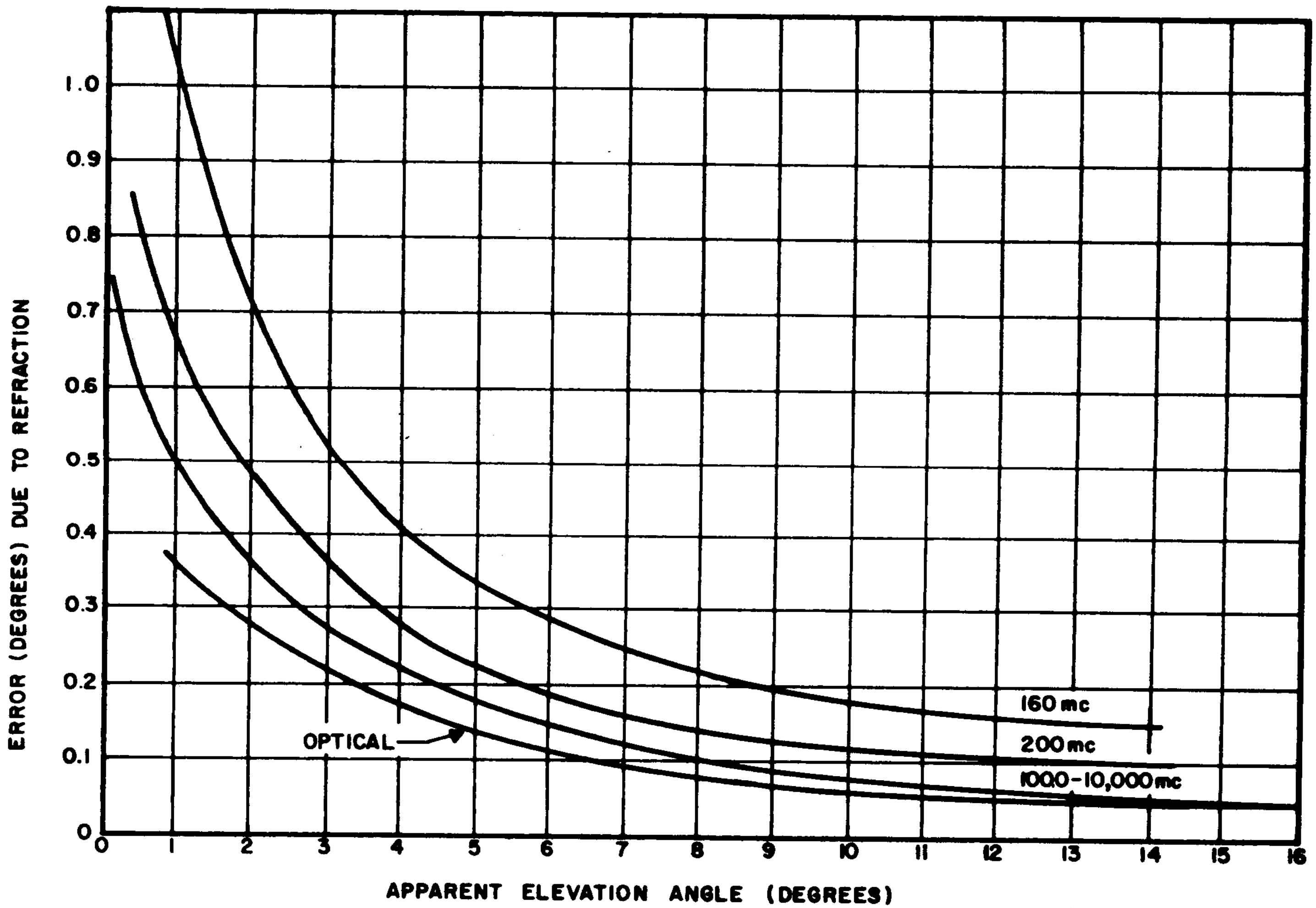

Figure III-4. Average Angular Refraction Errors for Low Elevation Angles was verified by peaking the signal received from the 136 mc beacons. During the passes where manual pointing was used, the USSR reports that the pointing error relative to the predictions did not exceed 0.25°. Since the half-power beamwidth of the Zimenki antenna is 9°, it is concluded that the fluctuations caused by the variations in pointing and prediction errors of the Zimenki antenna were probably less than 0.5 db. It is interesting to note that the USSR reported that comparison of the USSR Academy of Science predictions with the GSFC predictions indicated time error differences of up to 40 seconds. Possibly these errors were of the same type shown in Figure III-2 and III-3.

It is stated that circular polarization was used on both antennas for most of the passes to minimize the variations while at the same time maximizing the average signal level. However, any mis-match in polarizations, either between the antennas themselves or due to cross-polarization by the Echo II satellite, would have caused some signal level variations. The sense of the polarization at the Zimenki station was checked by means of a spiral type of boresight antenna which was mounted on a pole 90 feet high and 330 feet away. When the antenna was switched to the polarization sense opposite to that of the boresight antenna, the test signal level into the receiver decreased by 20 db. This indicates that if the Jodrell Bank antenna had transmitted on the wrong circular polarization, the Zimenki facility would not have received any detectable signal from either the satellite or the moon. The fact that a 10 to 20 db drop in level occurs for oppositely polarized signals reflected from the moon or the Echo II or Echo I satellite has been reported by other experimenters [1] (also see Appendix C).

In session 10 of the moon tests on 8 March (See Table II-3), the Jodrell Bank antenna was changed to emit a linearly polarized wave, whereas the Zimenki antenna remained connected for a circularly polarized wave. As a result, in session 10, an additional loss of 3 db in the signal level was to be expected. However, as shown in Table II-3, this was not the case, indicating that throughout the entire experiment period, the Jodrell Bank antenna may have been essentially linearly polarized. This would result in an additional loss of 3 db in communicating via the Echo II and the moon. This possibility is further indicated by sessions 2-a and 2-b with the moon on 23 February 1964 (See Table II-3), in which the polarizations at the Zimenki antenna were switched, while the Jodrell Bank antenna continued to transmit the same sense of

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(1) BTL report "Project Echo I Communication Experiment" Final Report, p. 39.

(supposedly) circular polarization. The interesting fact is that the average signal level did not appreciably change (See Figure B-35 and B-36). As indicated previously, tests on the Zimenki antenna and polarization tests with the moon indicate that the received signal level should have dropped by 10 to 20 db.

It should also be noted that during passes 560 and 568 with Echo II, the transmitting antenna emitted a linearly polarized wave and concurrently the receiving antenna was connected to receive circularly polarized radiation. As a result, in these passes, an additional loss of 3 db would be expected in comparison with the previous sessions when circularly polarized waves were emitted. However, according to reports such appreciable losses failed to occur in these sessions.

Possible errors in following the doppler shift at the receiving terminal could also contribute to the observed signal fluctuations. Manual tuning was used to follow the frequency variations of the signal due to doppler. The doppler shift at 162.4 mc can be as high as 3 kc. The receiver bandwidth was selectable between 5 kc and 1 kc. The resolution of the tuning indicator was reported as 50 cps. In this case, signal scintillation would be a function of operating efficiency, which cannot be evaluated in this report.

Finally, signal fluctuations might have been caused by fluctuations in the gain of the receiver and/or in the recorder. However, sufficient information to evaluate this possibility is not available.

2.4 SATELLITE IRREGULARITIES

If the satellite is not perfectly smooth or perfectly spherical, signal fluctuations will result from cancellation and enhancement of the reflected signals from different portions of the satellite. That the reflected signal from the Echo II satellite does indeed fluctuate has been verified by both radar and communication experiments conducted by the Echo Project at GSFC (See Appendix C).

Figure III-5 shows the type of signal fluctuations observed at the Collins facility from the phase-lock radar signal at 2190 mc. The phase-lock radar signal is a square-wave, amplitude-modulated signal with a modulation frequency that varies between 50 and 180 cps. The time constants of the receiver are such that the signal appears to the receiver as a cw signal. Figure III-6 shows a time expanded section of the trace in Figure III-5.

Figure III-7 is a sample of a typical pass indicating the type of signal received at NRL during these GSFC conducted experiments previously referred to in Section III, paragraph 2.1.

A comparison of these signal traces with the Zimenki signal traces in Appendix B reveals that the fluctuations observed in the GSFC experiments are somewhat less. Furthermore, it is of interest that in the GSFC experiments no correlation in the signal fluctuations and the rotation of the Echo II satellite has been observed as yet, indicating that the Echo II satellite is quite spherical. This is contrary to one of the concluding statements in the USSR report in which signal fades with durations of 1 to 2 minutes were attributed to rotation of a nonspherical satellite. Similar signal strength recordings received at the Ohio State University at 2270 mc, during the time period of the Jodrell-Zimenki experiments, support the conclusion that the signal characteristics are essentially the same as shown in Figures III-5 and III-6.

One point that should be considered is that the British-USSR experiments were conducted at 162.4 mc. If the fluctuations shown in Figure III-5 and Figure III-7 are due to surface irregularities of the satellite itself (and it is assumed that this is the case, since the antenna pointing was verified optically) then the fluctuations should be significantly less at 162 mc than they were at 2190 mc. Since this is not the case, it is concluded that factors other that satellite irregularities were the major contributors to the fluctuations of the signal level observed during their experiments. The results of radar experiments (Appendix C) show the relationship of operating frequency and signal scintillations.

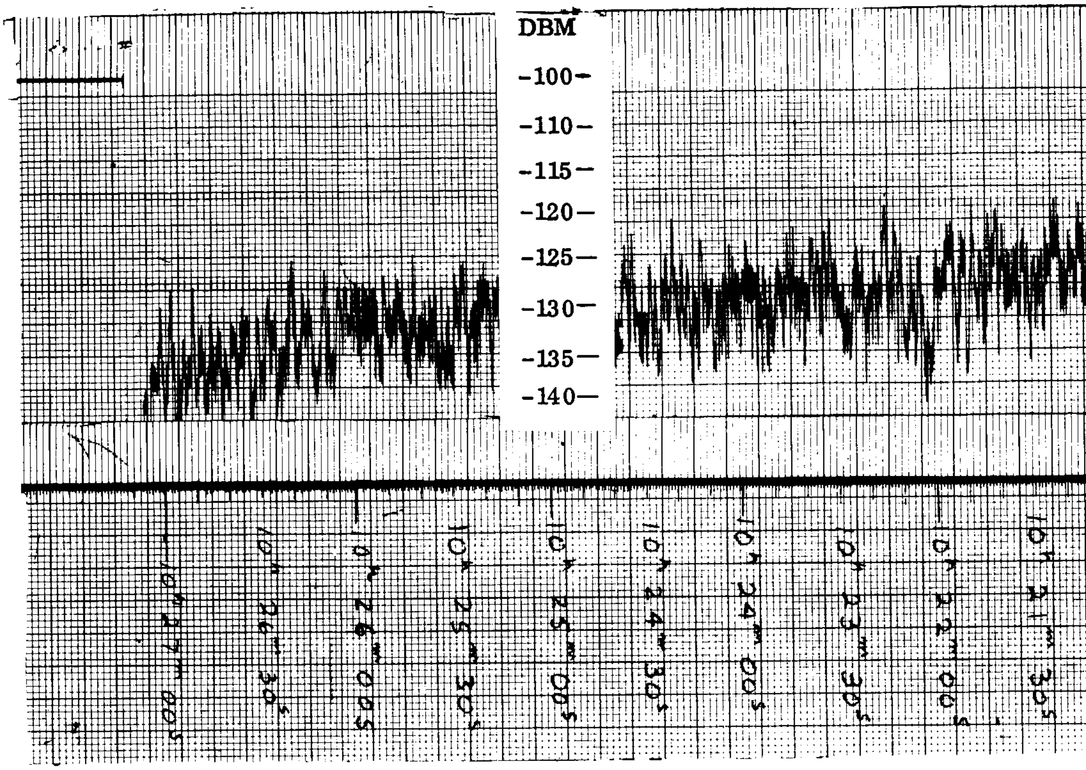
3.0 COMMUNICATION EXPERIMENTS

Various types of RF modulated signals were transmitted via Echo II. The results of these experiments are outlined in Section II, paragraph 3.4 through 3.7.

As indicated in the discussion of experimental results, the information transmitted was unintelligible at the receiving terminal in essentially all cases. The reason for such poor results obviously lies in the character of the received signal, which ranges from bad to poor.

In some of the experiments, such as facsimile and TTY, there is the ever-existing problem of equipment compatibility between the transmitting and receiving terminals. Sufficient information has not been provided to enable the Echo II project office to evaluate the effect of this parameter.

1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-100
-110
-115
-120
-125
-130
-135
-140
10h 27m 00s
10h 26m 30s
10h 26m 00s
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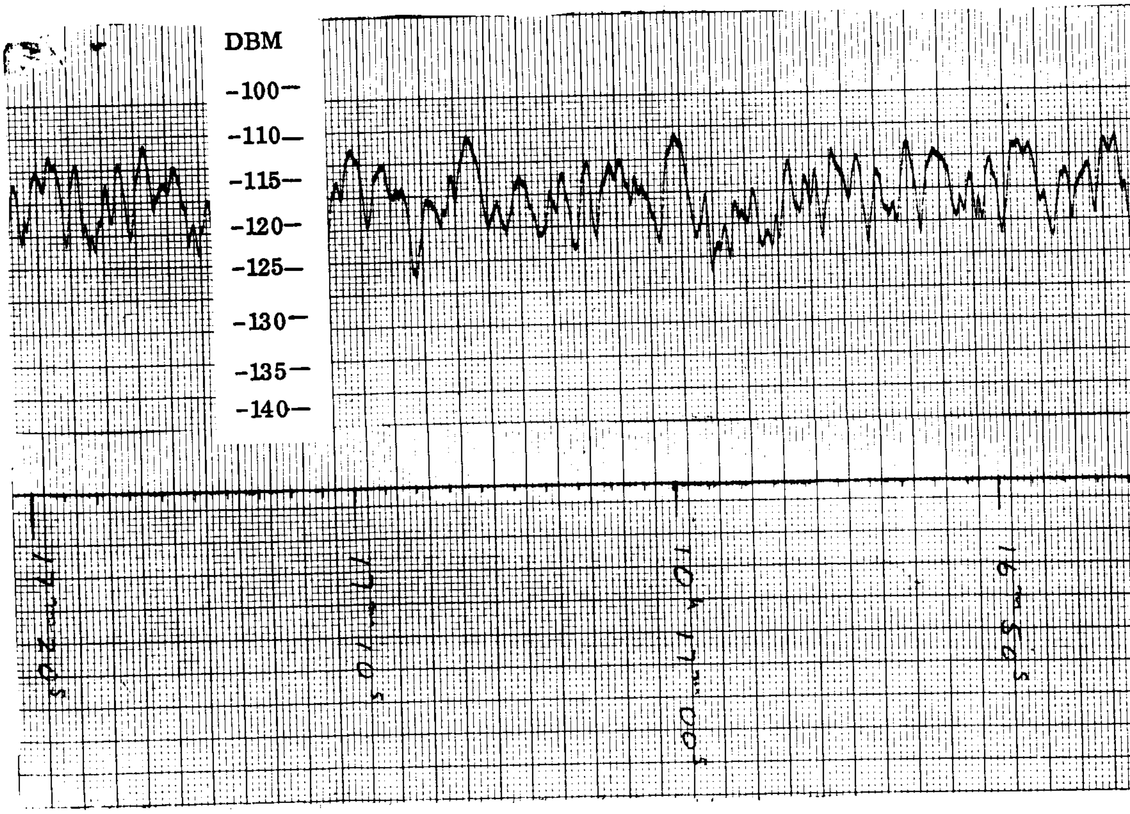
10h 22m 00s
10h 21m 30s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17m 20s
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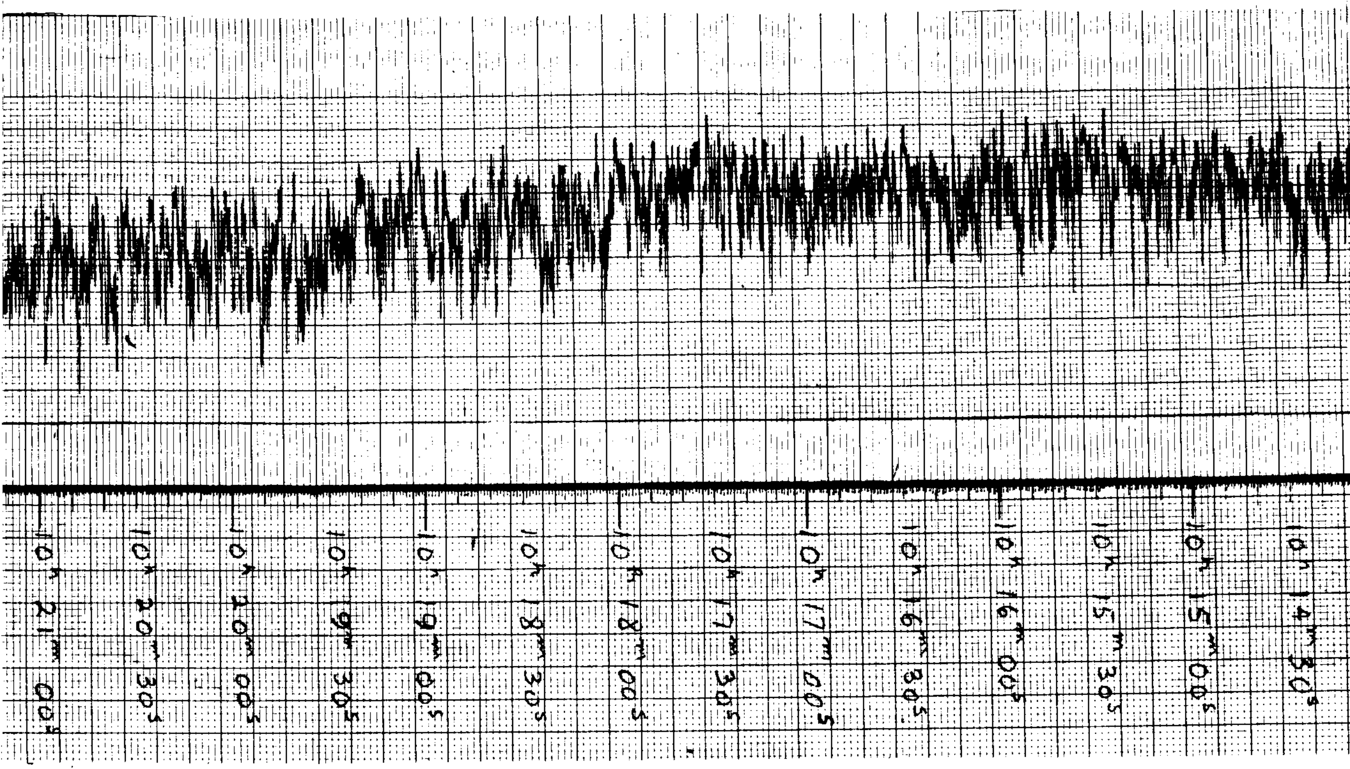
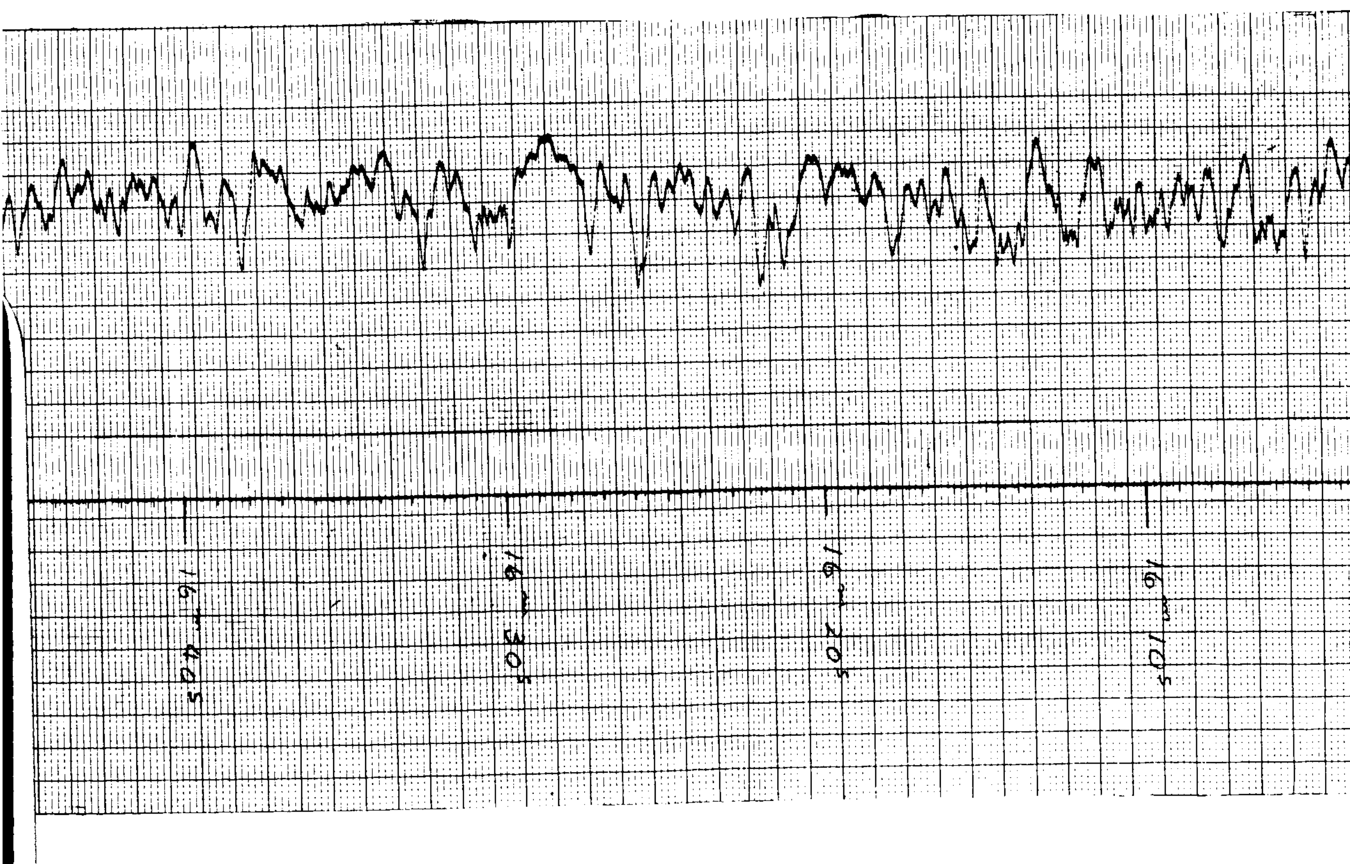
10h 17m 00s
16m 50s


10h 21m 00s
10h 20m 30s
10h 20m 00s
10h 19m 30s
10h 19m 00s
10h 18m 30s
10h 18m 00s
10h 17m 30s
10h 17m 00s
10h 16m 30s
10h 16m 00s
10h 15m 30s
10h 15m 00s
10h 14m 30s


16m 40s
16m 30s
16m 20s
16m 10s

3

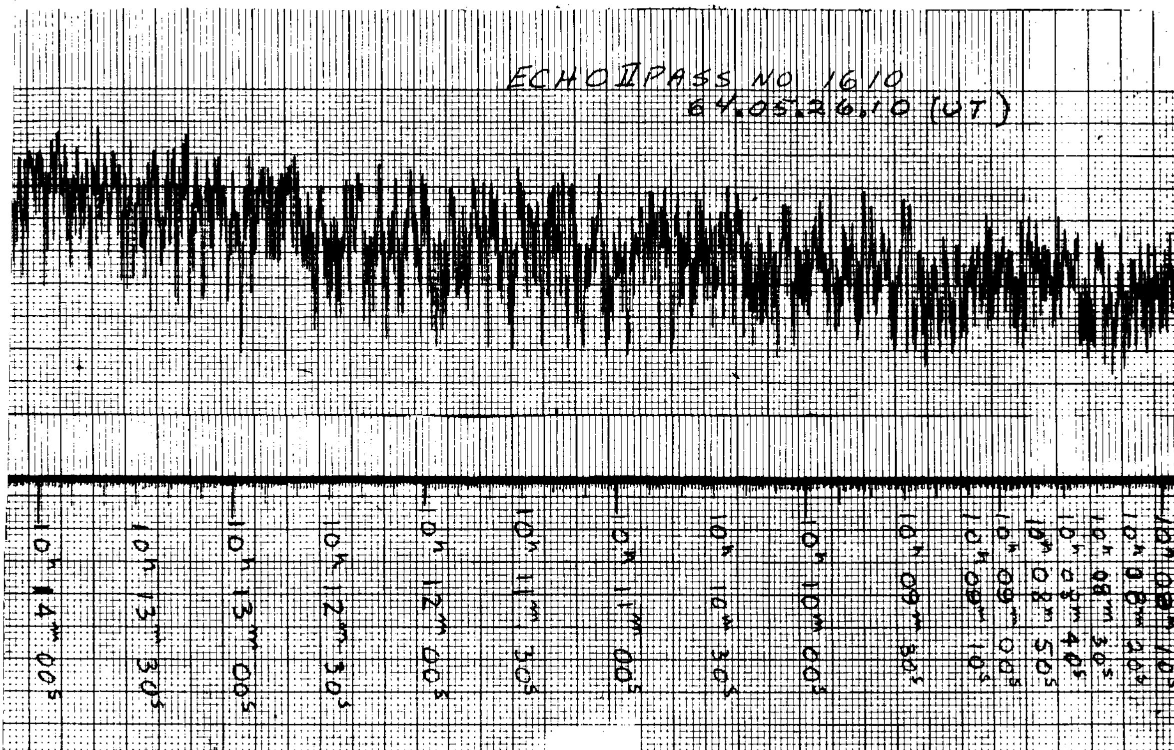


Figure III-5. Signal Level Vs. Time for Signals Reflected from Echo II Pass No. 1610 5 May 1964 Measured at Collins Radio Company at 2190 Mc.

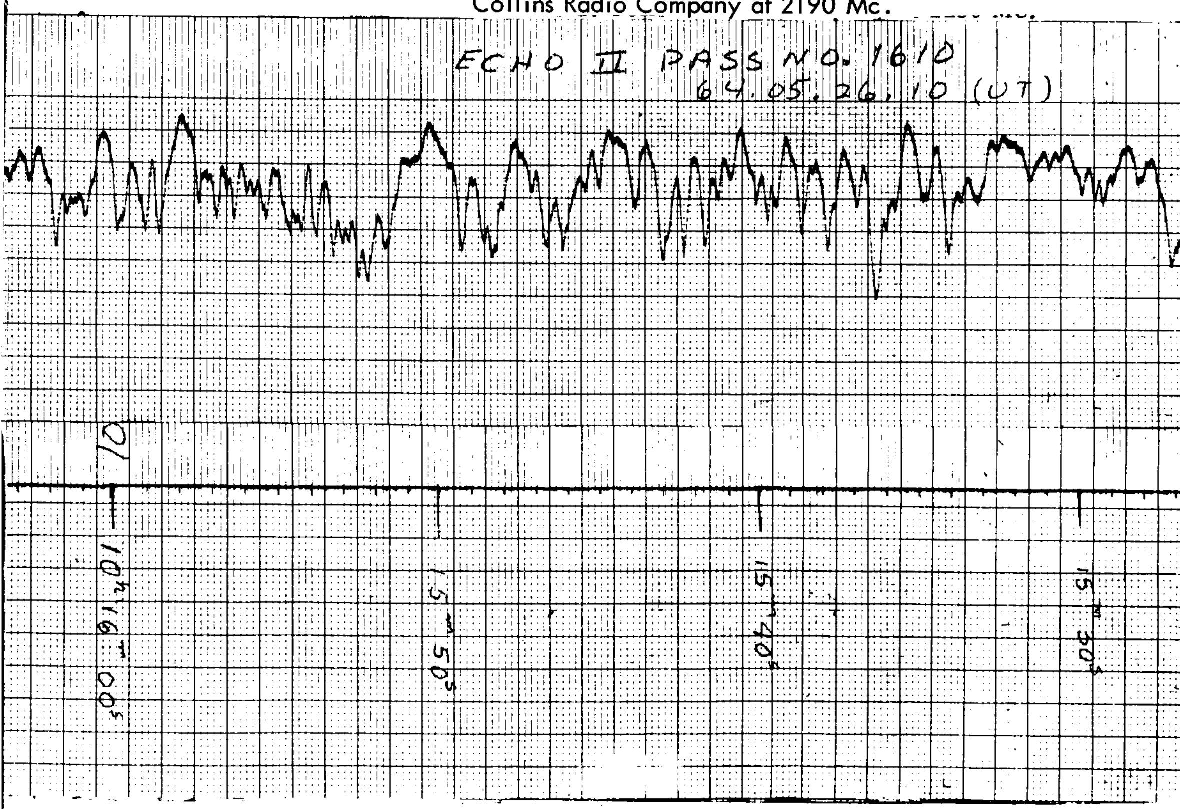


Figure III-6. Signal Level Vs. Time (Expanded Scale) for Echo II Pass 1610

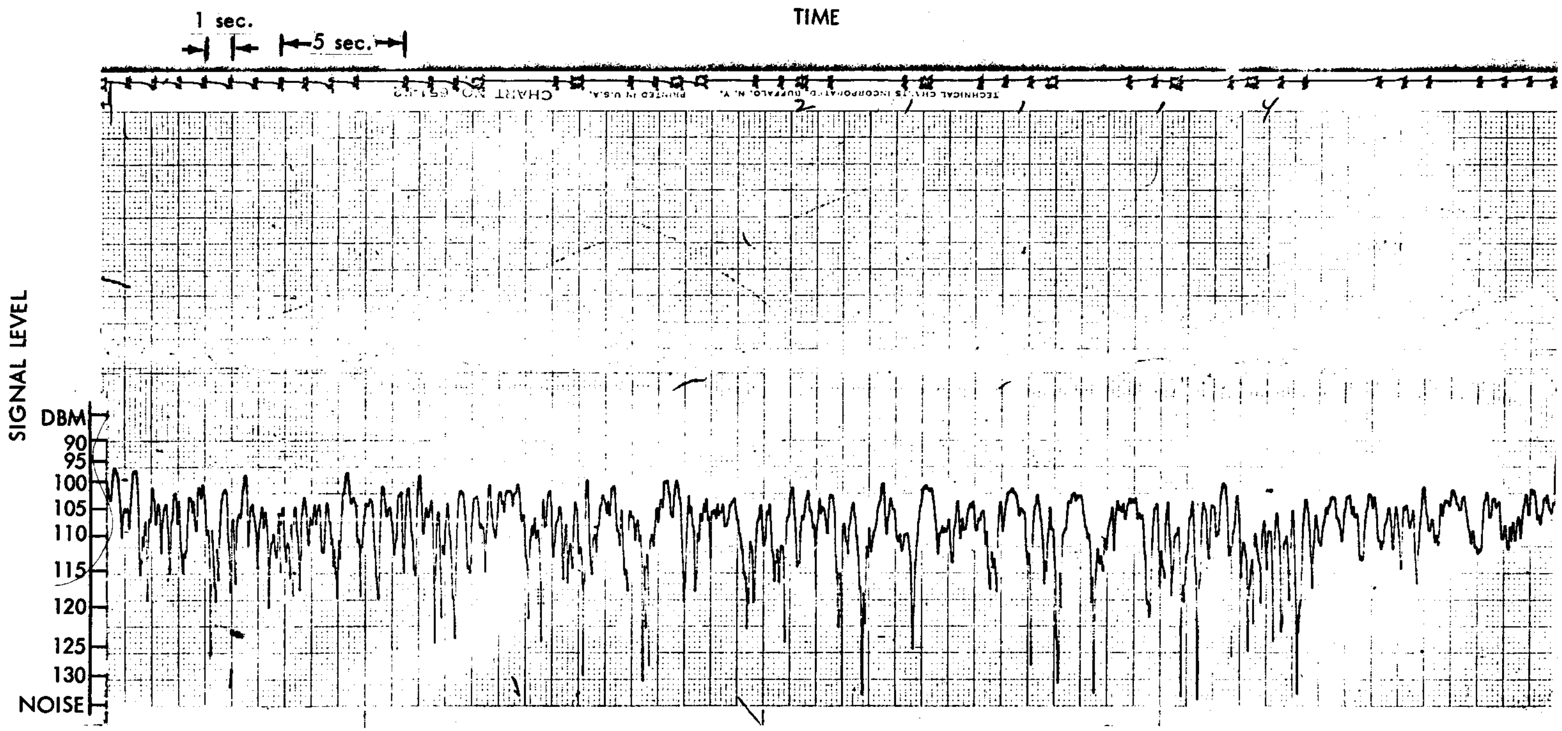


Figure III-7. Signal Level vs. Time on Pass No. 1414 at NRL on May 11, 1964 at 1106 U.T.

Further evaluation of the test results can best be accomplished by comparing some of the results from the communication experiments currently being conducted under the direction of the Echo Project Office at GSFC. Although, no attempt was made to duplicate the Jodrell-Zimenki experiments, the types of experiments conducted are comparable.

A description of the GSFC experiments is given in Appendix C. Among other things it can be seen that in contrast to the Jodrell-Zimenki experiments, good results have been obtained on voice and music tests and facsimile experiments despite the limitations imposed by the use of less than optimum receiving equipment.

IV. SUMMARY

Communication experiments have been conducted via the Echo II satellite, between the University of Manchester at Jodrell Bank (U.K.) and the Gorki State University at Zimenki (USSR).

The Soviets provided a relatively complete and detailed account of the experiments as related to the receiving terminal. However, the British report did not provide adequate technical detail to properly evaluate station performance during the experiments.

Management of the experiment program within the USA was provided by NASA Headquarters with no participation by the Echo Project Office at GSFC. Transmission was accomplished by the British Jodrell Banks facility with reception by the Soviets at the Gorki State University in Zimenki.

The experiment period extended from 21 February to 8 March 1964, during which time thirty-four communication sessions were conducted via Echo II and ten via the moon.

In accordance with the agreement, 5 types of experiments were to be conducted:

a. Unmodulated carrier
b. Single Frequency Modulation
c. Telegraphy
d. Facsimile
e. Voice

The tests were conducted in accordance with the Bilateral Space Agreement between the USSR (Academy of Sciences) and the USA (NASA).

The Jodrell Bank facility, the transmitting end of the link, utilized a 1-kw transmitter at a frequency of 162.4 mc and a 250-foot diameter dish steerable antenna. Pointing of the antenna was accomplished by programmed autotrack based on predictions furnished by the Goddard Space Flight Center (GSFC) of the National Aeronautics and Space Administration except in the cases of revolutions 389 and 450. On those passes, the antenna was manually positioned to point at positions in space through which the satellite was expected to travel.

The 162.4 mc signals were received at the Zimenki facility by a steerable 15-meter (49-foot) diameter circularly polarized parabolic reflector antenna and associated receiving equipment. In addition to receiving the 162.4 mc signals from Jodrell Bank, the system also received and recorded the telemetry beacon signals from the satellite at 136 mc. In both cases, the variation in the received frequency due to doppler was compensated for by manual tuning.

A digital drive tape and an antenna programmer were used to point the Zimenki antenna during the experiments. The data points were furnished by the Astro-Council of the USSR Academy of Sciences.

Two basic types of experiments were conducted:

a. Received signal level
b. Communication (or carrier modulation) experiments.

Significant signal fluctuations were noted throughout the experiments. The following were investigated as possible causes for this signal characteristic:

1. Transmission Terminal
2. Transmission Media
3. Receiving Terminal
4. Satellite

The Jodrell Bank (transmitting) facility employed a type of manual programmer tracking system which had no apparent means for optical correction. Because such a system is not suitable for tracking the Echo type satellite, it was probably the major contribution to the observed scintillations. Other factors which might have contributed to the scintillations (such as varying transmitter output) cannot be evaluated because of the lack of technical information provided.

At Jodrell Bank over 50% of the passes were below 17°. It is therefore likely that refraction effects of the atmosphere and ionosphere contributed to the scintillations. Although the elevation angles were generally higher at the Gorki facility, it is probable that some of the observed scintillations were also caused by ground reflections since the half power beamwidth of the antenna was approximately 9°.

The Zimenki receiving facility also used program tracking. However, because of their antenna beamwidth, the availability of "fresh" orbital data and their capability for "peaking up" on the beacon signal, there was probably little tracking error at this facility.

It has been verified through experiments here in the USA that the reflected signal from the Echo II satellite does exhibit scintillations. However, even at S-band, the average scintillations are only about ±5 db. This is somewhat less than the average scintillations observed in the subject experiments at the ultimately low frequency of 162 mc where one would normally expect considerably less scintillations than at the higher frequency at S-band (See App. C).

Several communications type (modulated carrier) experiments were conducted. These were:

a. Carrier wave single tone modulation tests

b. Decelerated speech transmission

c. Telegraphy and teletype transmission

d. Facsimile experiments

In nearly all cases, the signal to noise ratio was so low that very little intelligible information was received. This is not surprising, in view of the character of the signal as revealed by the received signal level experiments. Uncertainties involving equipment compatibility between the two sites may have also contributed to these results. However, lack of technical information precludes an evaluation of this possibility.

V. CONCLUSIONS

Based on the data received from the participants the following conclusions can be made:

1. The character of the received signal at Zimenki was typified by the presence of high and frequent signal fluctuations with persistent dropouts and an overall low signal to noise ratio.

2. While there is no question that the reflected signal from Echo II does ordinarily possess some scintillations, these (average) scintillations are on the order of approximately ± 5 db at S-band and somewhat less at UHF frequencies (See App. C & D). Therefore, it is concluded that the character of the signal observed in the Jodrell-Zimenki experiments is due primarily to causes other than satellite irregularities.

3. After a thorough examination of the experimental results supplied by the participants it is concluded that the character of these signals is due primarily to inaccurate pointing of the antenna at the transmitting site. Also contributing to this condition are such things as: a) the refractive effect on the signal at the low elevation angles and the wide beam widths employed; and b) polarization mis-matches between the transmitting and receiving antennas.

4. The results obtained in the communications (modulated carrier) experiments are the logical outcome of the signal characteristics described above.

5. The system parameters employed, such as the operating frequency; transmitter power; acquisition and tracking methods; and the receiving dish size could only yield low signal to noise ratios at the receiving facility (as indicated in App. D). With these low signal to noise ratios, results on modulation type experiments could only be marginal at best.

APPENDIX A

SIGNAL LEVEL CALCULATIONS

Part I. Russian Signal Level Calculations

During the use of a passive relay satellite for communication between two points, the signal strength at the input of the receiving device can be calculated from the known formula:

$$P_s = \frac{P_t G A_\varphi \eta_\varphi A_\mu}{16\pi^2 R_t^2 R^2} \tag{1}$$

where P_t = output strength of the transmitter, G_t = the gain transmitting antenna, A_φ = the area of the satellite's disk, η_φ = the utilization factor of the satellite's area, A_μ = effective surface of the receiving antenna, R_t and R = the distances from the satellite to the transmitting and receiving antennas. We shall hypothesize that:

$$P_t = 10^3 \text{ watts},\ G_t = 40 \text{ db},\ A_\varphi = 1320 \text{ m}^2,\ \eta_\varphi = 1,\ A_\mu = 88 \text{ m}^2$$

and in calculating the value for A_μ, we assume that the utilization factor for the area equals 0.5.

As a result of the movement of the Echo-II, the distances R_t and R varied during a session. The minimal value for the product of $R_t^2 R^2$ during the experiments conducted was around $1.2 \cdot 10^{25}$ m^4.

Substituting the values adduced into Eq. (1), we get:

$$P_s = \frac{10^3 \cdot 10^4 \cdot 1.32 \cdot 10^3 \cdot 88}{16\pi^2 \cdot 1.2 \cdot 10^{25}} = 0.61 \cdot 10^{-15} \text{ watts}$$

The noise strength at the input of the receiving device:

$$P_N = k\, T_\Sigma\, \Delta f \tag{2}$$

where k = the Boltzmann constant, T_Σ = the full equivalent noise temperature of the receiving system, and Δf = the frequency pass band of the receiver.

The complete noise temperature of the receiving system is determined by the effective temperature of cosmic radio radiation T_k, by the radiation of the Earth, being picked up by the antenna through the side lobes, and also by the noise temperature of the receiver T_μ and by the transmission factor in respect to the strength of the feeder linking the antenna exciter with the receiver input η_W.

$$T_\Sigma = T_k (1 - \beta) + T \epsilon \beta + T_o \frac{1 - \eta_W}{\eta_W} + \frac{T_\mu}{\eta_W} \tag{3}$$

where β = the factor allowing for the strength of radiation entering the side lobes of the receiving antenna, T_ϵ = the temperature characterizing the thermal radio radiation of the Earth, while T_o = the temperature of the feeder.

Assuming $T_k \simeq 200°$ K, $T_o \simeq T_\epsilon \simeq 290°$ K, $\eta_W = 0.8$, $\beta = 0.3$, $T_\mu = T_o$ $(1 - N) = 290 \times 1.6 = 460°$ K, we find $T_\Sigma = 880°$ K and hence the noise strength introduced to the receiver's input in case of the 1 kc band $P_N = kT_\mu = 1.22 \cdot 10^{-17}$ watts. Hence in the region corresponding to the optimal visibility of the Echo II from the receiving and the transmitting points, the ratio of the strength of the incoming signal to the noise level equals

$$P_s/P_N = \frac{0.61 \cdot 10^{-15}}{1.22 \cdot 10^{-17}} = 50 \qquad (17 \text{ db})$$

The calculation made overlooks the loss in signal strength through tropospheric and ionospheric absorption of the radio waves since these losses are slight and can be disregarded.

For calculating the level of the signal during transmission through the Moon, we can use the above-adduced relationships, with the replacement of the area of the satellite's disk, A_ℓ by the area of the lunar disk A_M and the distances R_t and R_μ by the distance R_M to the Moon. The reflection factor of radio waves from the lunar surface η_μ in the meter wave band will vary from 0.05 to 0.01.* We shall consider that $\eta_M = 0.05$, the diameter of the Moon $D_M = 3{,}476$ km and the average distance to the Moon $R_M = 384{,}000$ km. In this case, the strength of the signal bounced off the Moon will exceed the noise strength by 10 db on an average (in the receiver band $\Delta f = 1$ kc), i.e., by 7 db less than during the communication through the Echo II under optimal conditions.

*Evans, I. V., Pettengill, G. H., J. Geophys. Res., No. 2, 1963.

It is worth noting that as a result of the increase in the distance from the Earth to the Moon during the experiments, the additional losses in the signal's strength can attain 1 db.

Part II. Goddard Space Flight Center Echo II Project Signal Level Calculations

The received signal level for transmission between two ground-based terminals via a passive reflector is given by the following general expression:

$$P_r = \frac{P_t G_t G_r \sigma \lambda^2}{(4\pi)^3 d_1^2 d_2^2} = P_t G_t G_r \frac{1}{L}$$

where

P_t = transmitter power

G_r, G_t = transmitter and receiver gains

λ = wavelength of radio frequency

d_1, d_2 = respective distance between communicating terminals to the satellite

σ = effective cross-section of the satellite

L = free space loss between isotropic antennas

The free-space transmission loss between isotropic antennas for a passive reflector satellite can be calculated from the nomograph in Figure A-1. For the Jodrell Bank-Zimenki circuit, the midpoint range to a satellite with an altitude of 1100 kilometers is given as 1.94×10^3 km. The effective cross-section of a perfectly reflecting sphere of 41.1 meters in diameter is 1320 square meters. Using the values along with the value of 162 mc for the operating frequency, the free-space transmission loss with the satellite located at midpoint is 248 db. In addition, the loss should include a loss factor for the tropospheric and ionospheric absorption. At 162 mc this can vary from 0.2 to 3.0 db, depending upon the conditions, such as elevation angle, percent humidity, time of day, number of sun spots, etc.[2]

As the satellite moves from midpoint, the loss will vary as the product of satellite ranges, $d_1 \, d_2$, varies.

The general expression for the product of the slant ranges may be obtained from Figure A-2 where ground stations are located at points G and F. Using simple geometry and trigonometry,

$$d_1^2 \, d_2^2 = A^2 \, (1 - M \cos \alpha) \, (1 - M \cos \phi \sin \alpha \sin \beta - M \cos \alpha \cos \beta)$$

where

$$A = R^2 + (R + H)^2$$

H = altitude of satellite above sea level

and

$$M = \frac{2R(R + H)}{A}$$

Using these equations and the nomogram of Figure A-1, the path loss at any point within the mutual visibility zone of the two stations can be determined. These in turn may be plotted as loss contours for the two stations, as shown in Figure A-3. The distortion of the contours is due to the particular type of projection that is used. The loss values of contours are relative to the midpoint loss value and are, therefore, independent of the operating frequency. However, they are only correct for a satellite that has an altitude of 1100 kilometers in height.

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[2]G. H. Millman, "Atmospheric Effects on VHF and UHF Propagation," Proceedings of the IRE, Vol. 46, August 1958, pages 1492 through 1501.

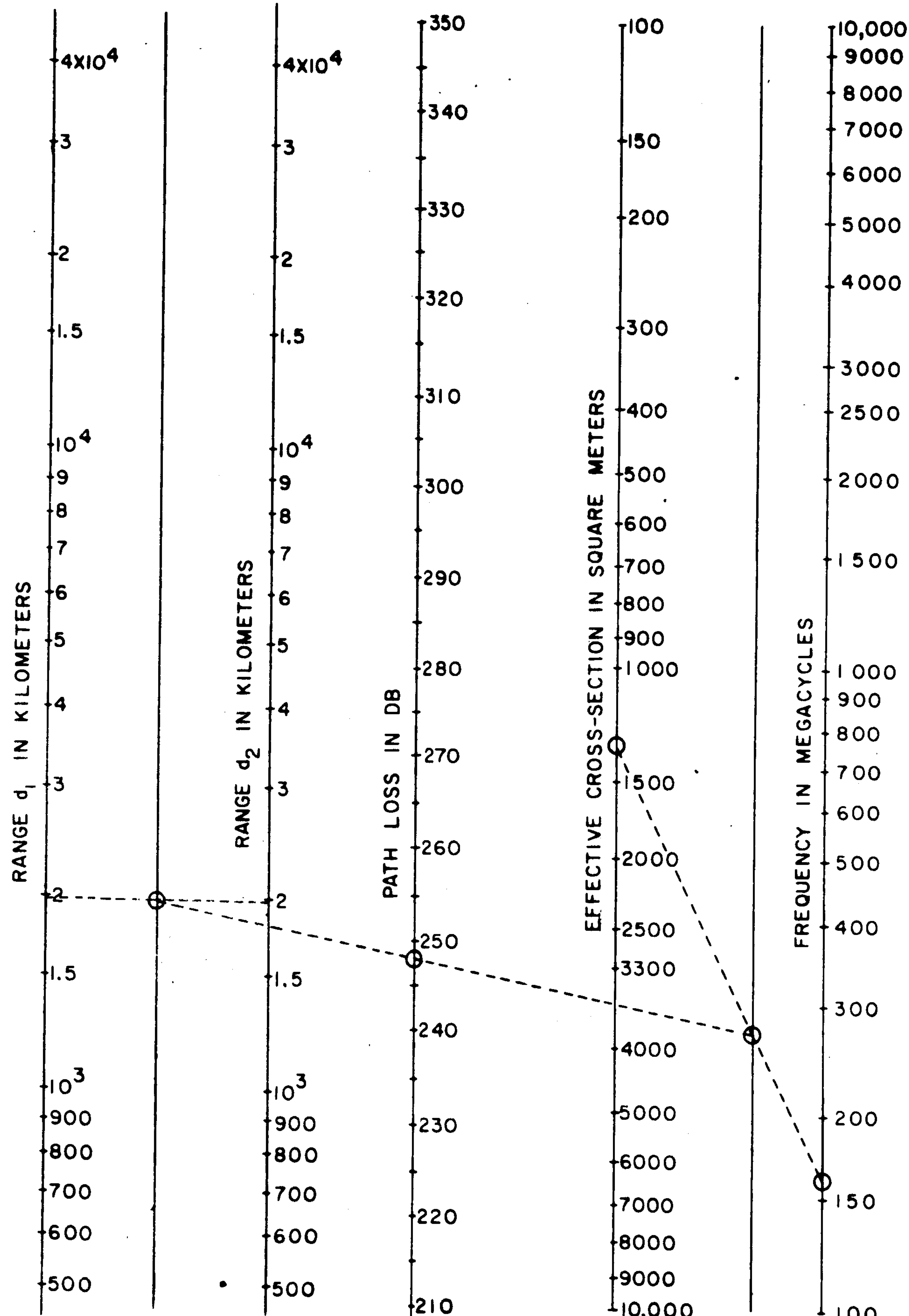
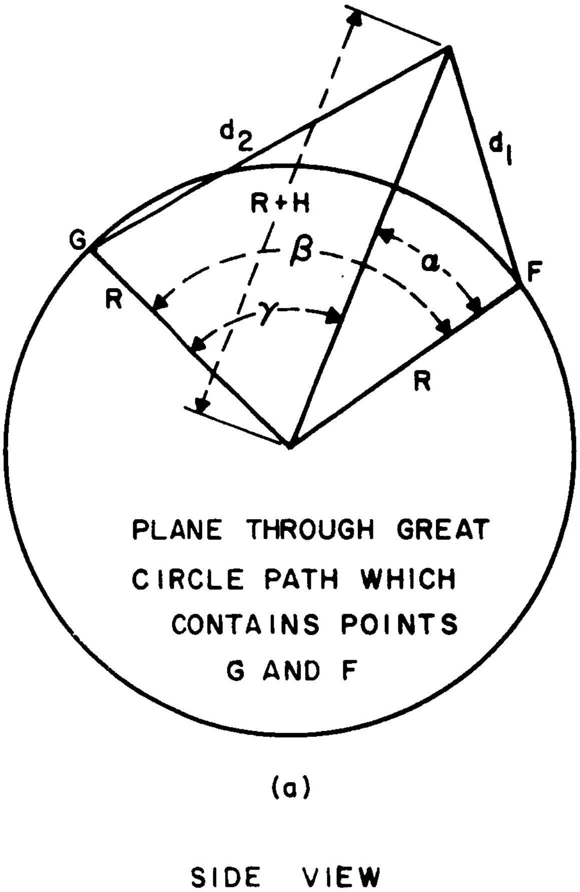


Figure A-1. Passive Satellite Path Loss Nomograph Between Isotropic Antennas



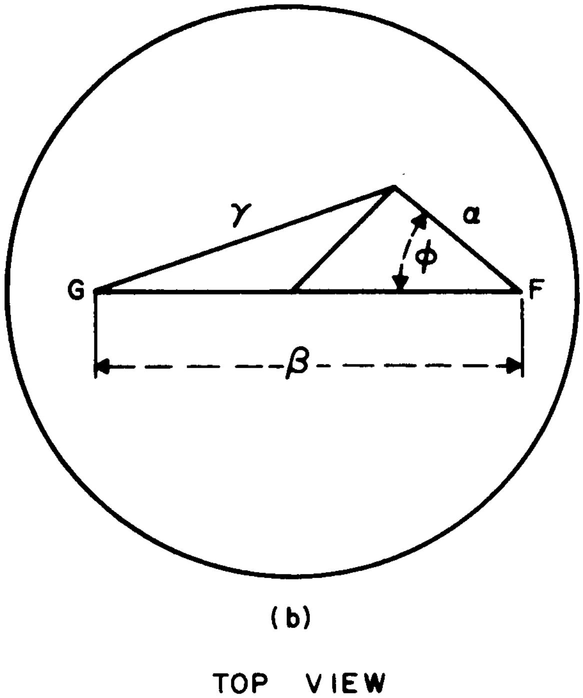


Figure A-2. Geometry for Path-Loss Calculations

Assuming the following values for the communication system parameters,

$$P_t = 10^3 \text{ watts}$$

$$G_t = 40 \text{ db*}$$

$$G_r = 24 \text{ db**}$$

and

$$L = 249 \text{ db}$$

*Assumes 55 percent illumination efficiency.

**Based upon values in the USSR report and includes 1 db for the transmission line loss.

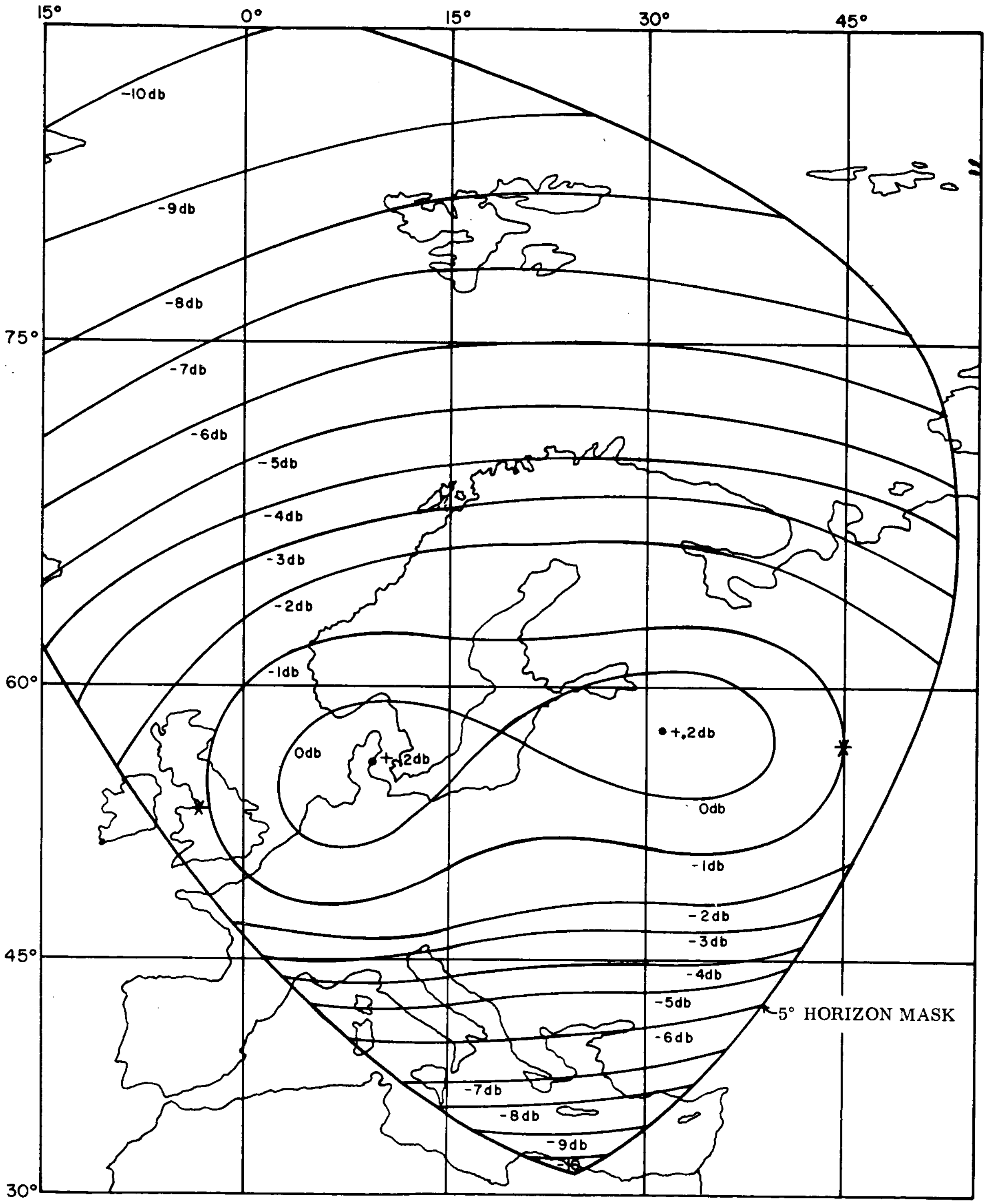


Figure A-3. Contours of Constant Path Loss Between Jodrell Bank and Zimenki, Satellite Height, 1100 Km then the calculated received signal level is -125 dbm with the satellite at the midpoint. This value is 3 db lower than the value calculated in the USSR report, because it includes ionospheric absorption and transmission line loss, and it is calculated for the midpoint rather than for the minimum value of $d_1 d_2$. As can be seen from Figure A-3, the minimum value of $d_1 d_2$ reduces the loss from the midpoint by about 0.2 db. The remaining difference between the two values is apparently due to the assumption of different altitude heights for the satellite. It is believed that a -125-dbm signal level at the midpoint is a more realistic value. From the values of maximum elevation angle given in Table II-1, it can be seen that midpass signal level should have been at least -126 dbm. As the satellite approaches the extreme mutual horizon points (assuming 5° masks at each station), the signal level approaches -136 dbm.

The same relationship can be used for calculating the signal levels for communication experiments with the moon. The diameter of the moon is 3476 km, and the average distance to the moon is 384,000 km. The reflection coefficient of the moon varies from 0.01 to 0.1.[3,4] Assuming a value of 0.05 and the same system parameters as before, the calculated received signal level is -130 dbm, which agrees with the average value calculated in the USSR report.

The input noise density to the receiver system is given by the general expression:

$$\Phi_N = k T_N$$

where

k = Boltzmann's constant = 1.38×10^{-23} joules per deg K

T_N = the system noise temperature in deg K

$T_{ANT} + 290° (F - 1)$

where

T_{ANT} = the antenna noise temperature

F = the receiver noise figure (numerical ratio)

[3] I. V. Evans and G. H. Pettengill, Journal of Geophysical Research, No. 2, 1963.

[4] Jet Propulsion Laboratory, Research Summary No. 36-5, Vol. I, 1 August 1960 to 1 October 1960.

Assuming a value of 2.6 for the receiver noise value and 420° K for the antenna noise temperature, the input noise density is -169 dbm/cps. For a receiver bandwidth of 1 kc, this results in a signal-to-noise ratio of 14 db when the Echo II satellite is located at the midpoint, which is 3 db lower than the value calculated in the USSR report. The input noise density will vary with the elevation angle, the position of the antenna relative to the galactic plane, and ionospheric conditions.*

*According to many published reports, 420° K represents a lower value, and the average value is more like 1000° K to 3000° K. When the antenna is looking at the galactic plane, the antenna noise temperature can become as high as 10,000° K to 15,000° K. See, for example, "The Effective Noise Temperature of the Sky," by D. C. Hogg and W. W. Mumford, the Microwave Journal, March 1960.

APPENDIX B

PHOTOCOPIES OF SIGNAL LEVEL RECORDINGS

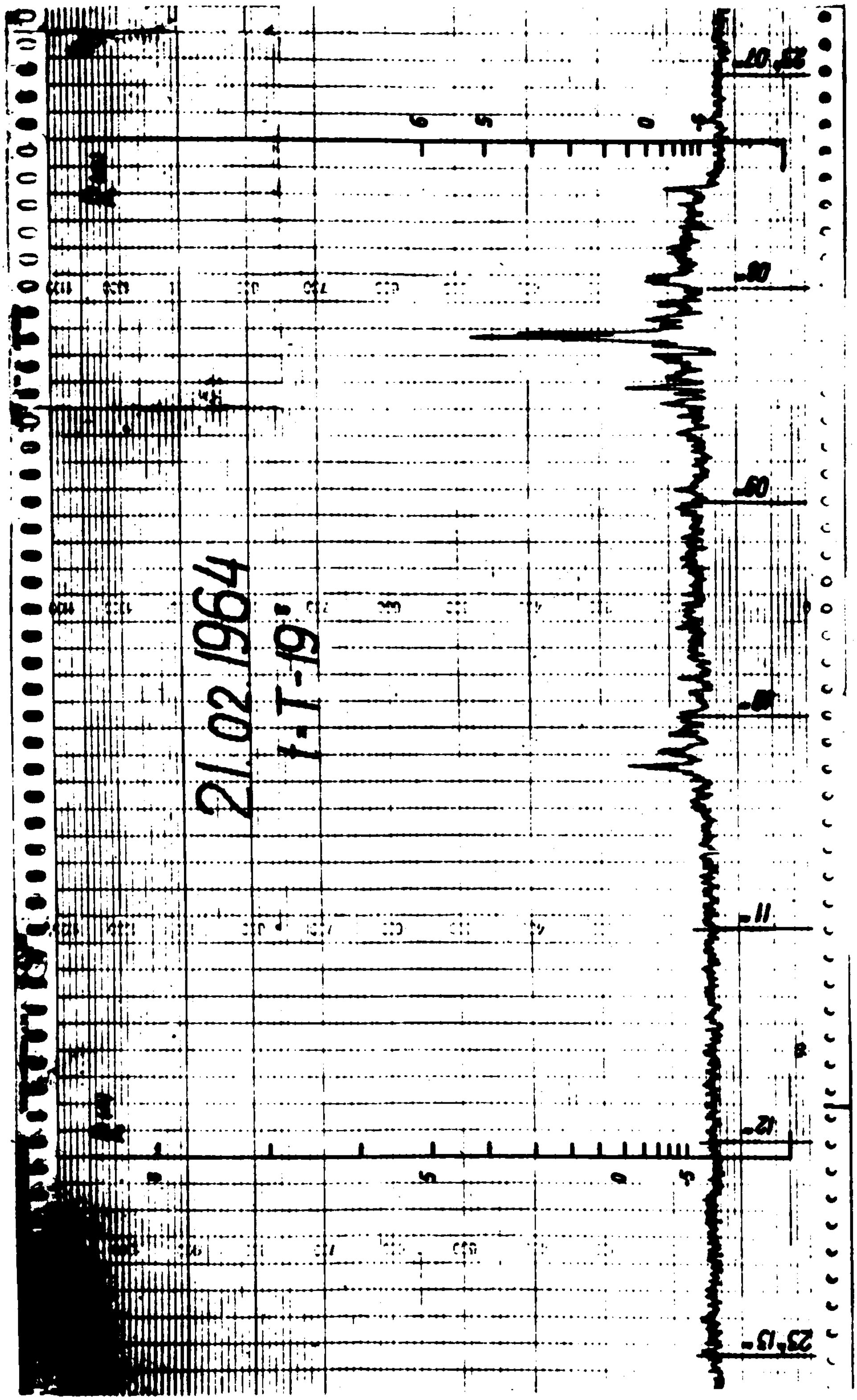


Figure B-1. Pass No. 362

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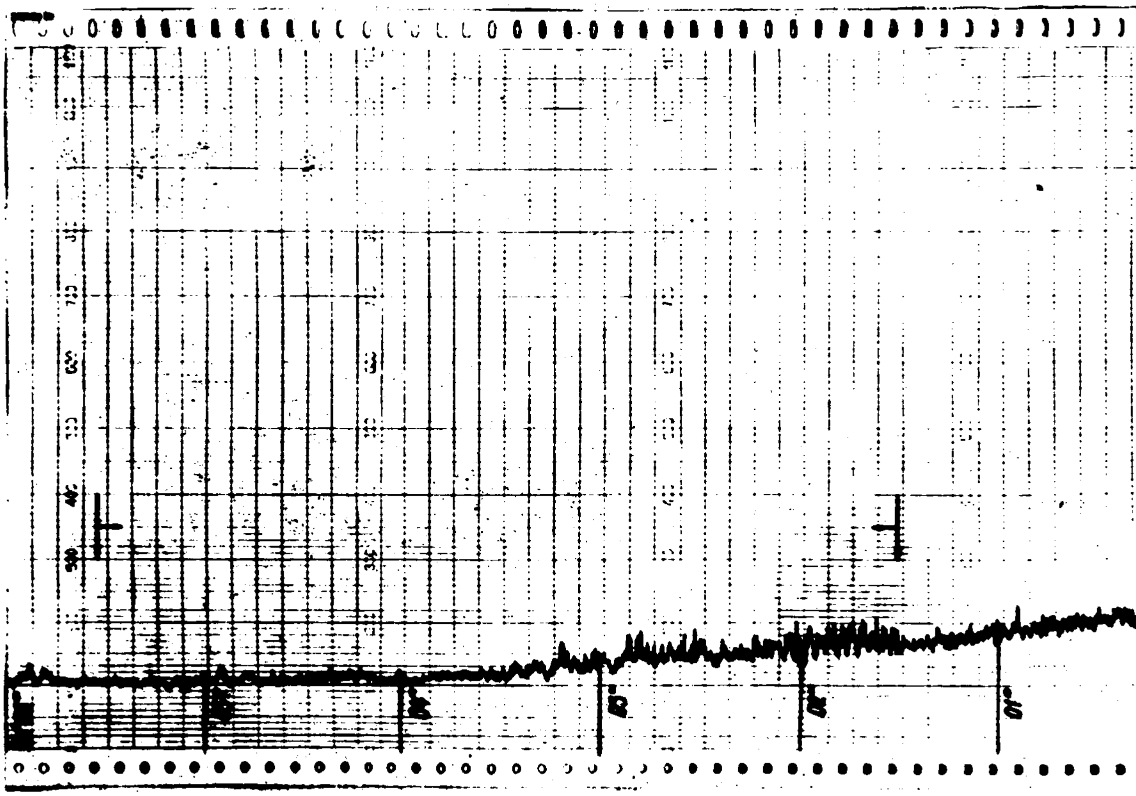
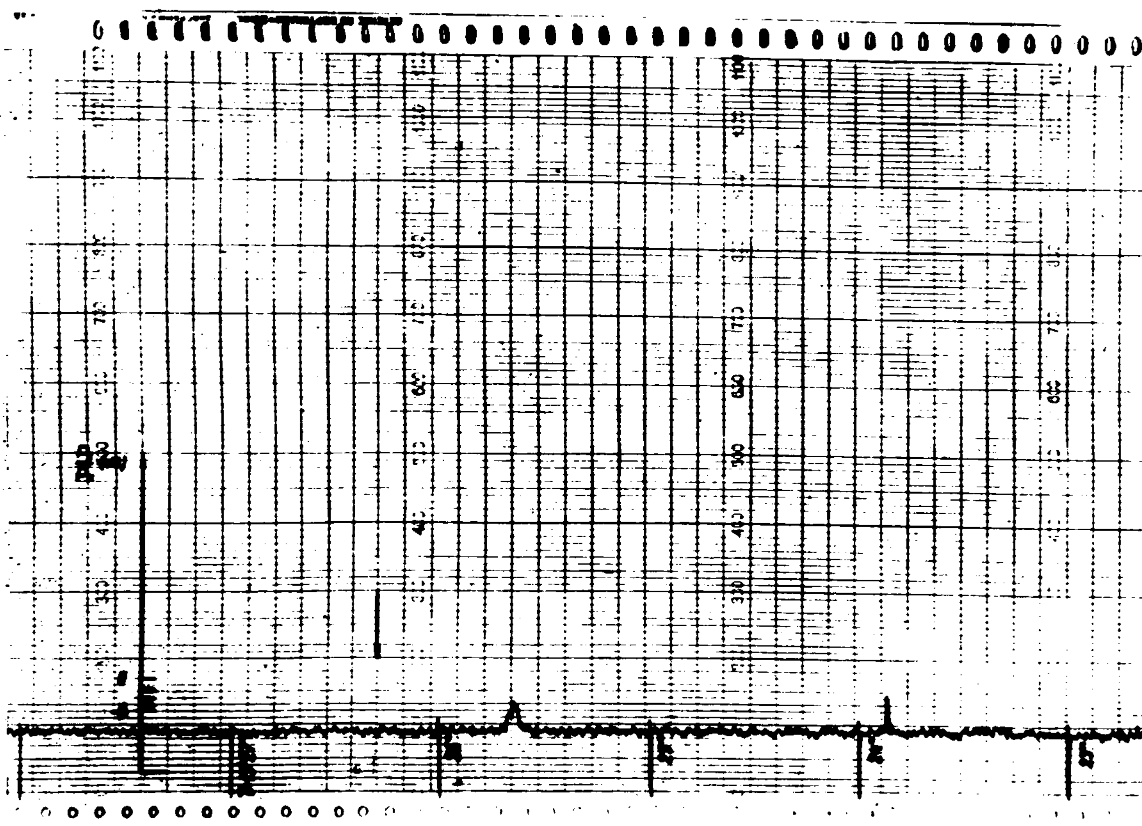
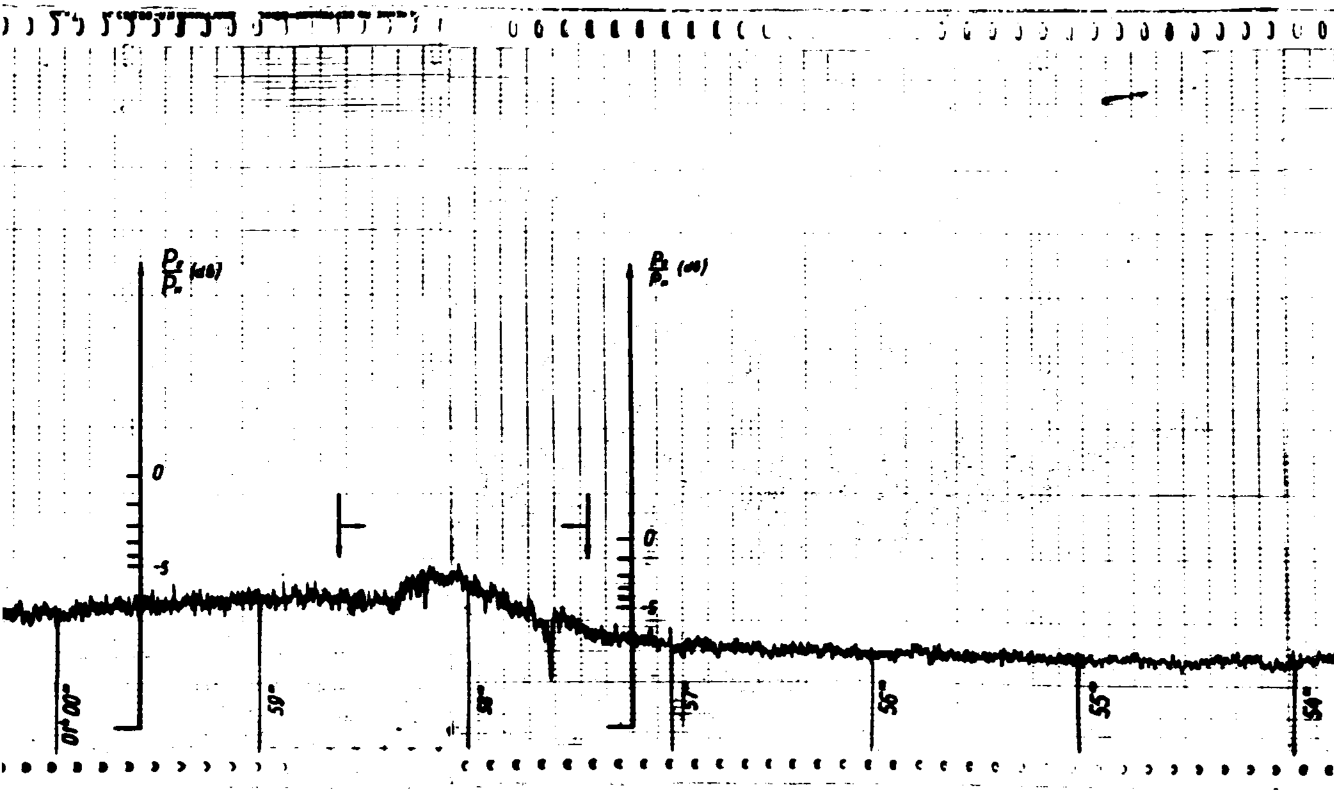
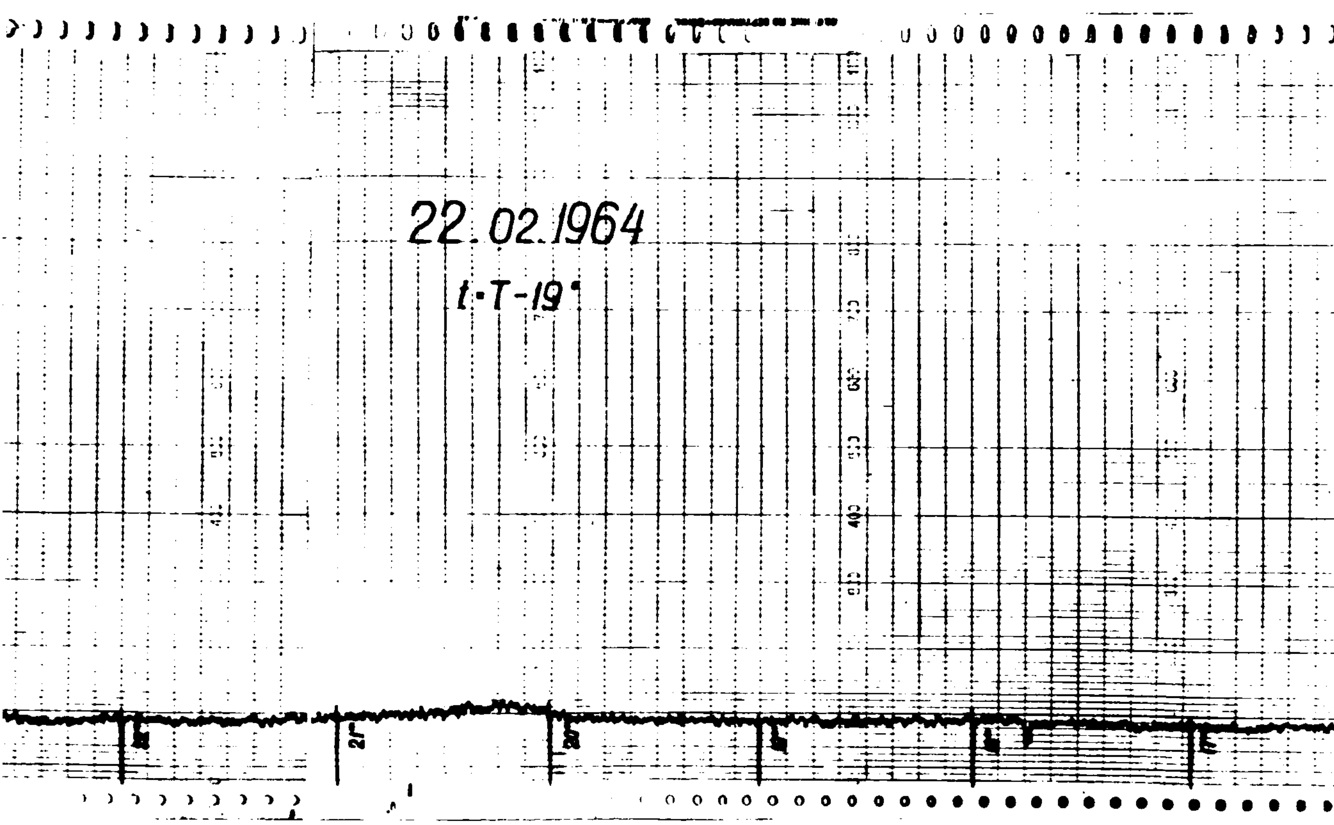




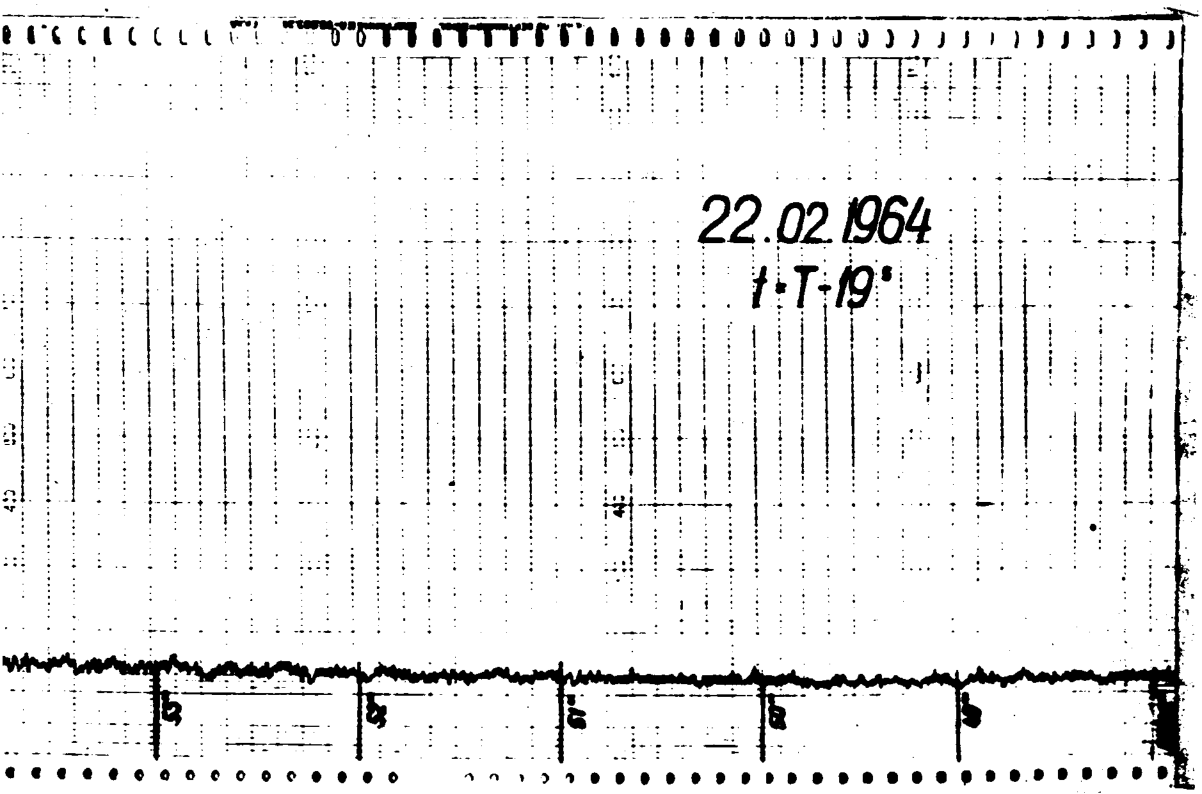


0
-5
59m
58m
57m
56m
55m
54m



22.02.1964
t-T-19°
21m
20m

3



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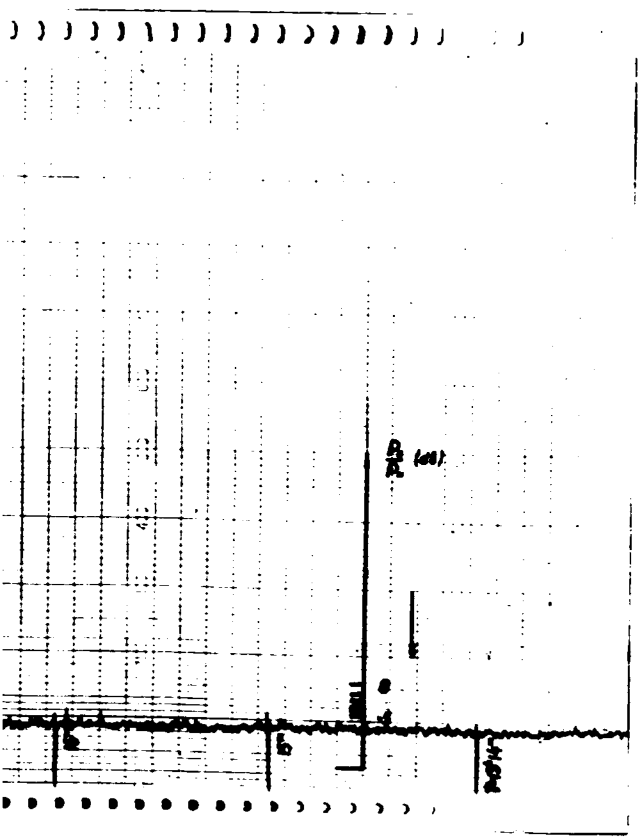

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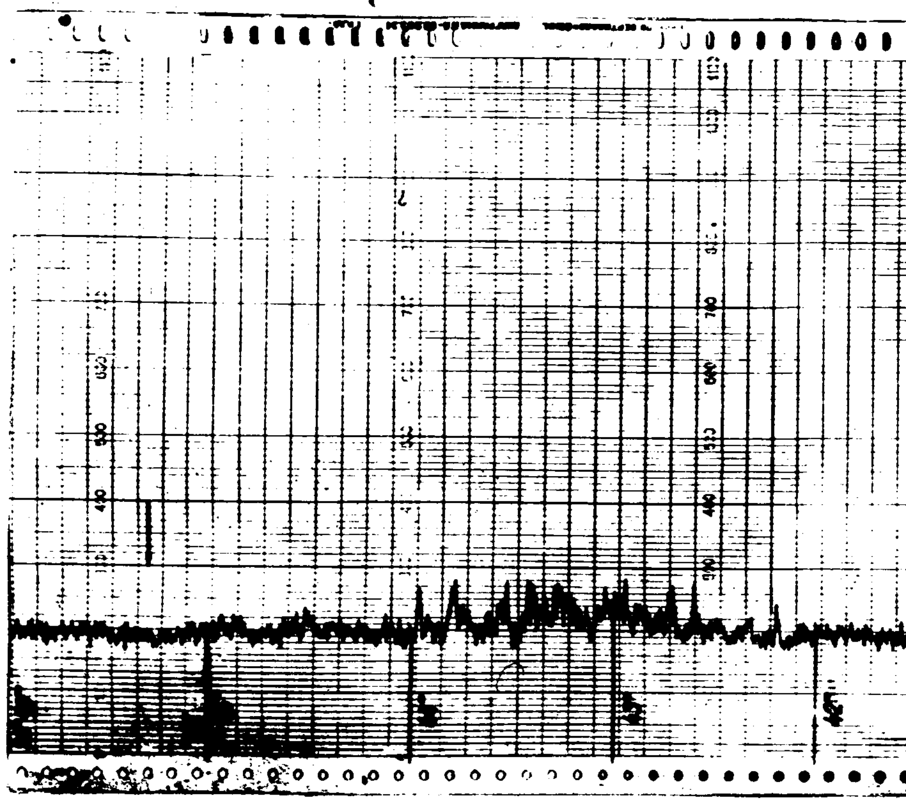

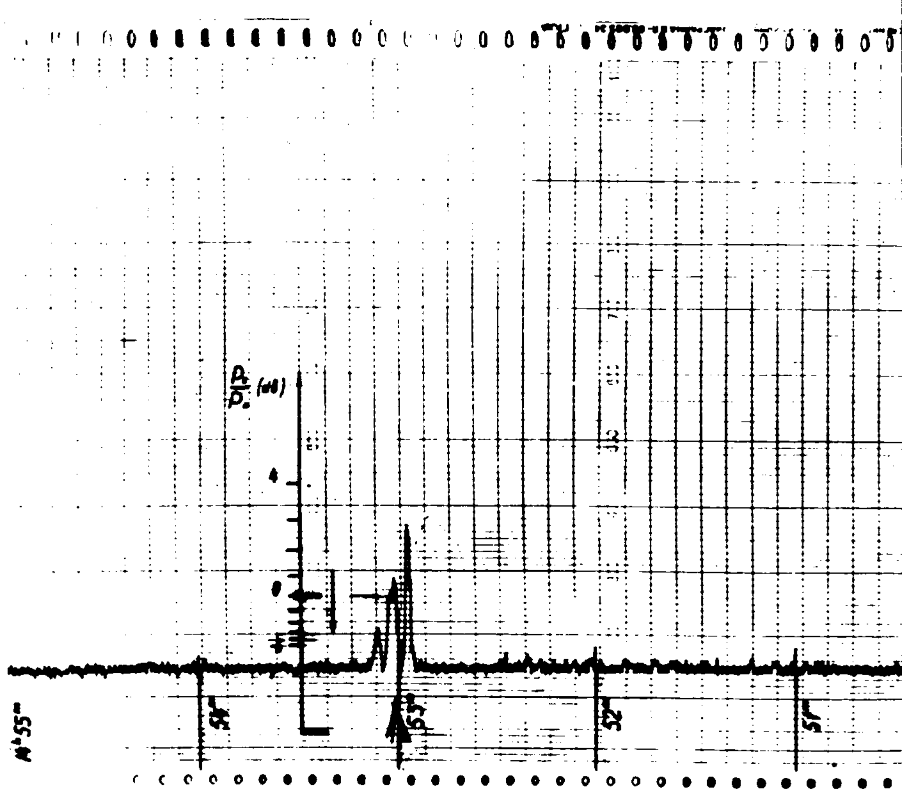

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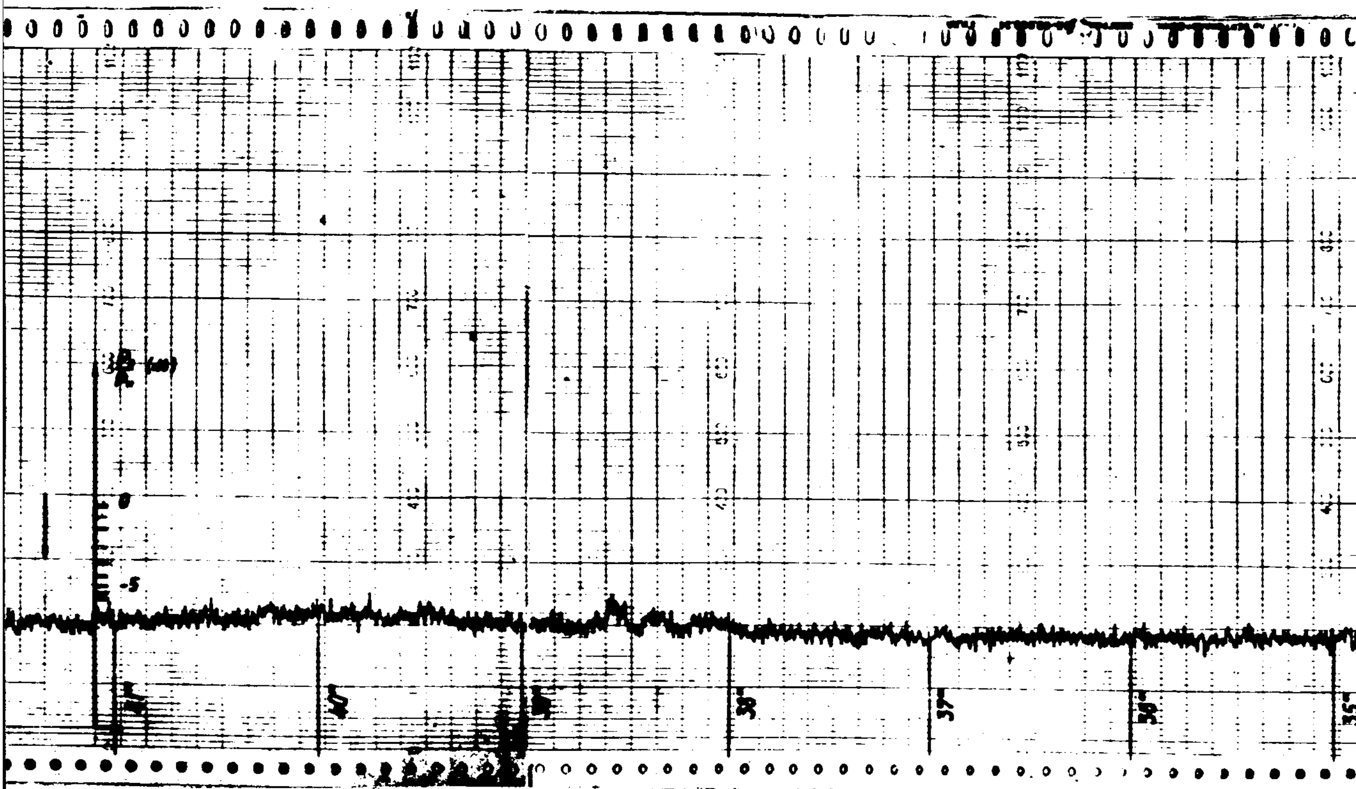

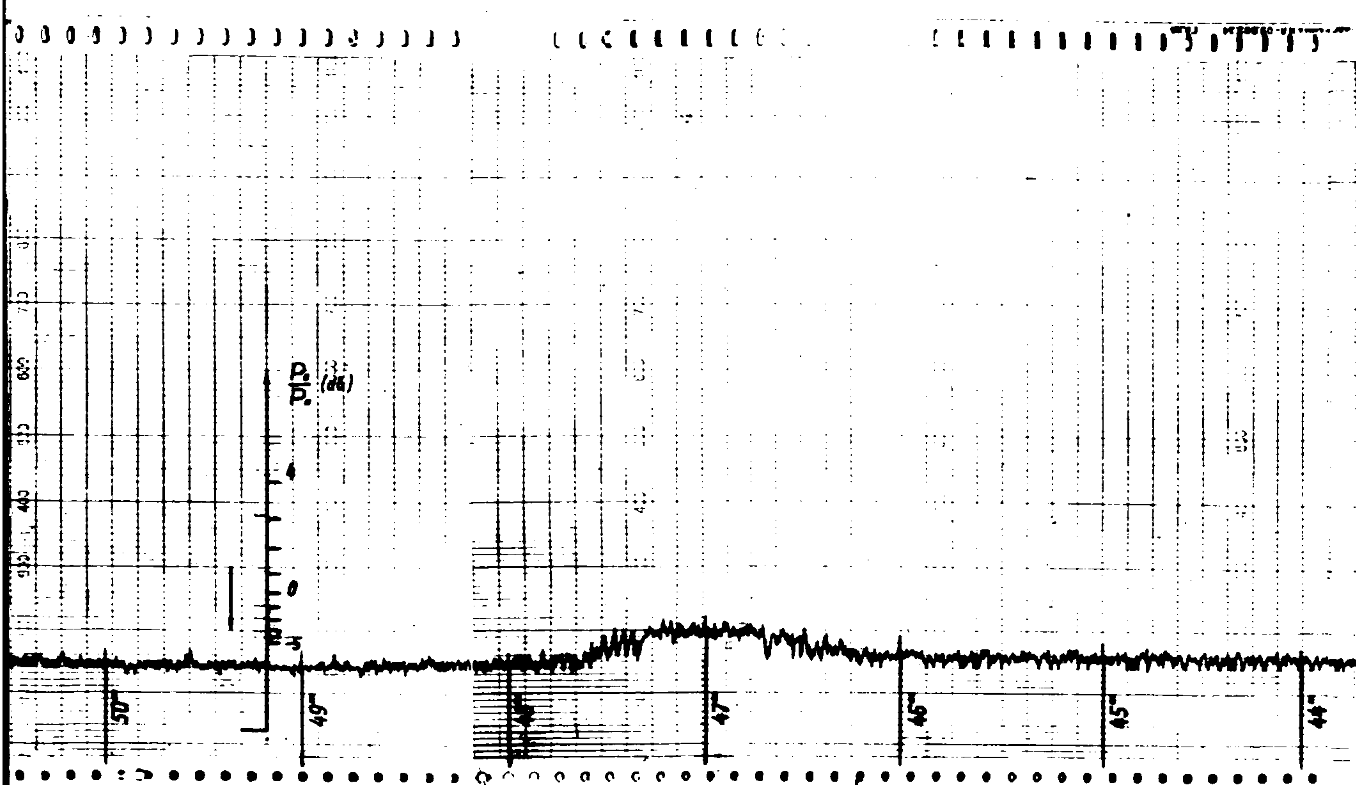

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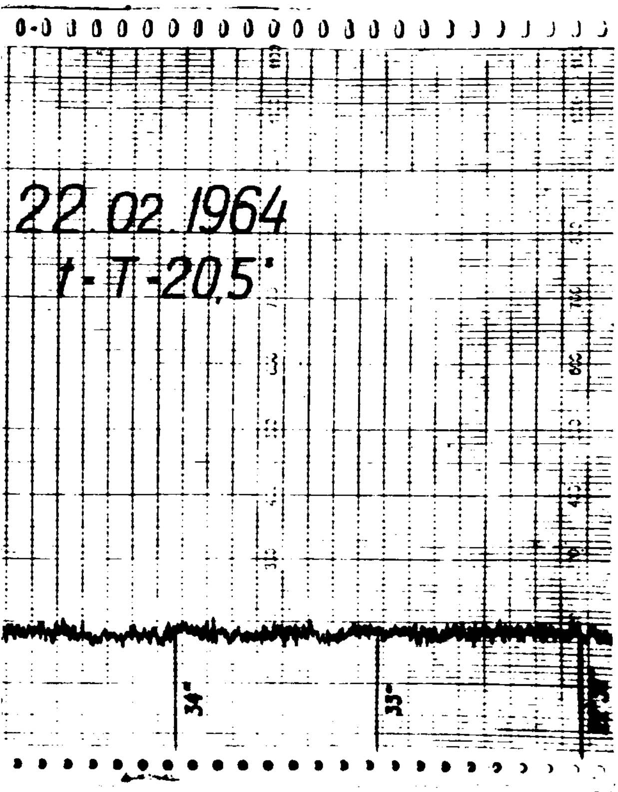

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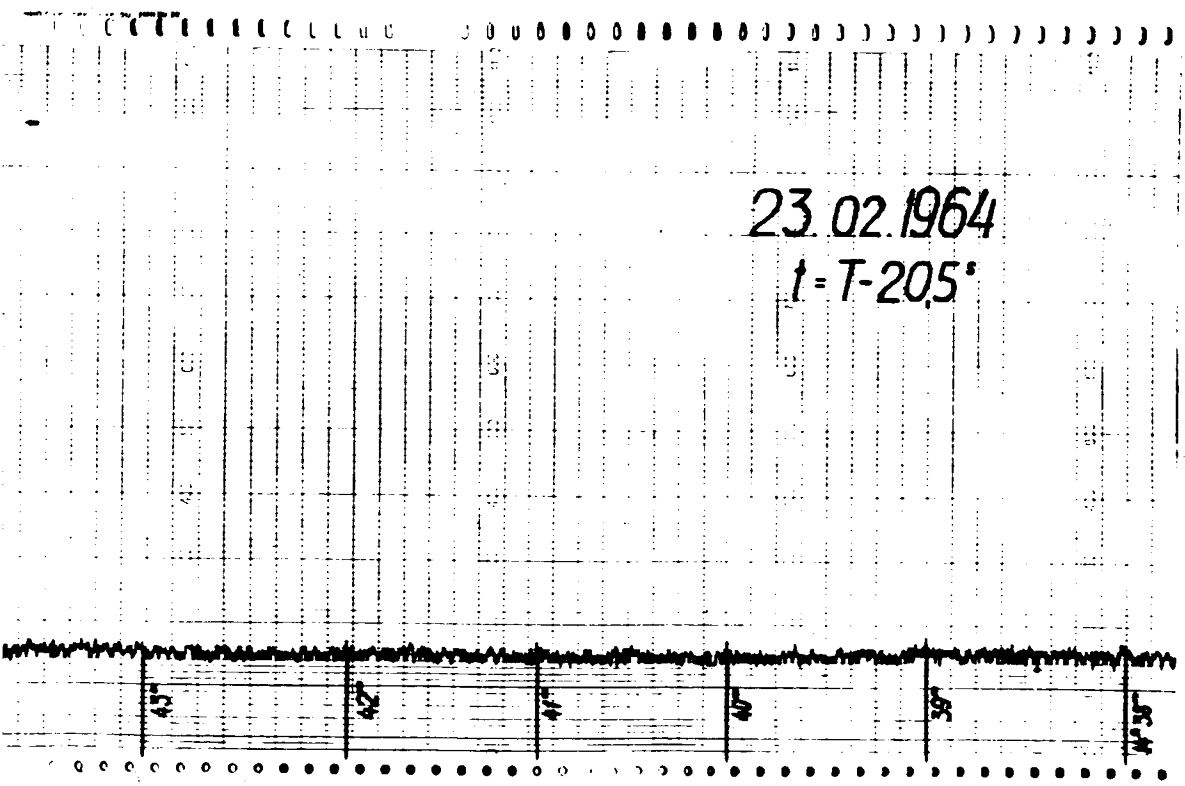

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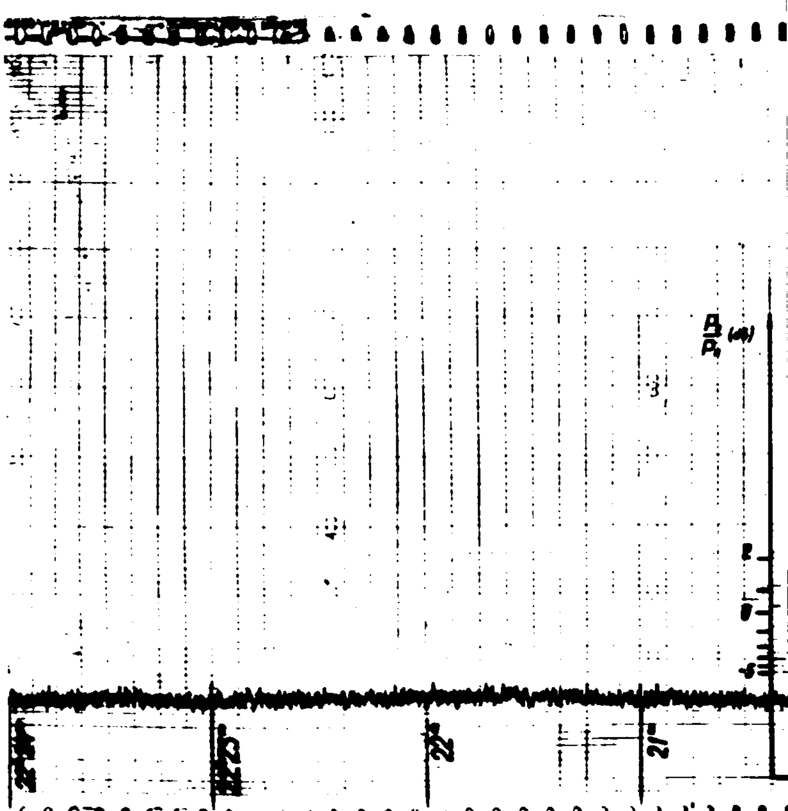

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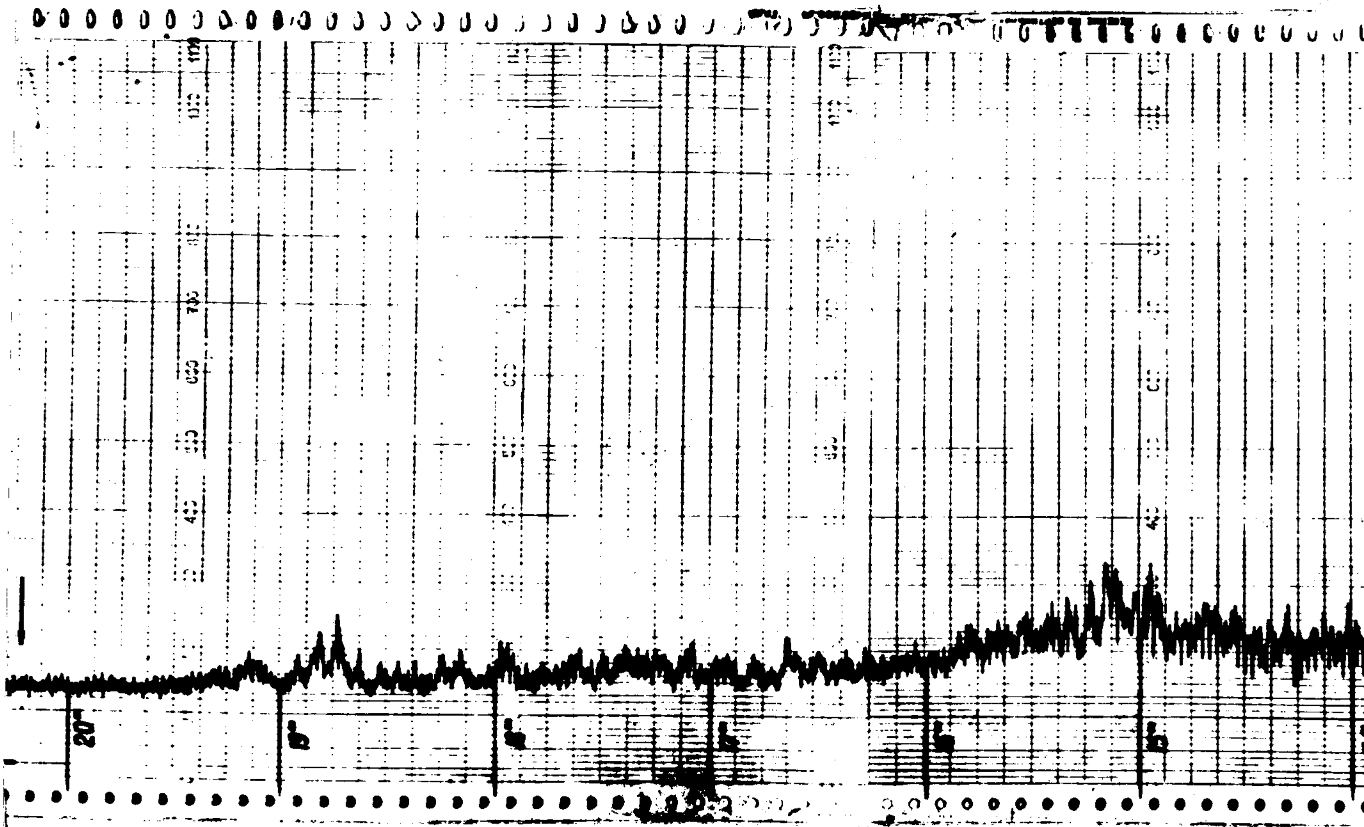

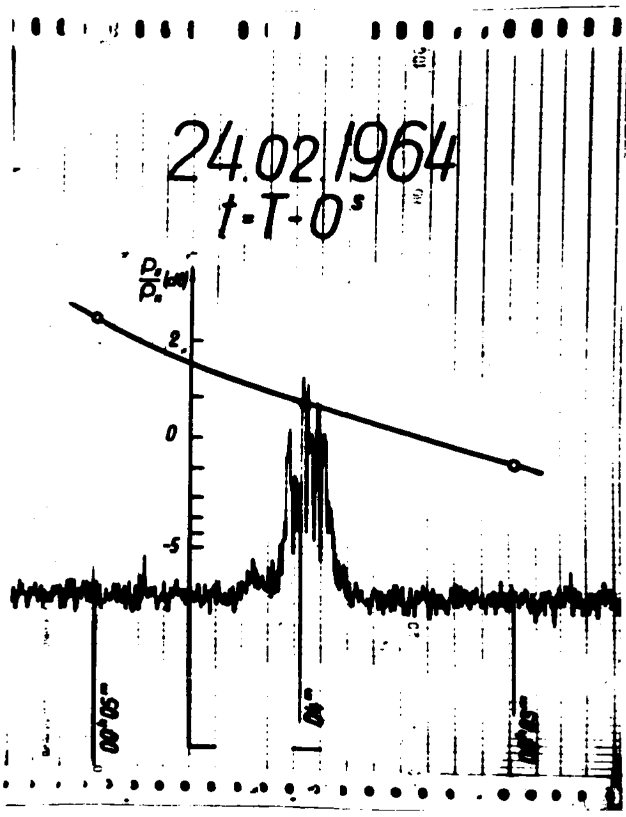

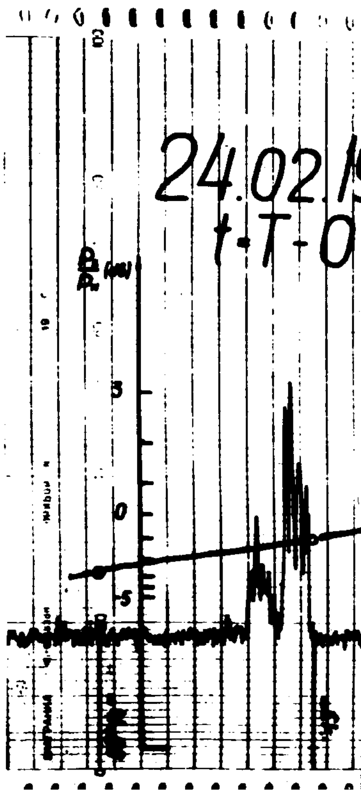

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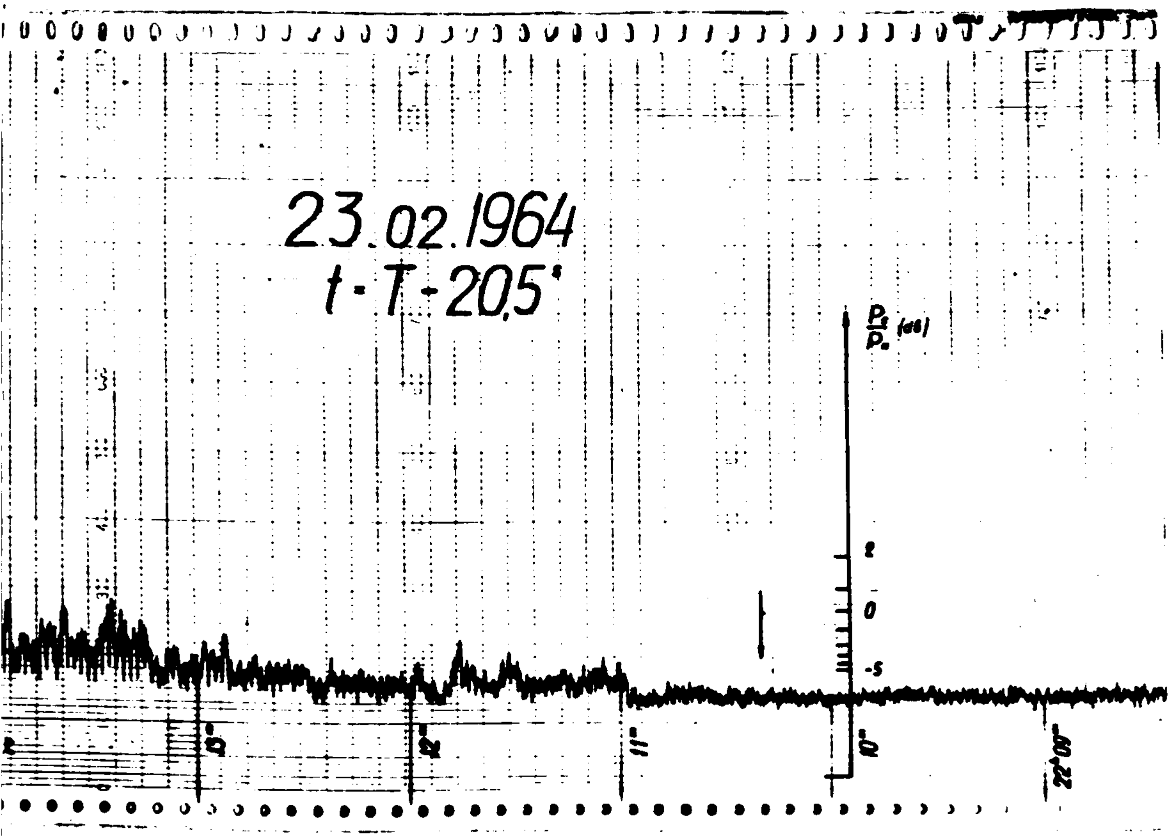

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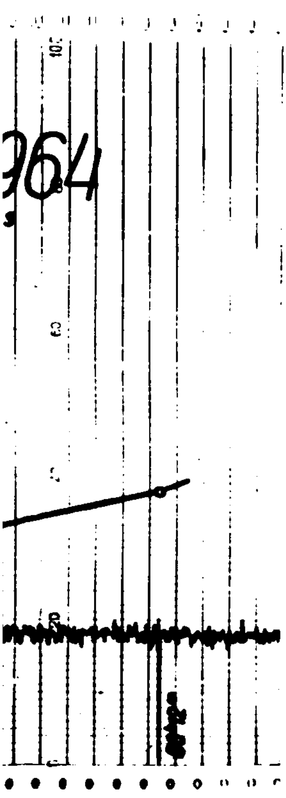

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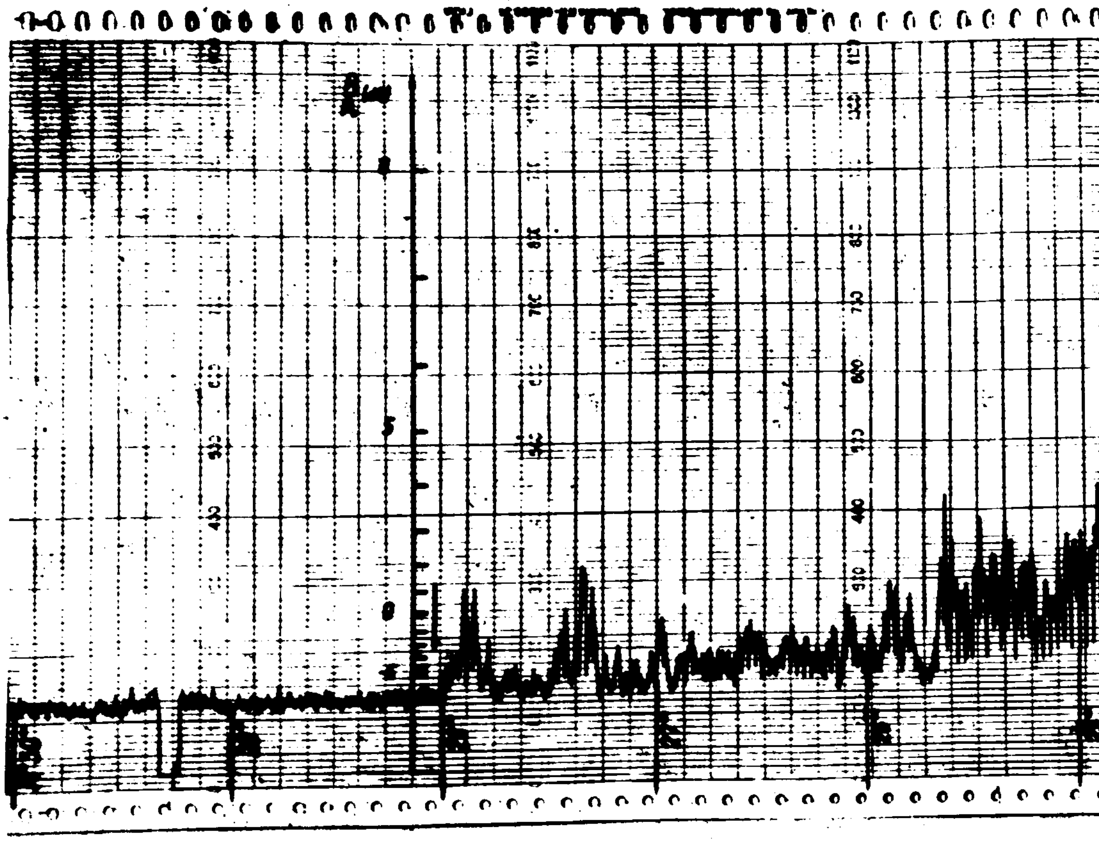
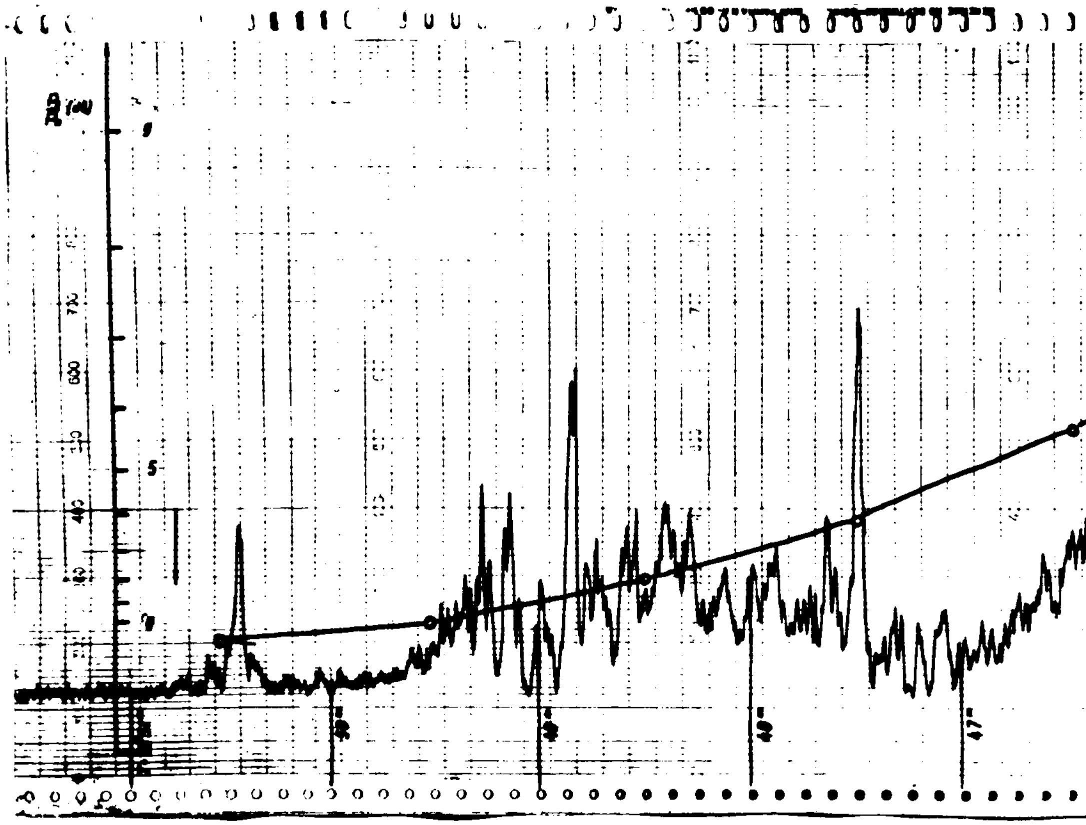
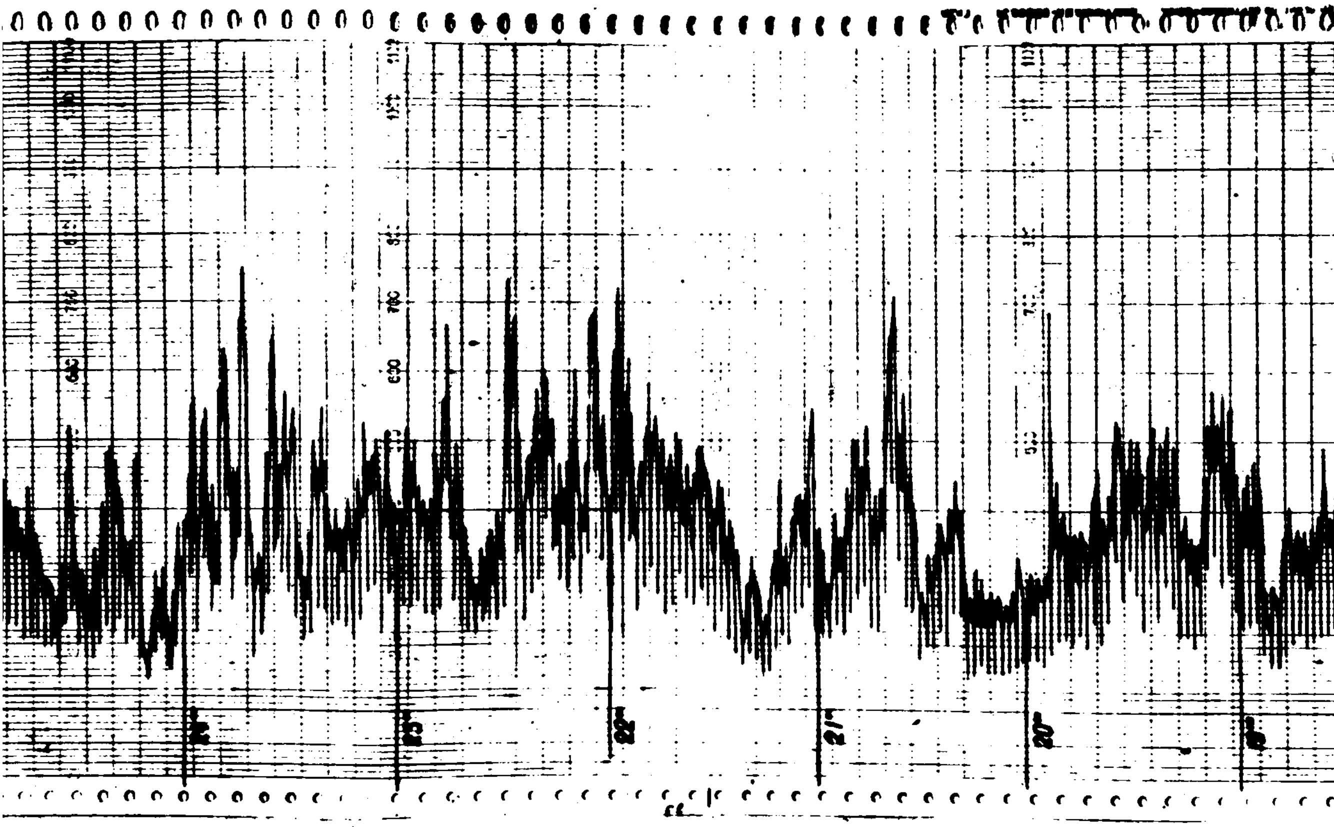
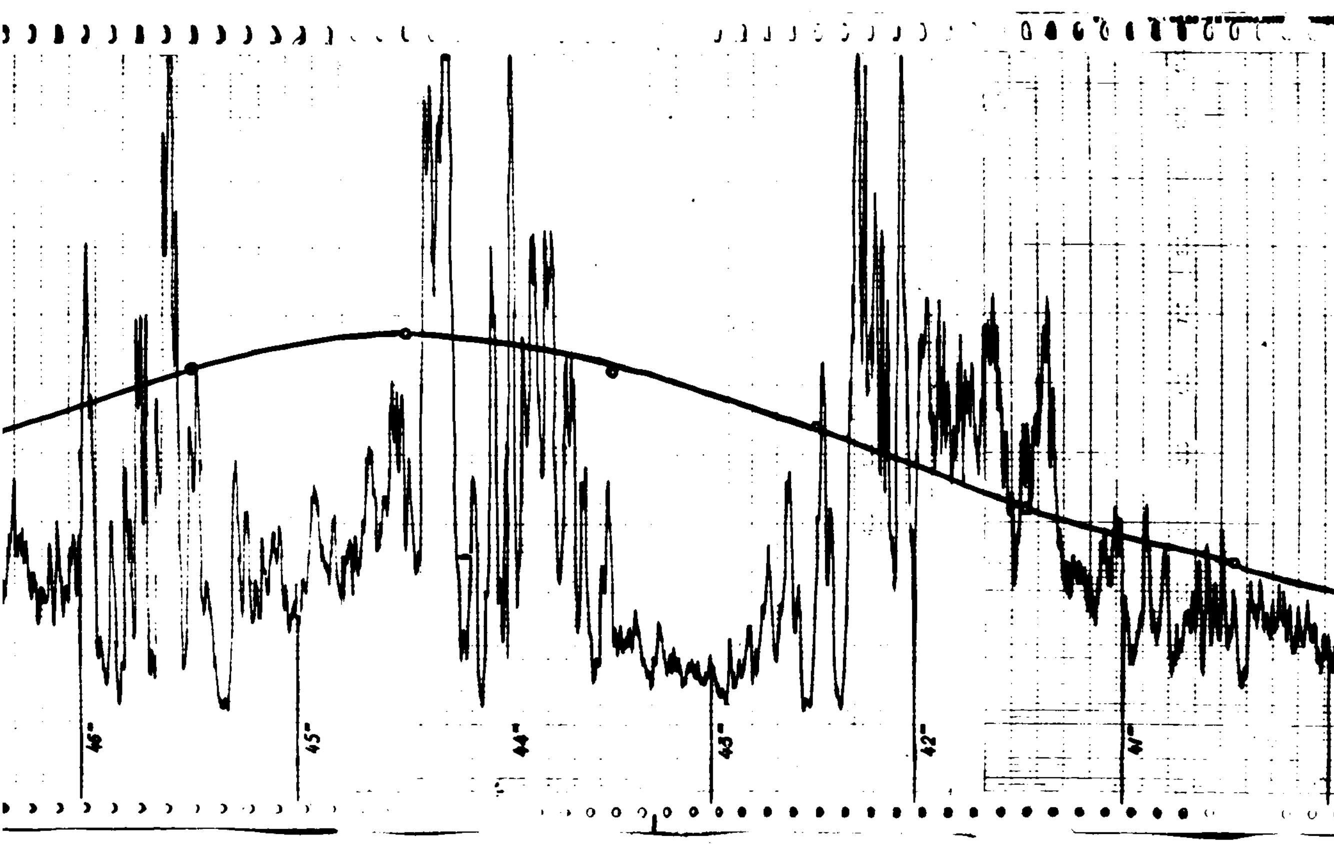
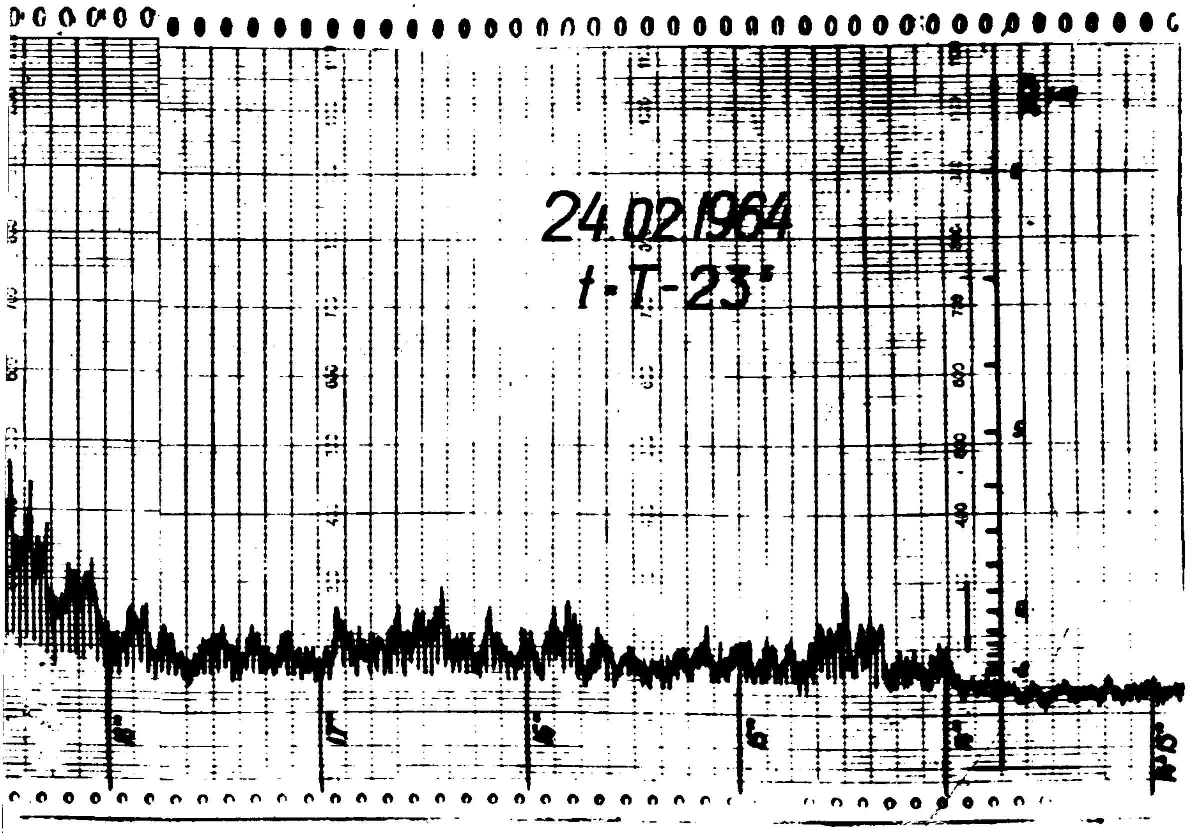





24"
23"
22"
21"
20"
19"


46"
45"
44"
43"
42"
41"

3



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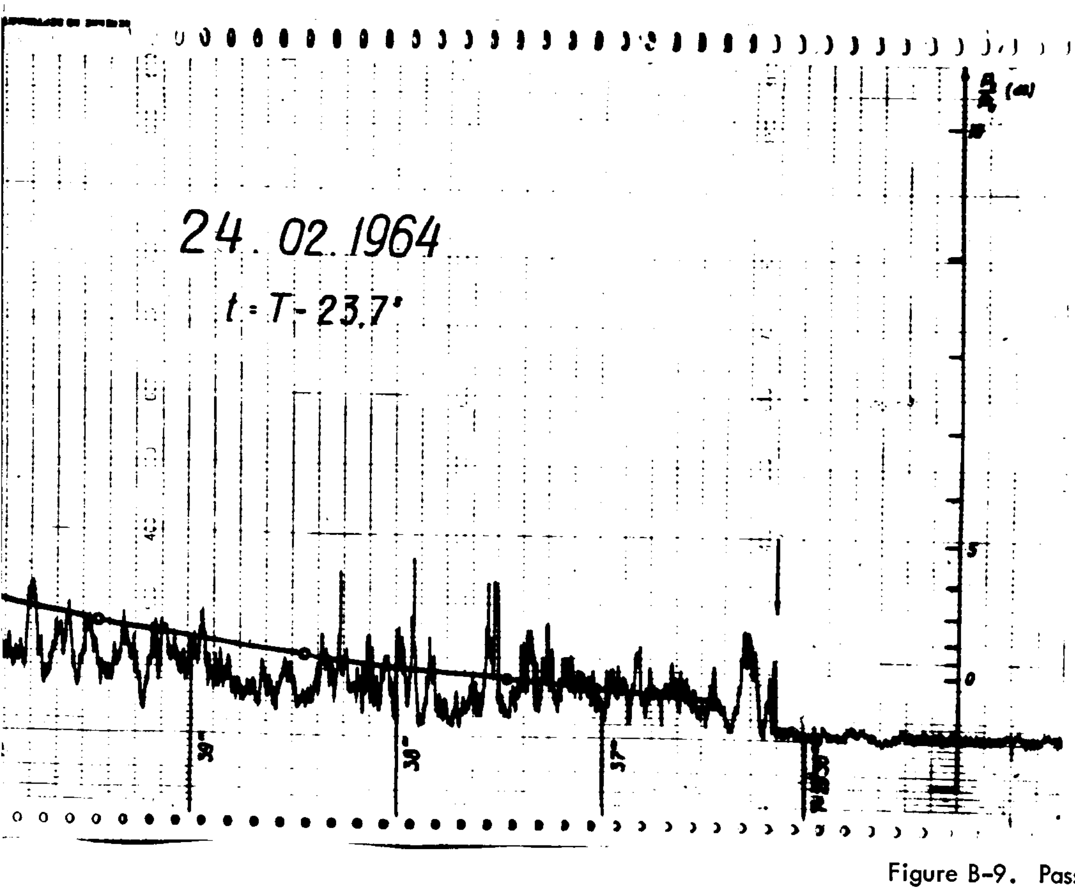

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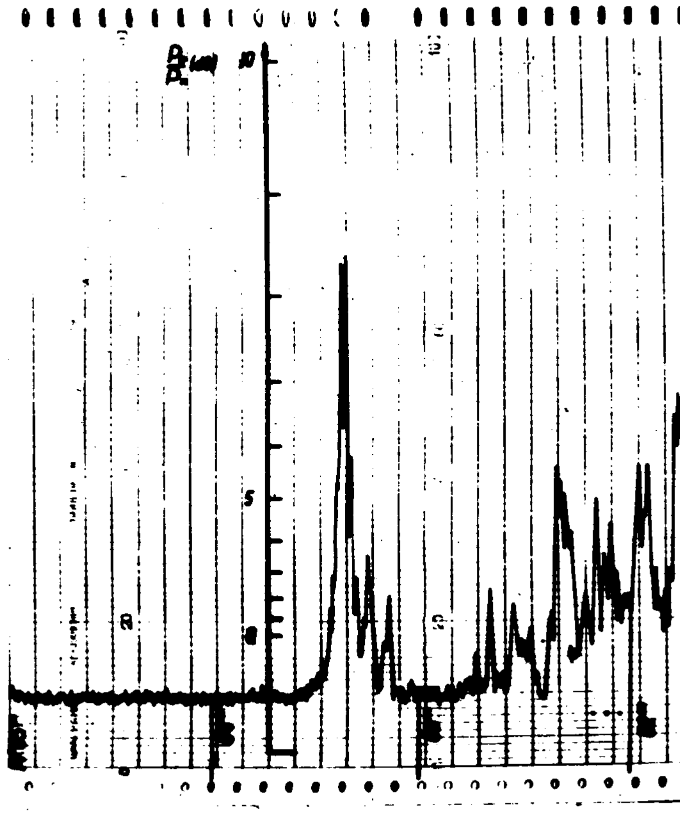

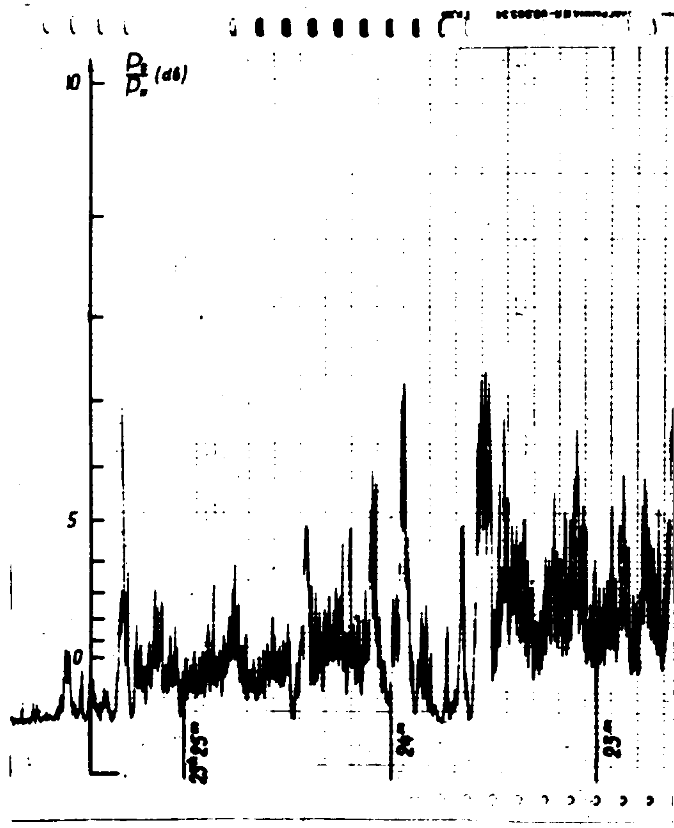

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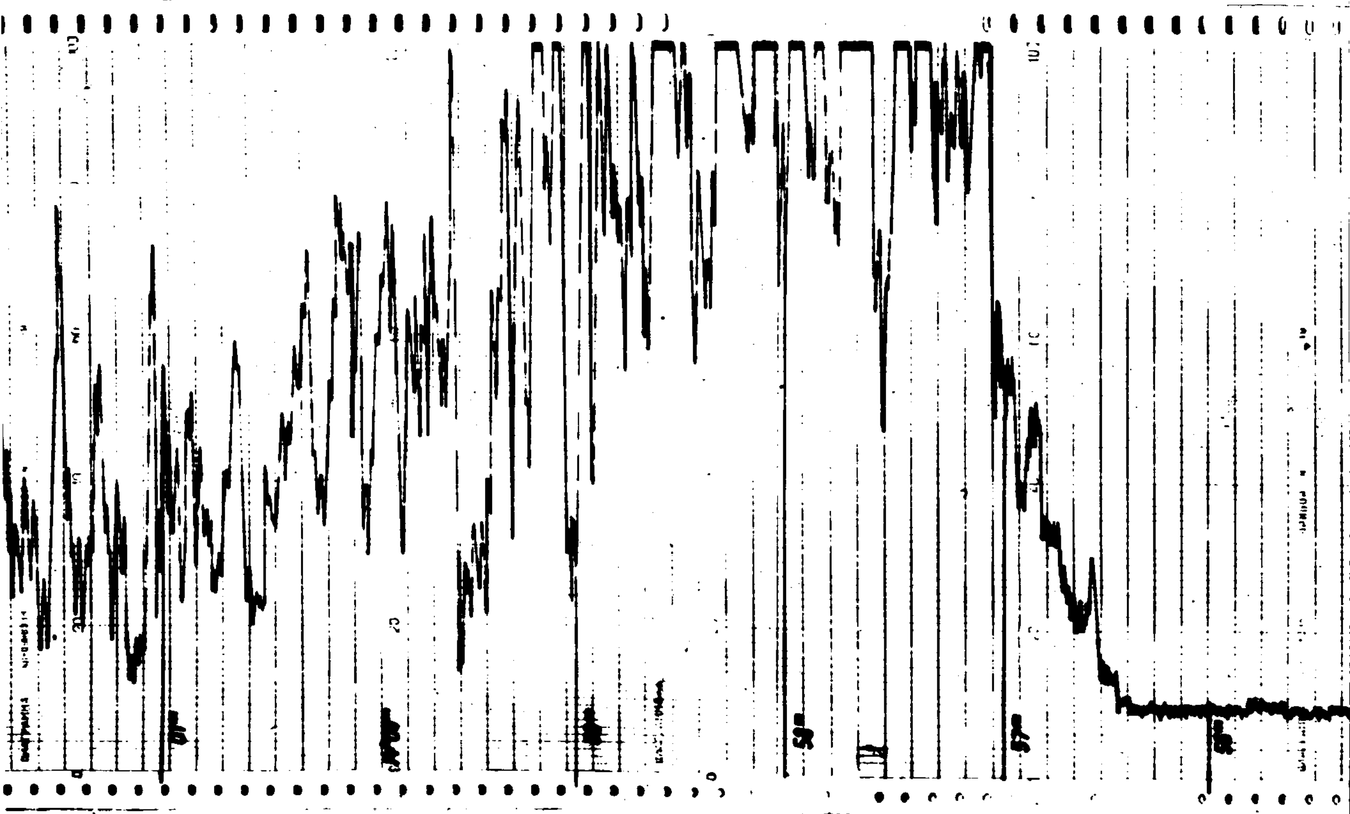

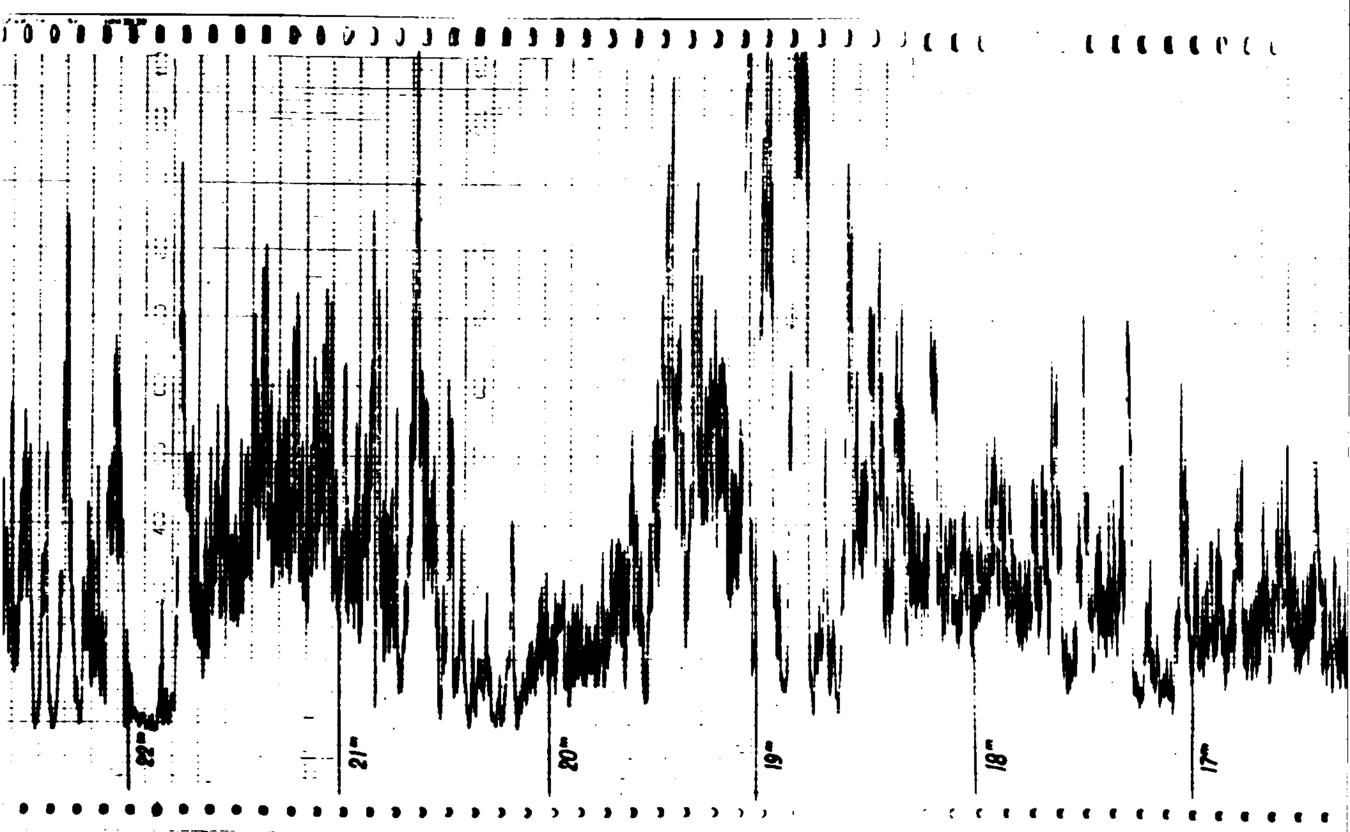

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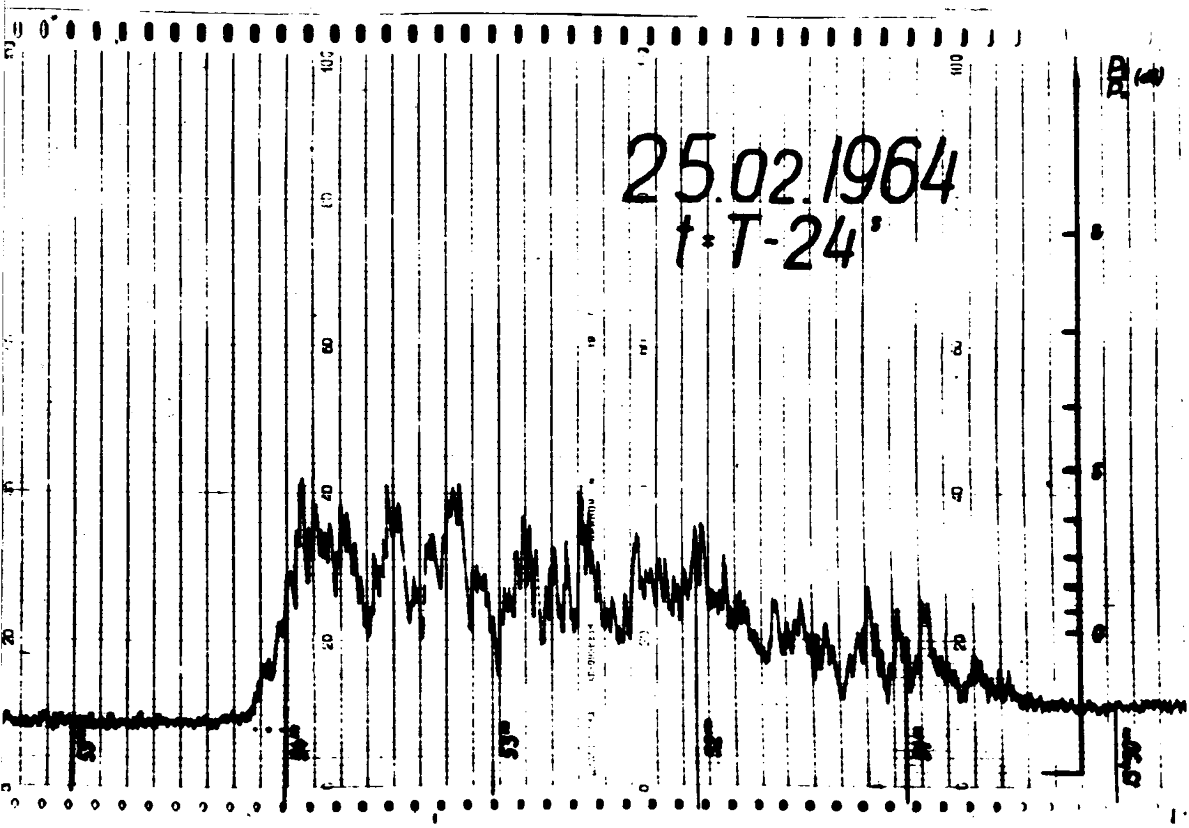

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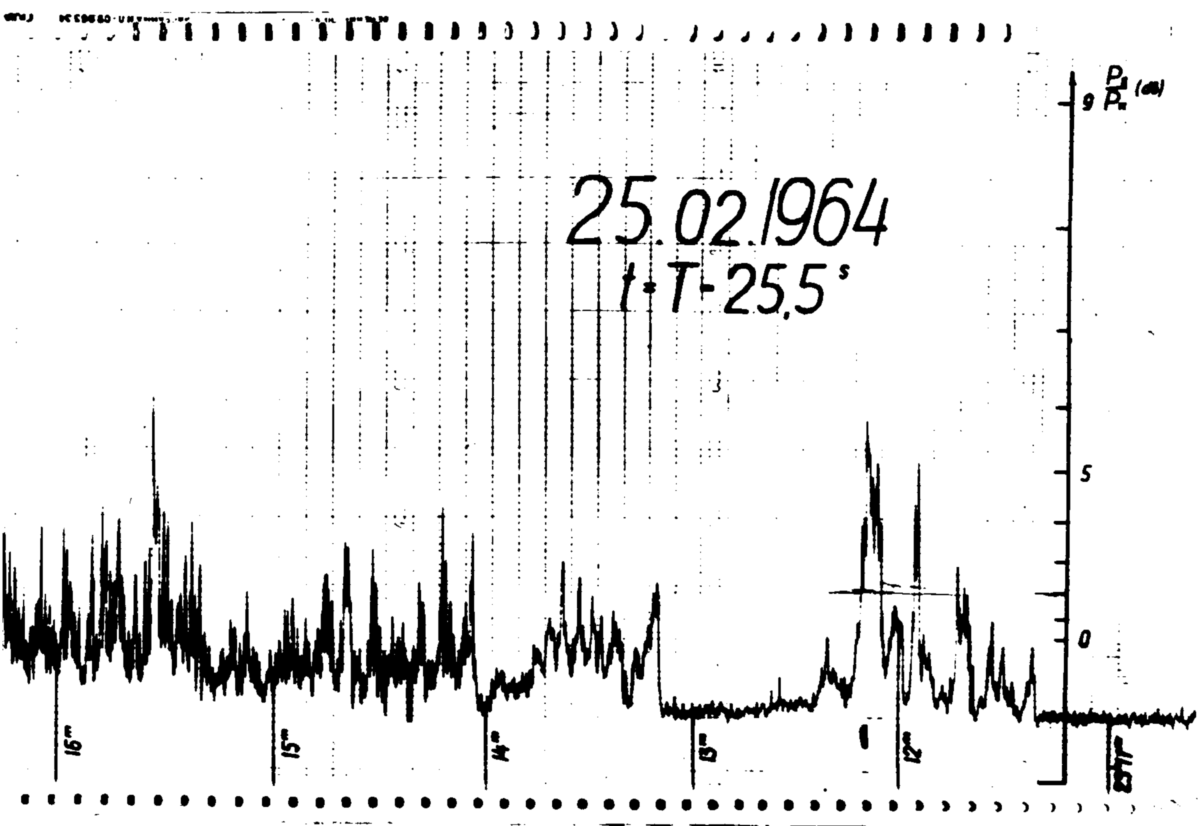

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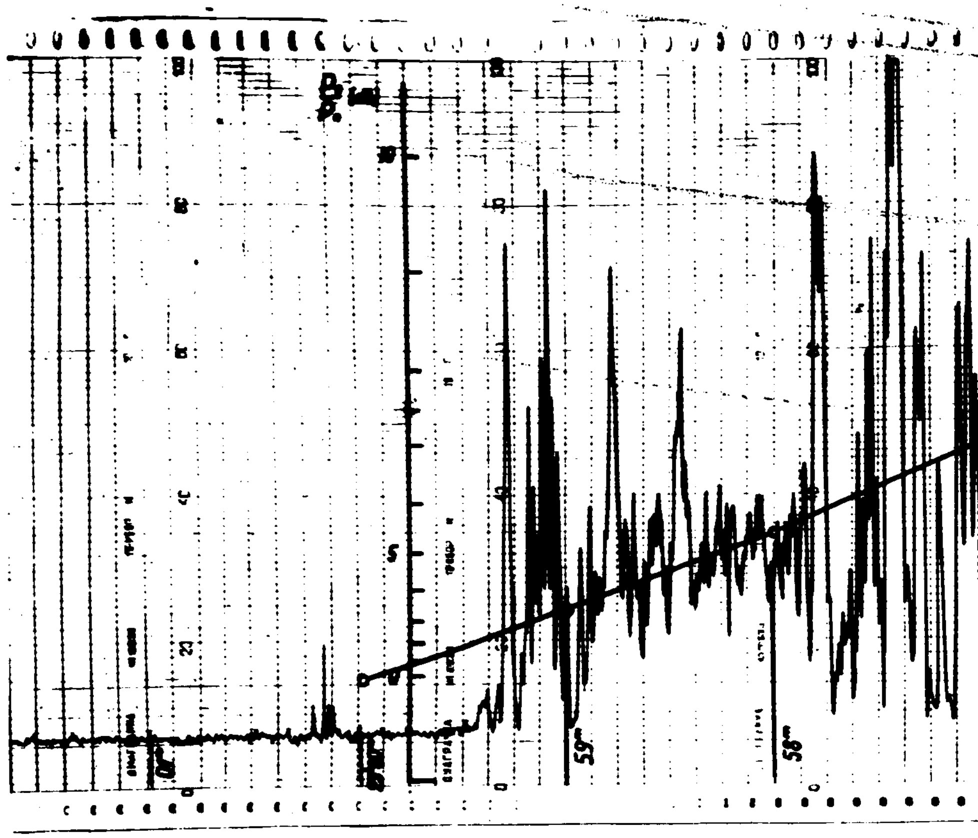
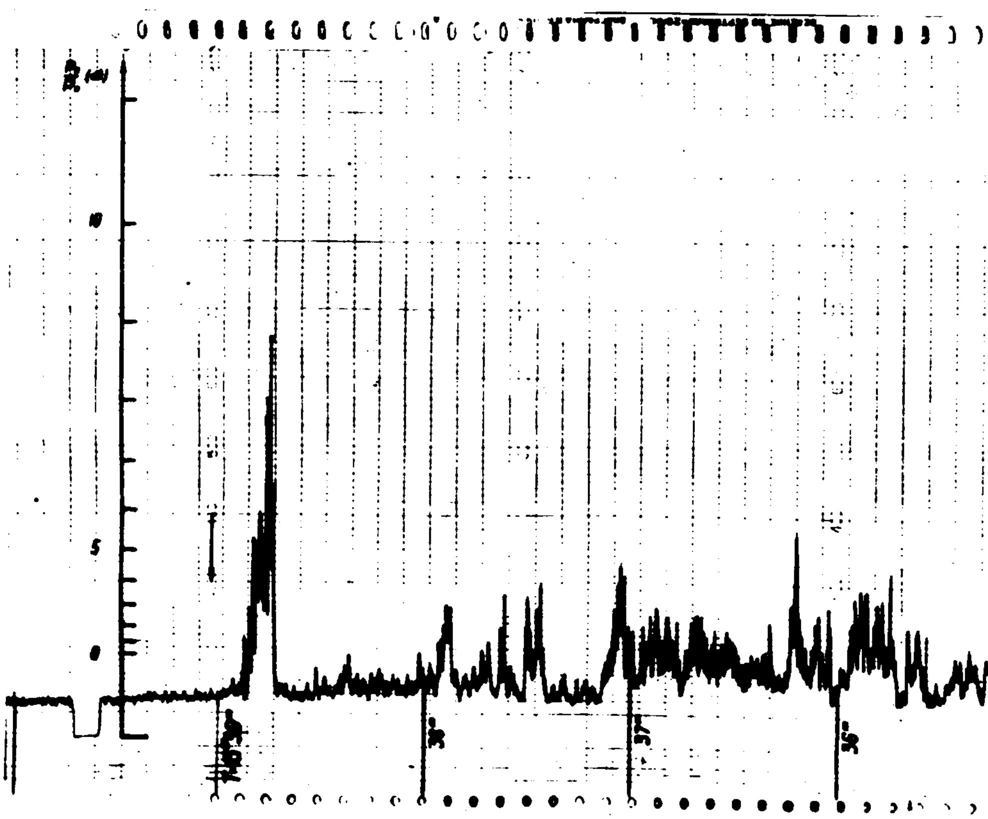
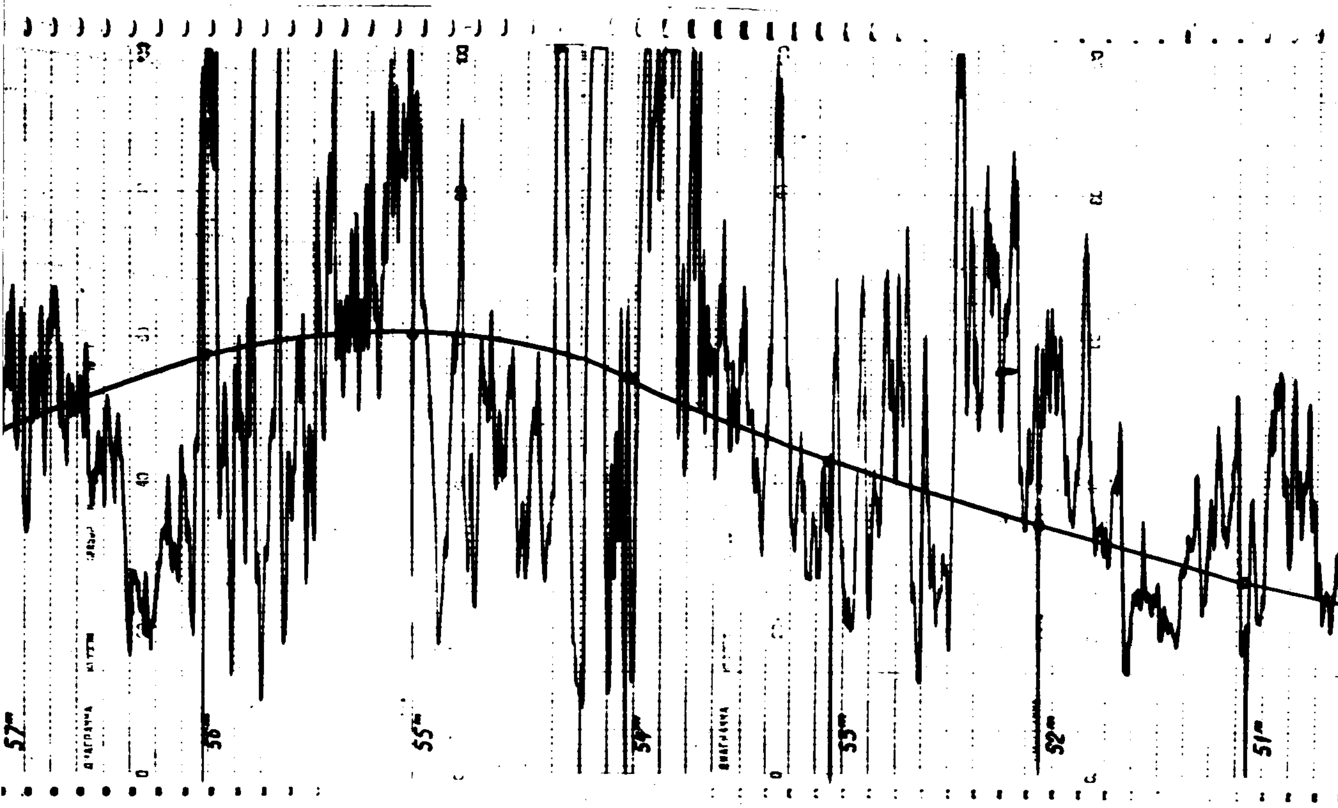
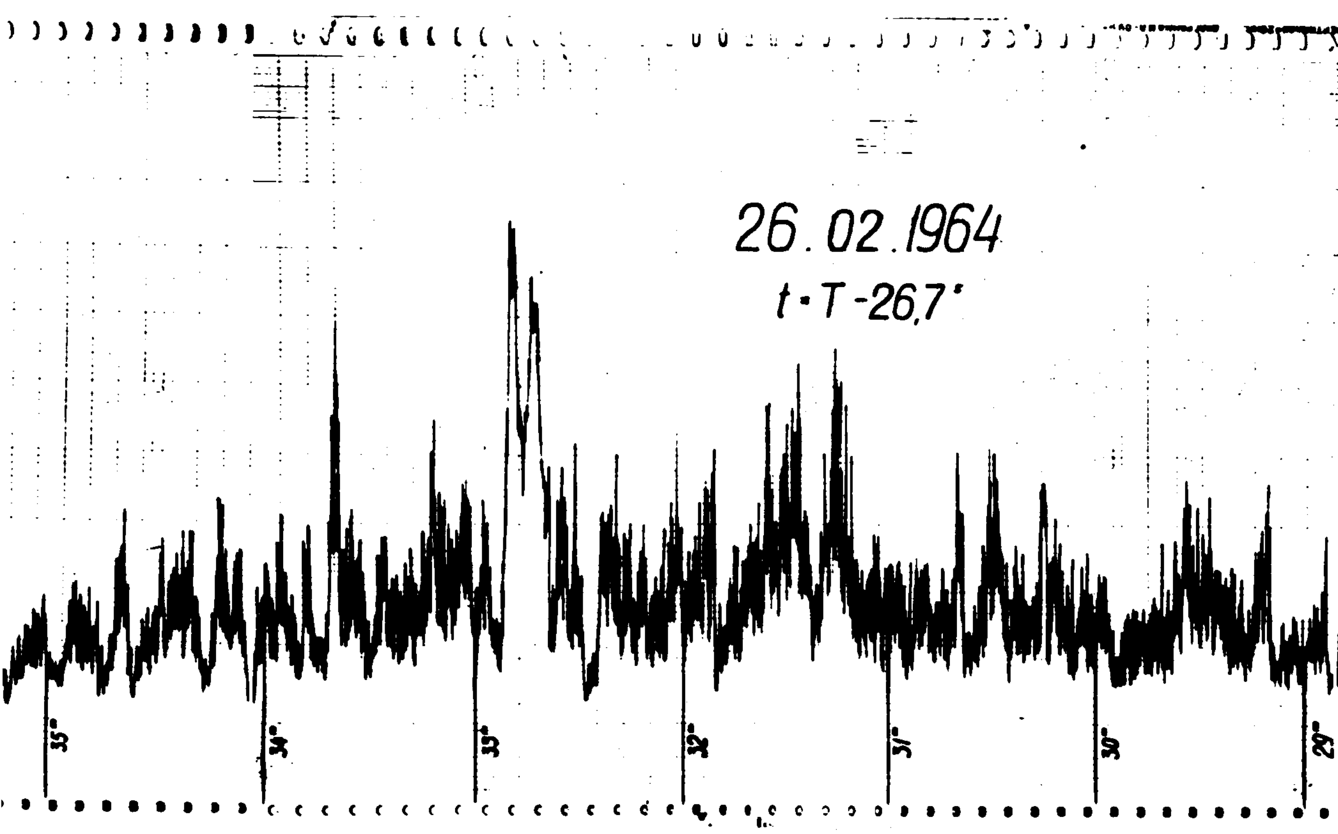
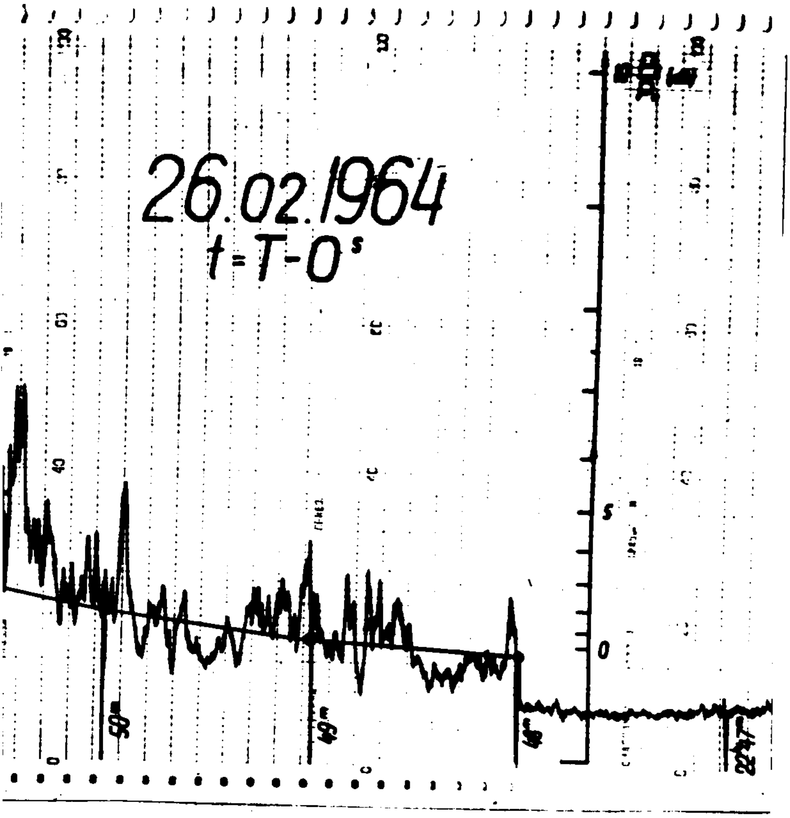





57m
56
55m
54m
53m
52m
51m


26.02.1964
t - T -26,7°
35
34
33
32
31
30
29

3



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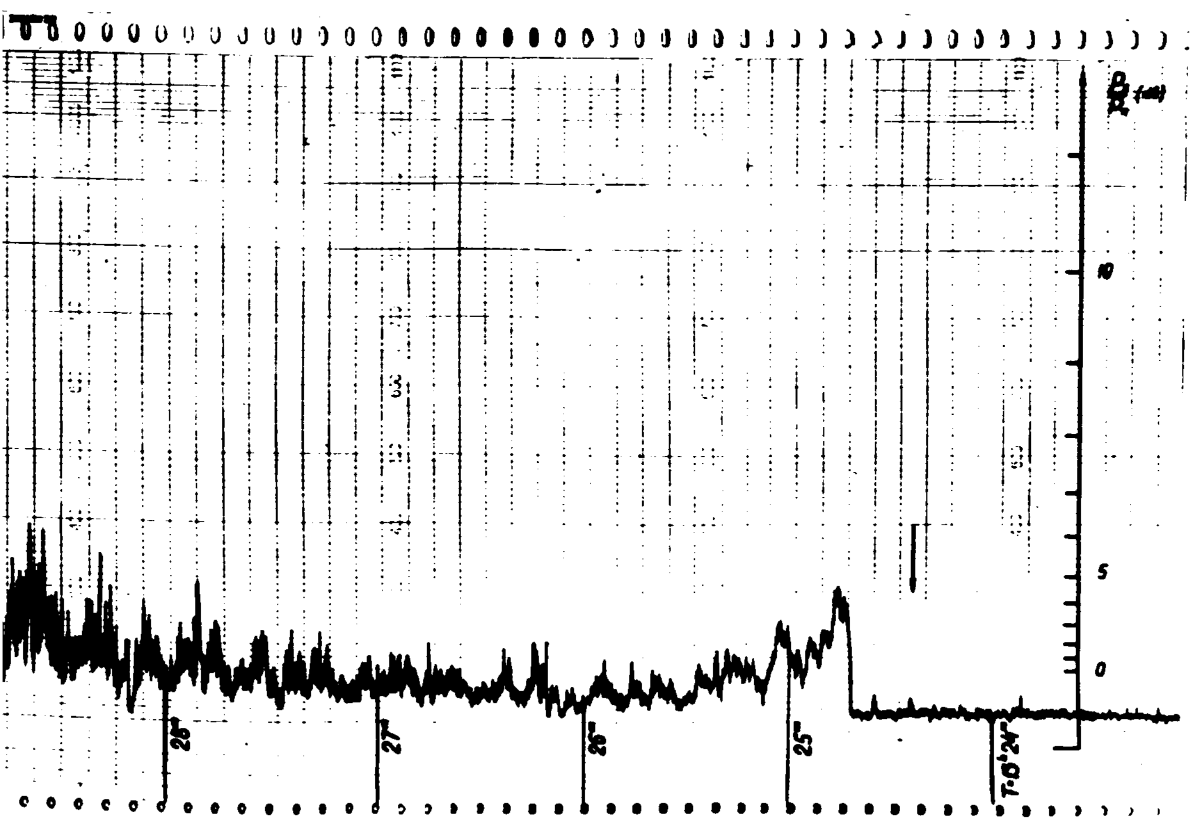

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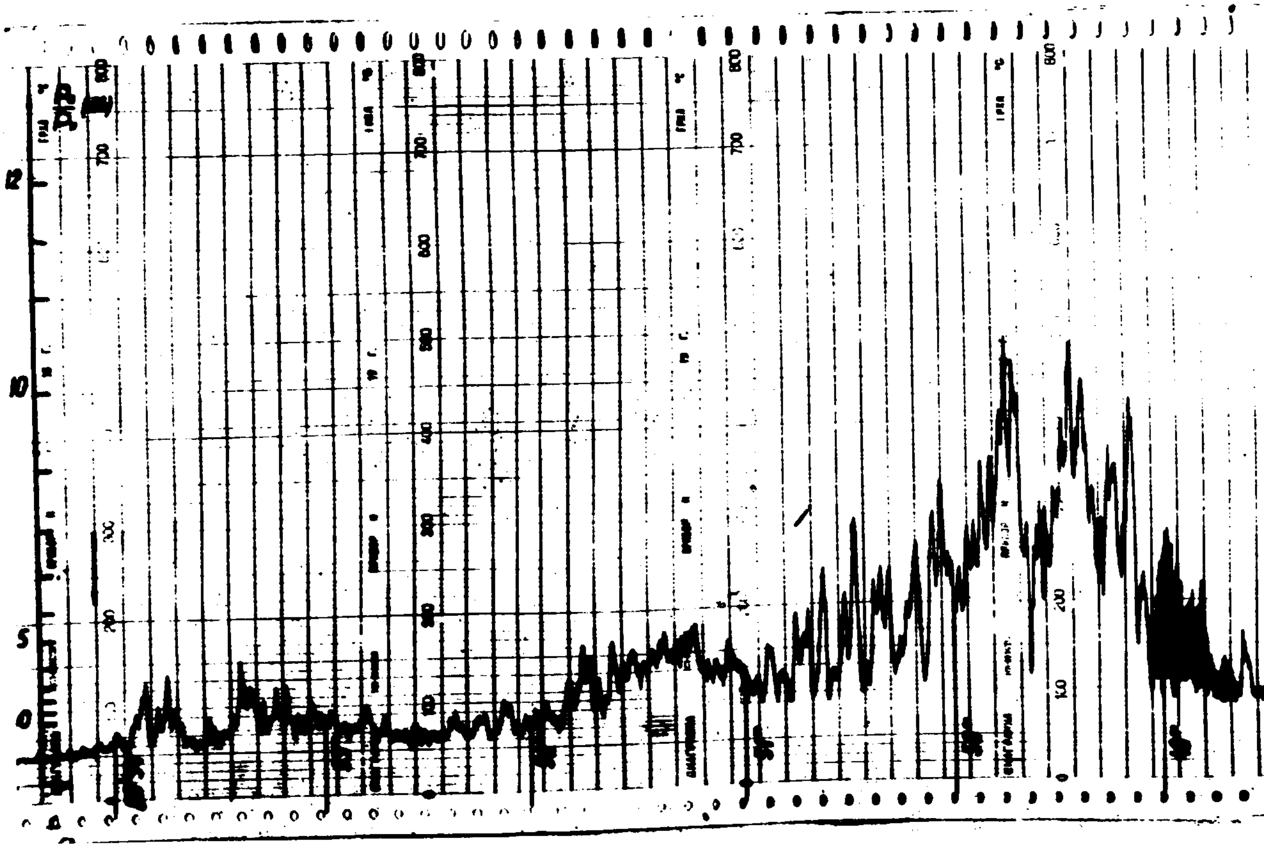

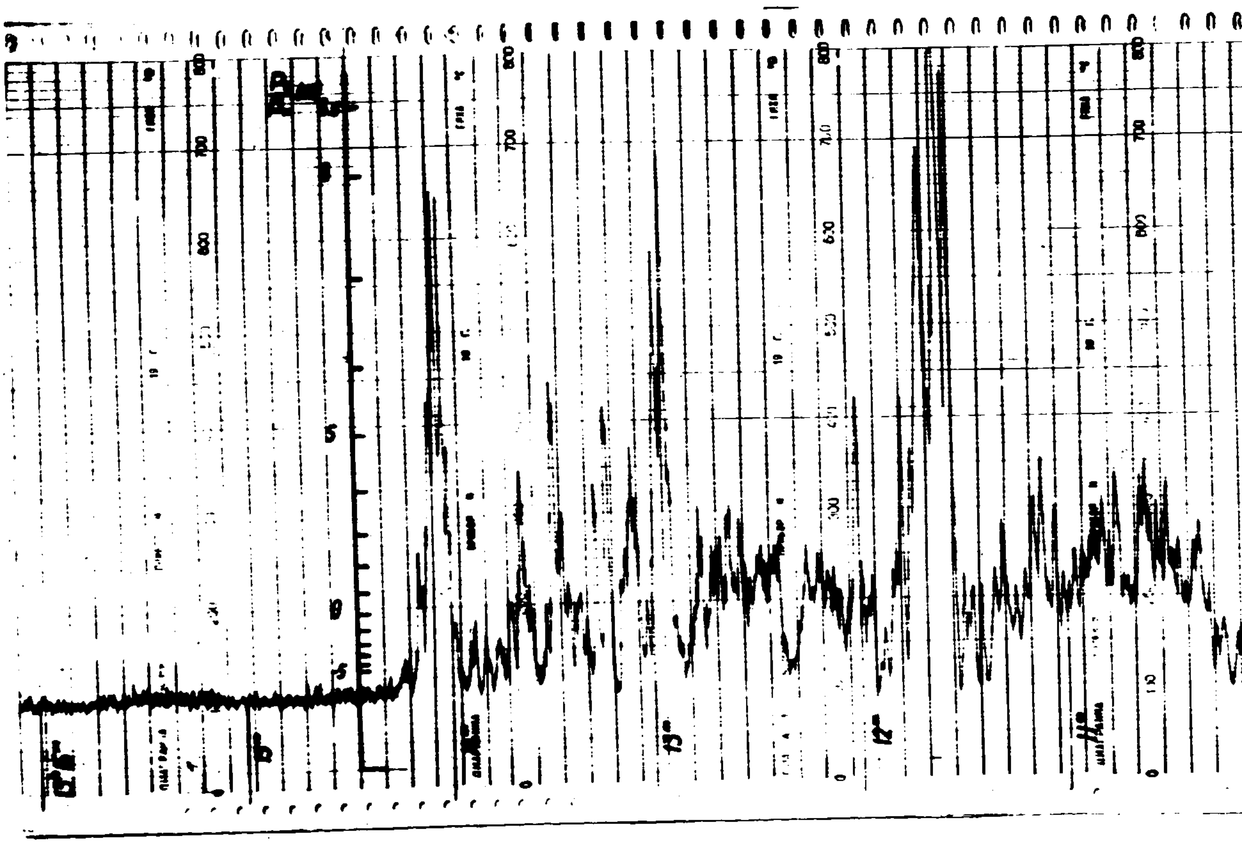

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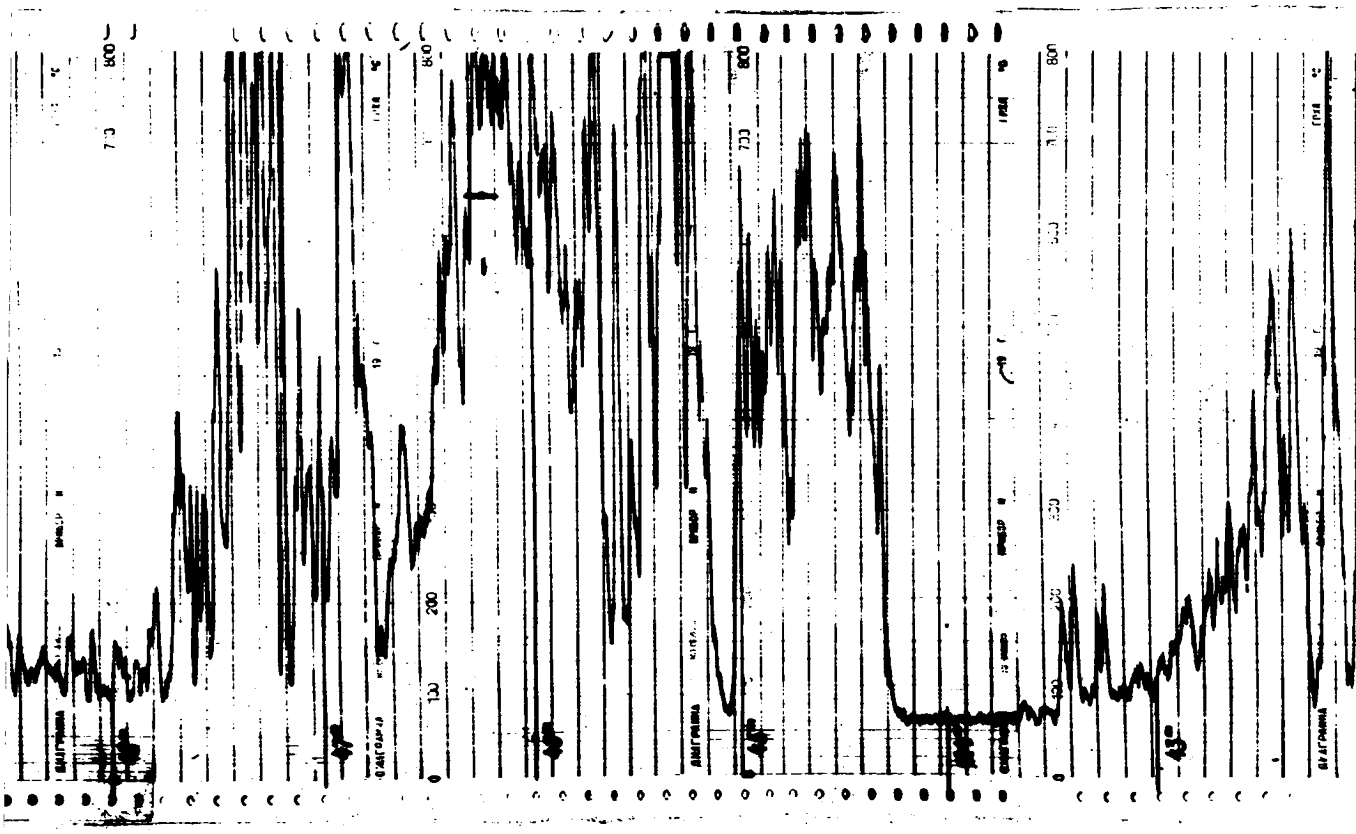

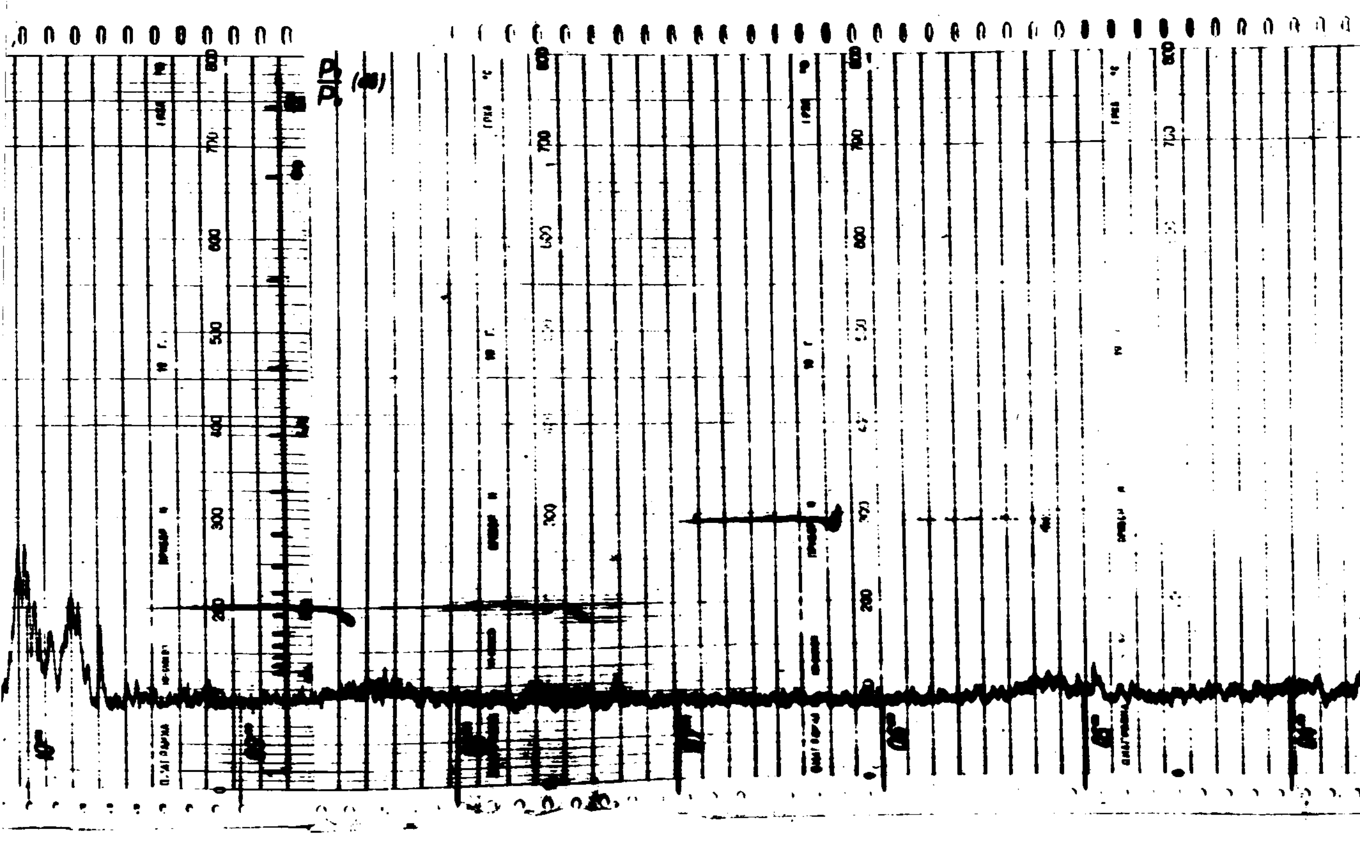

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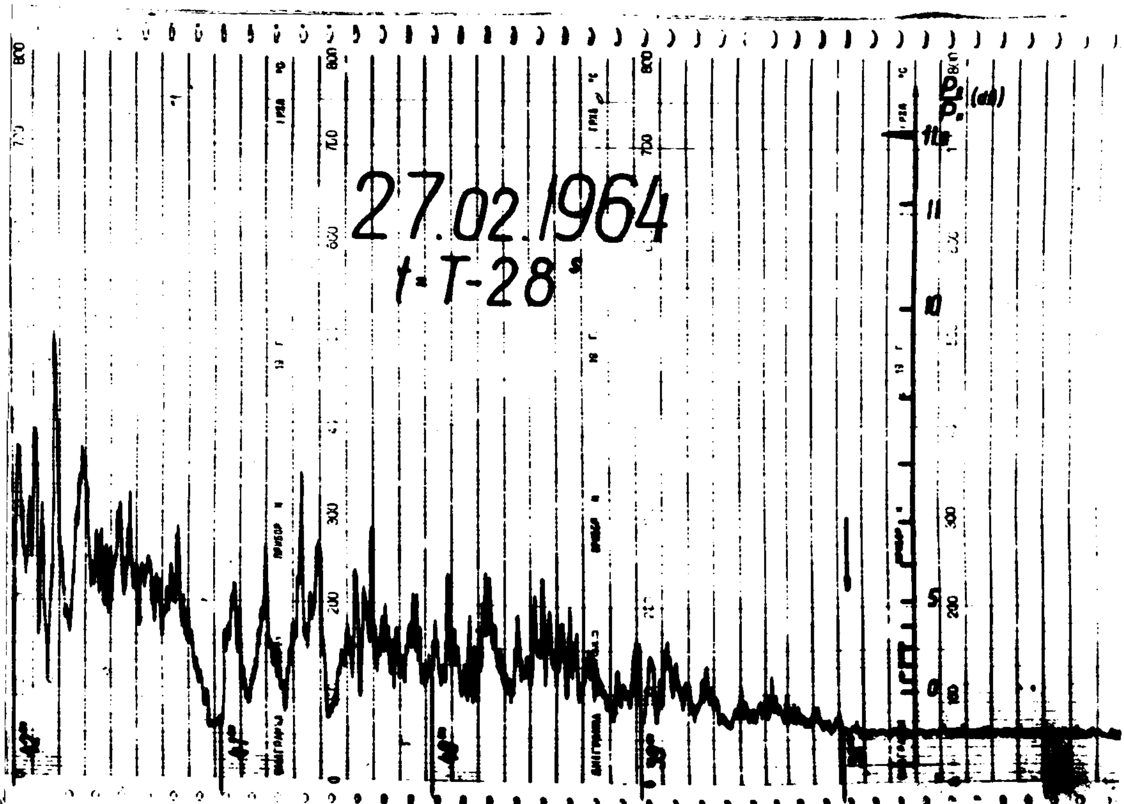

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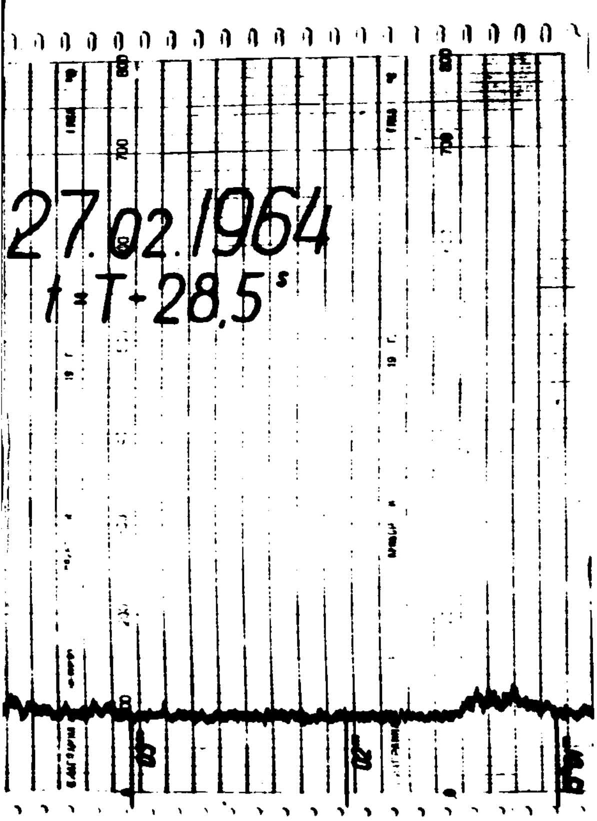

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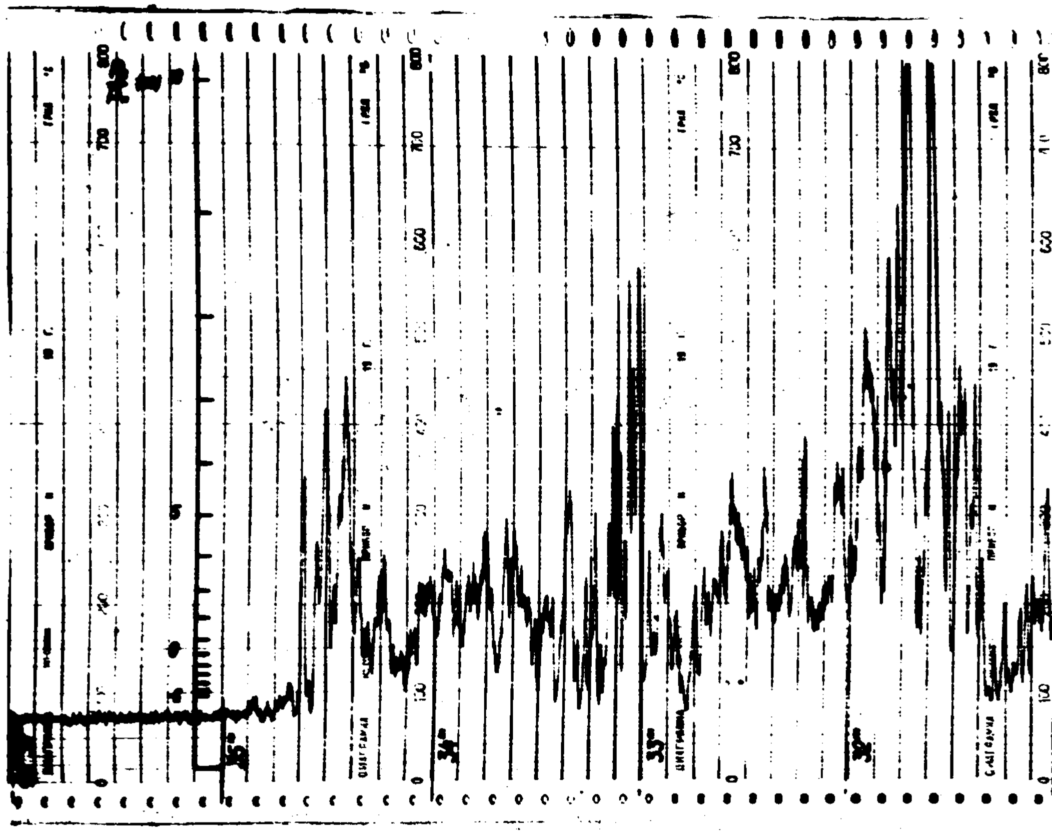

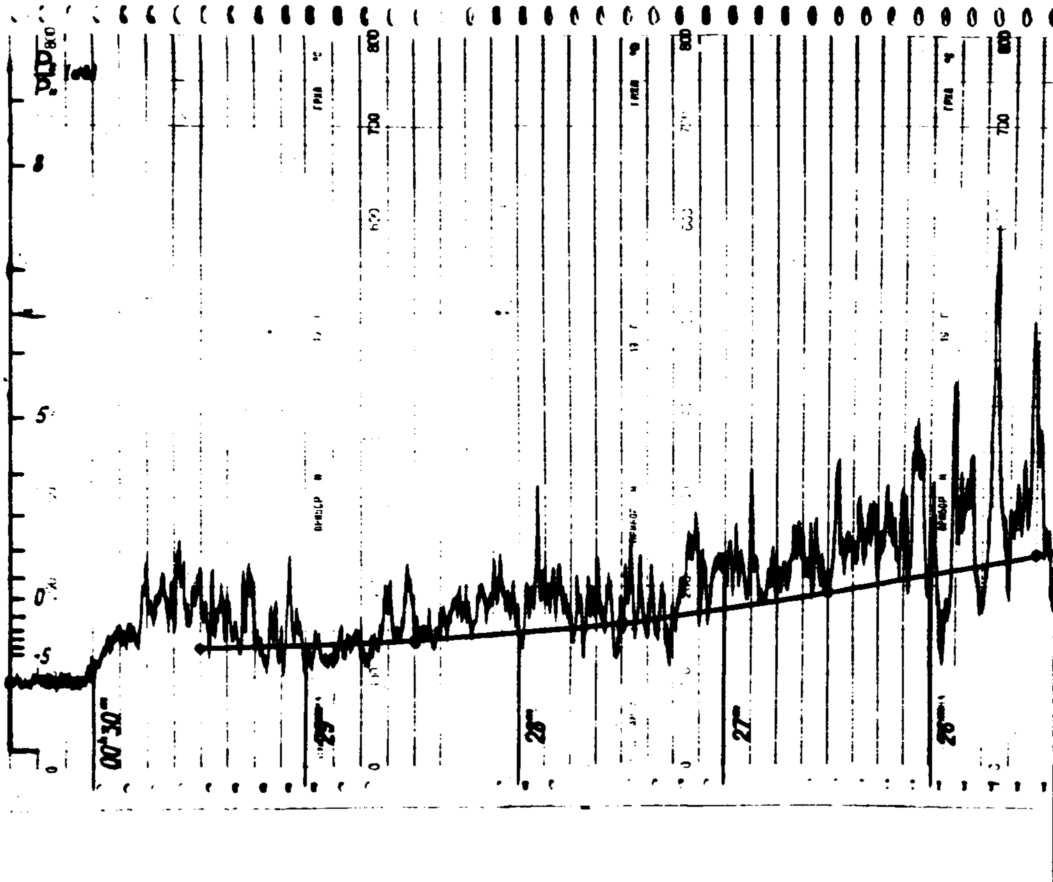

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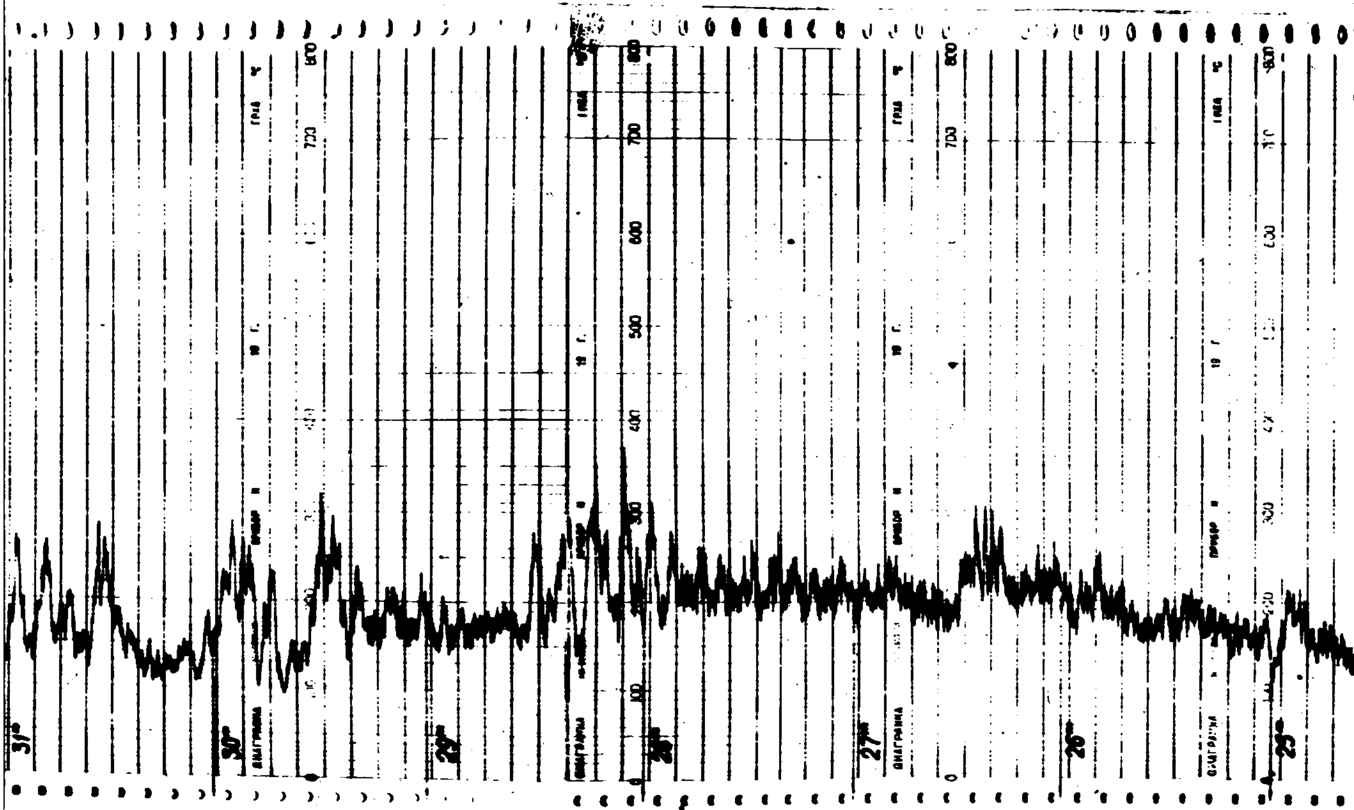

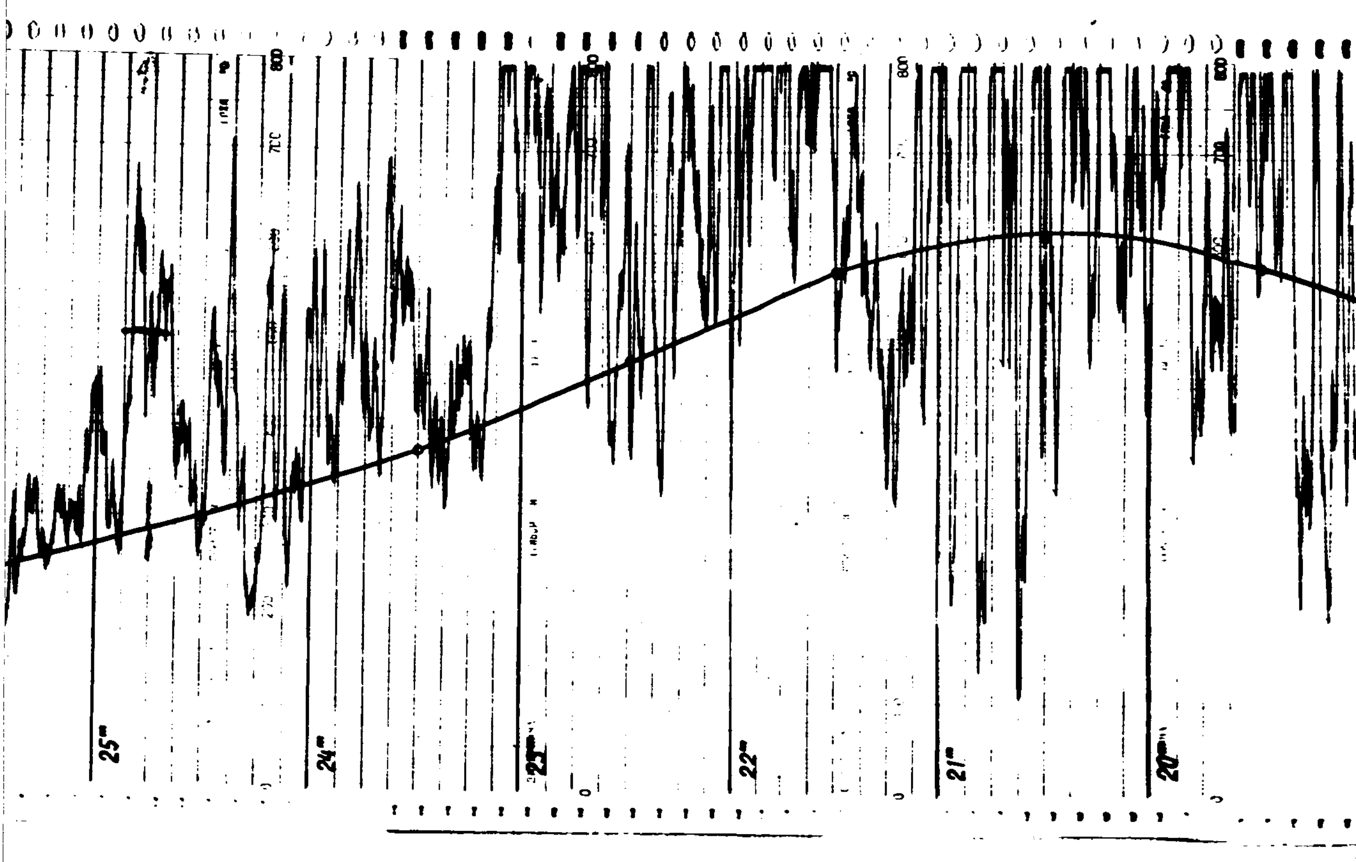

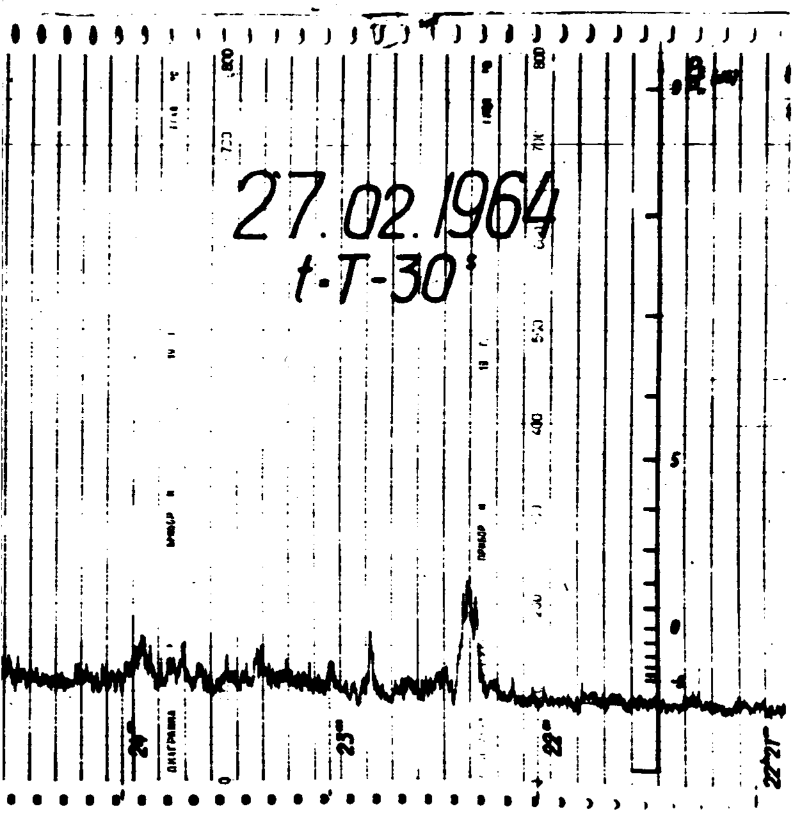

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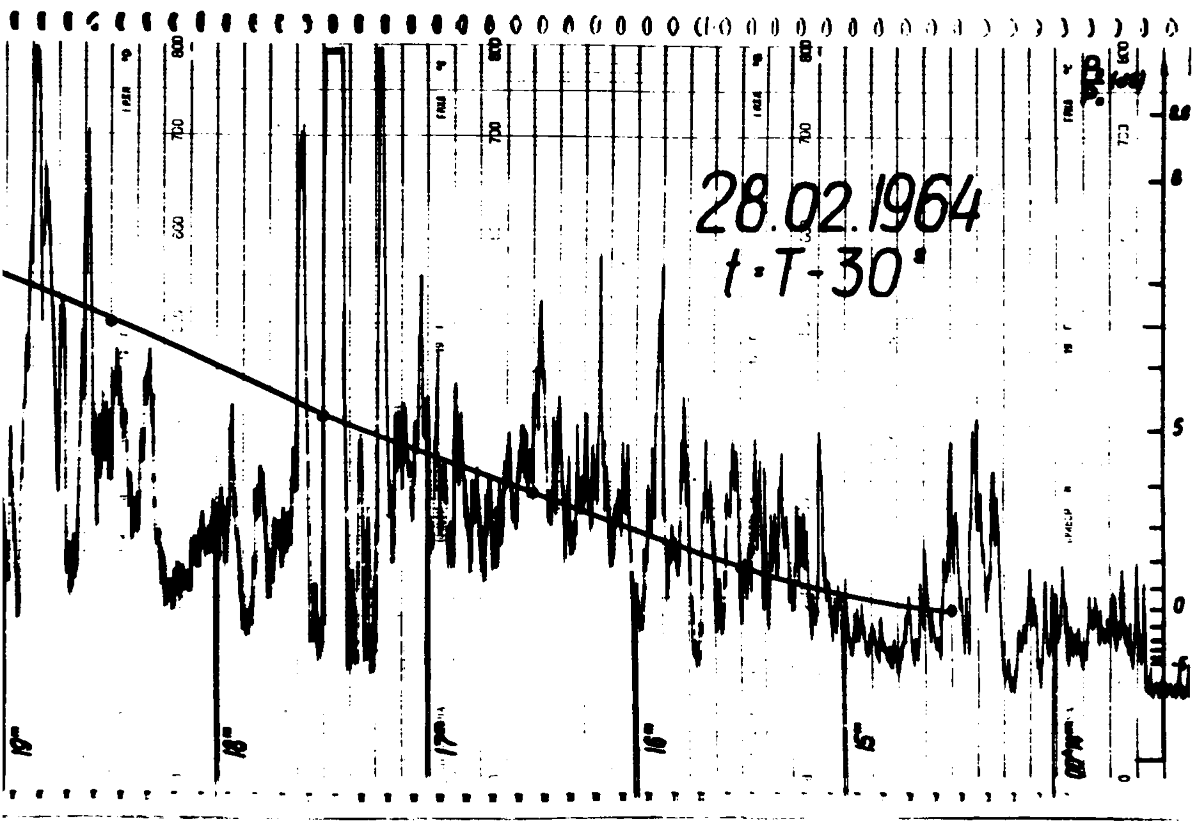

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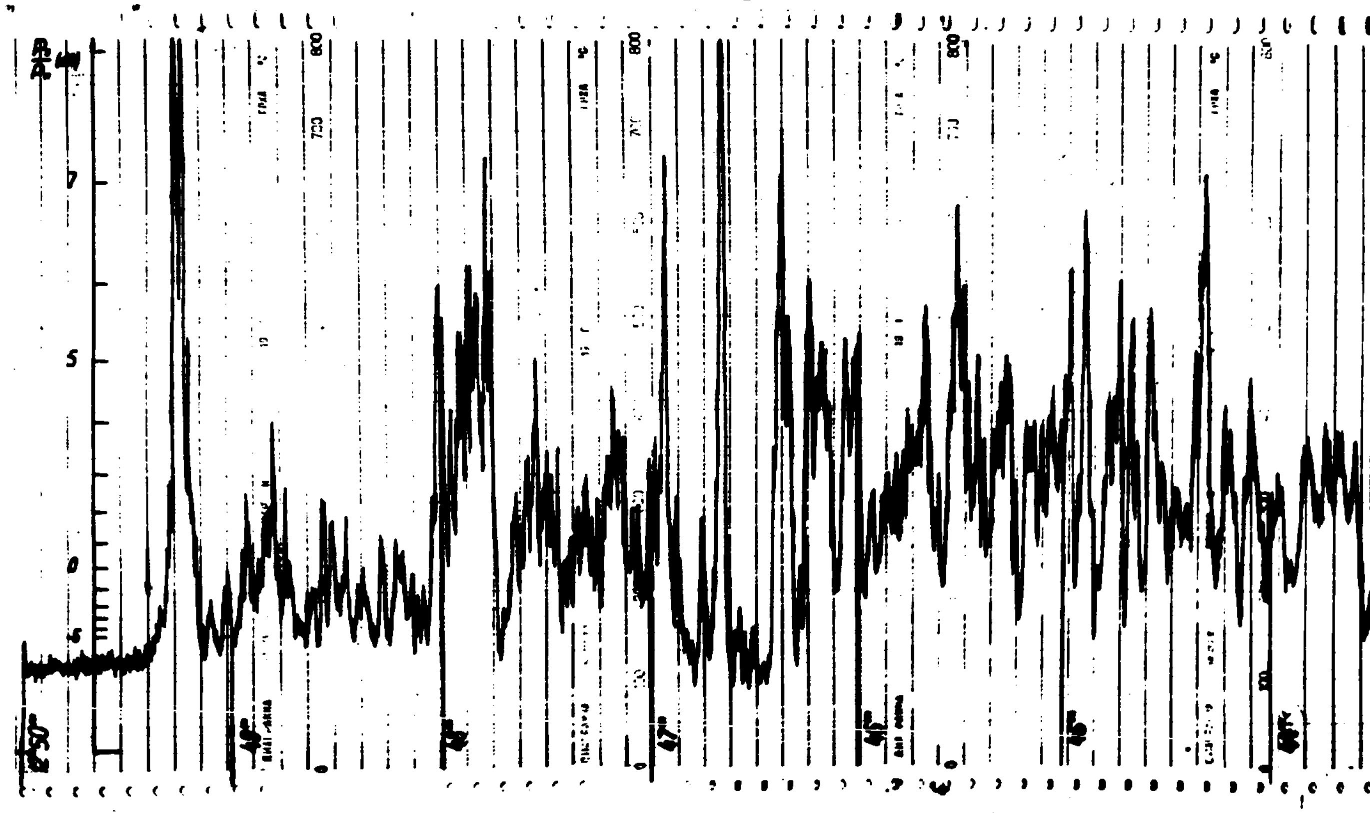

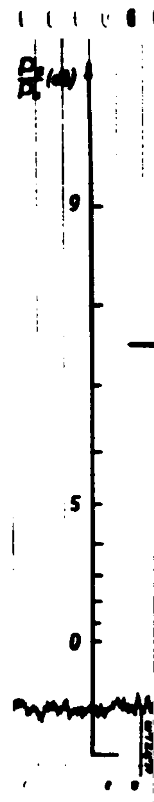

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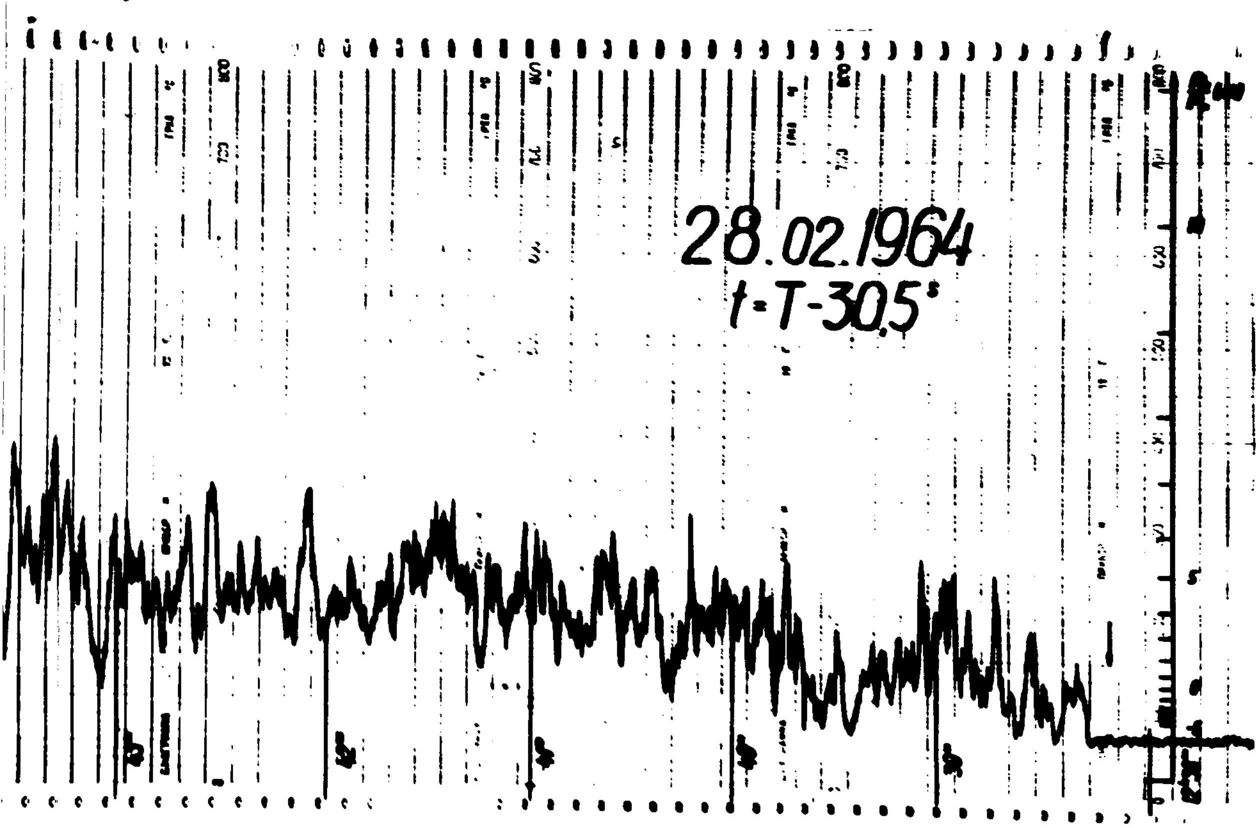

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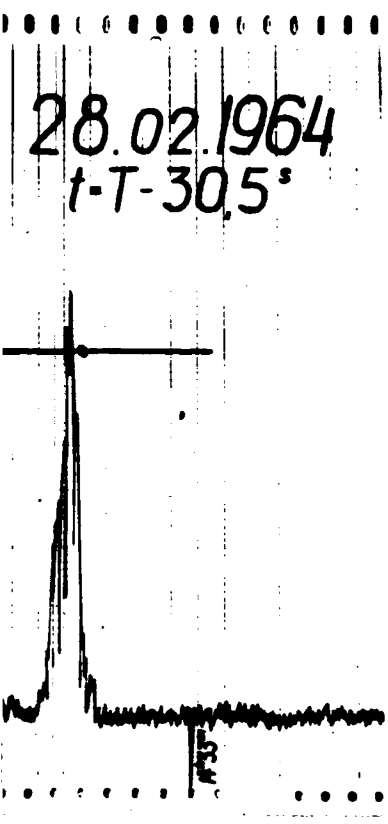

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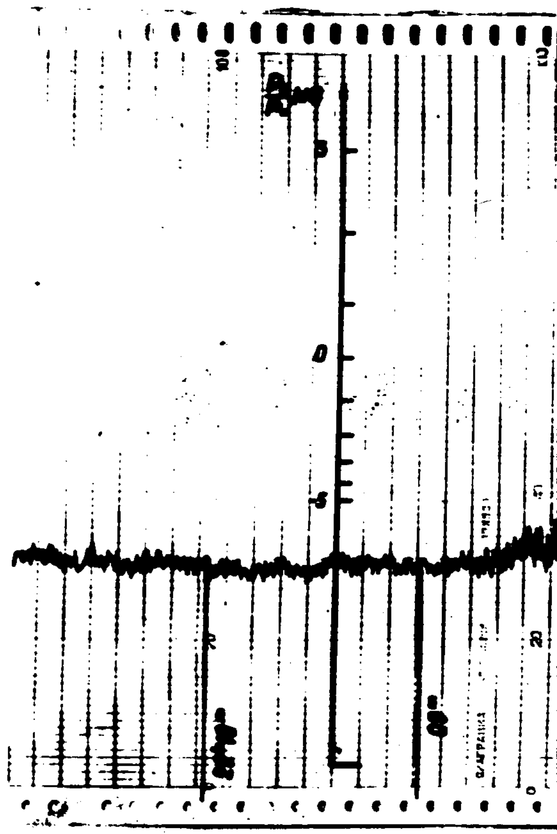

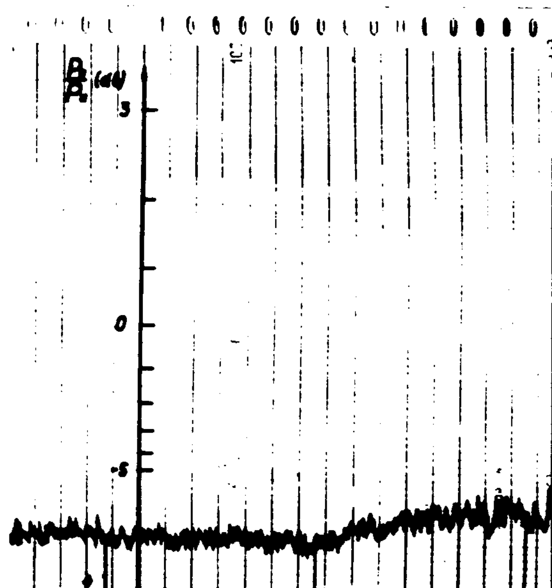

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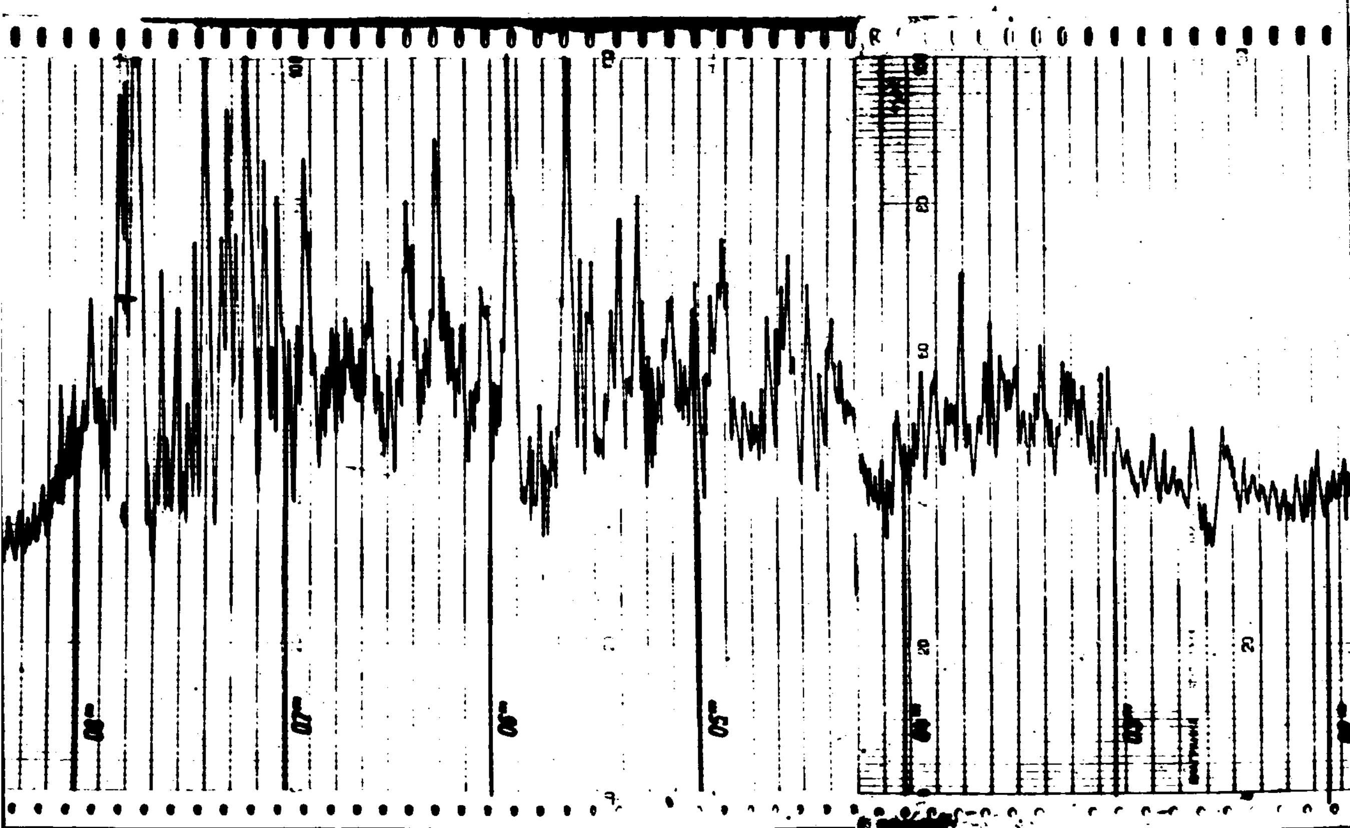

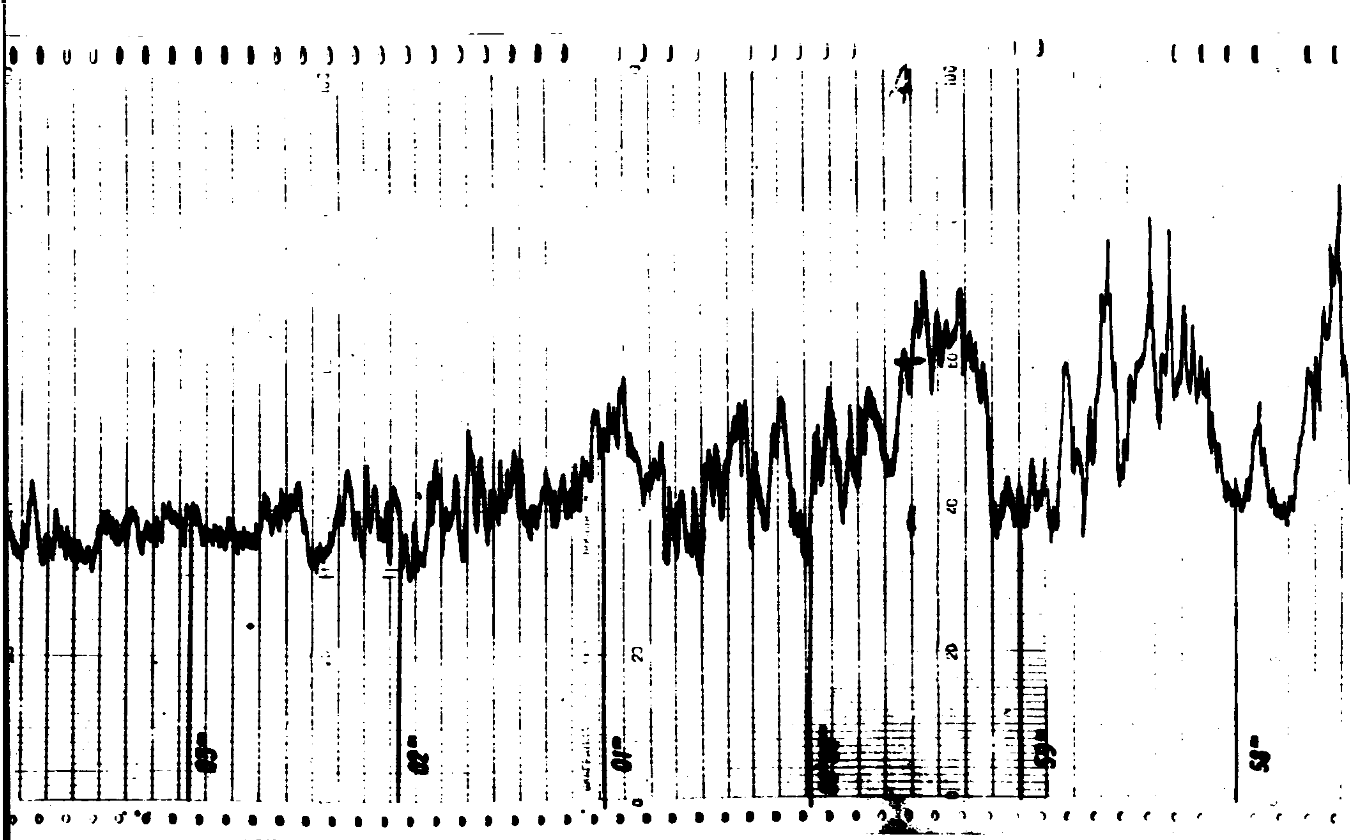

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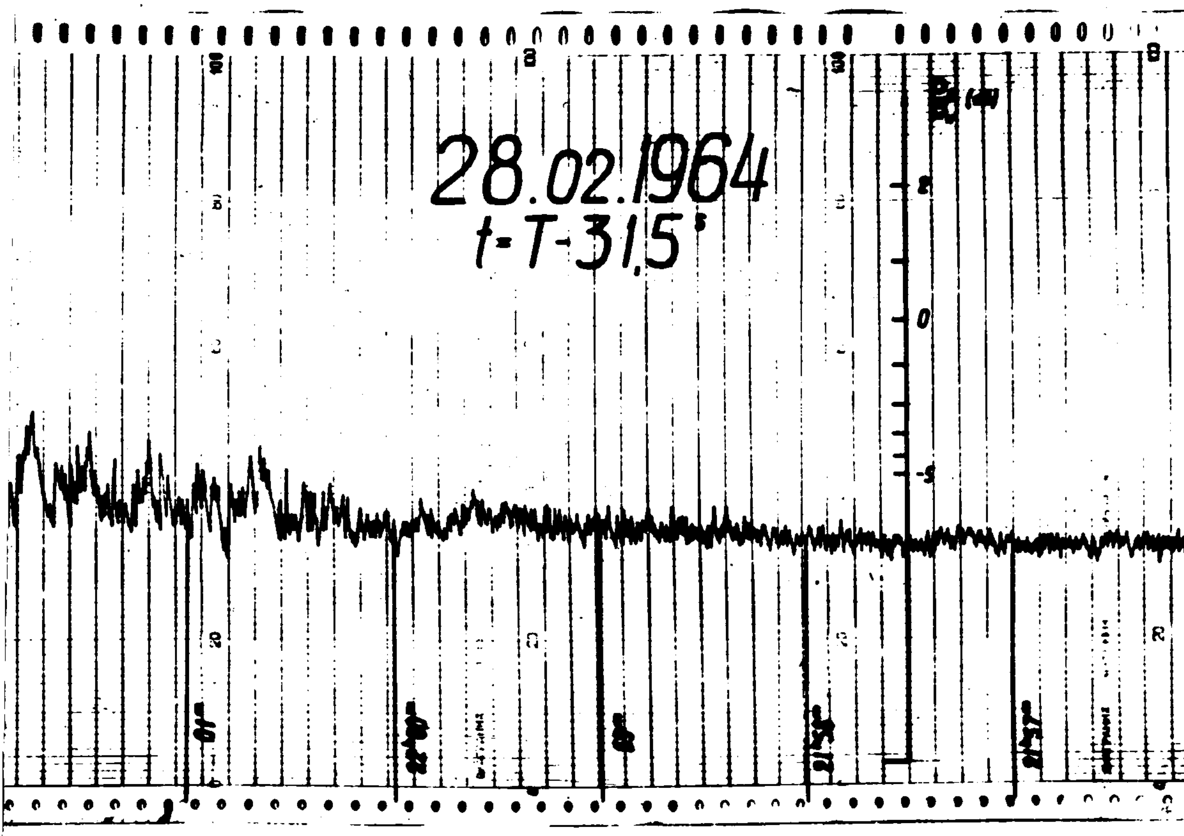

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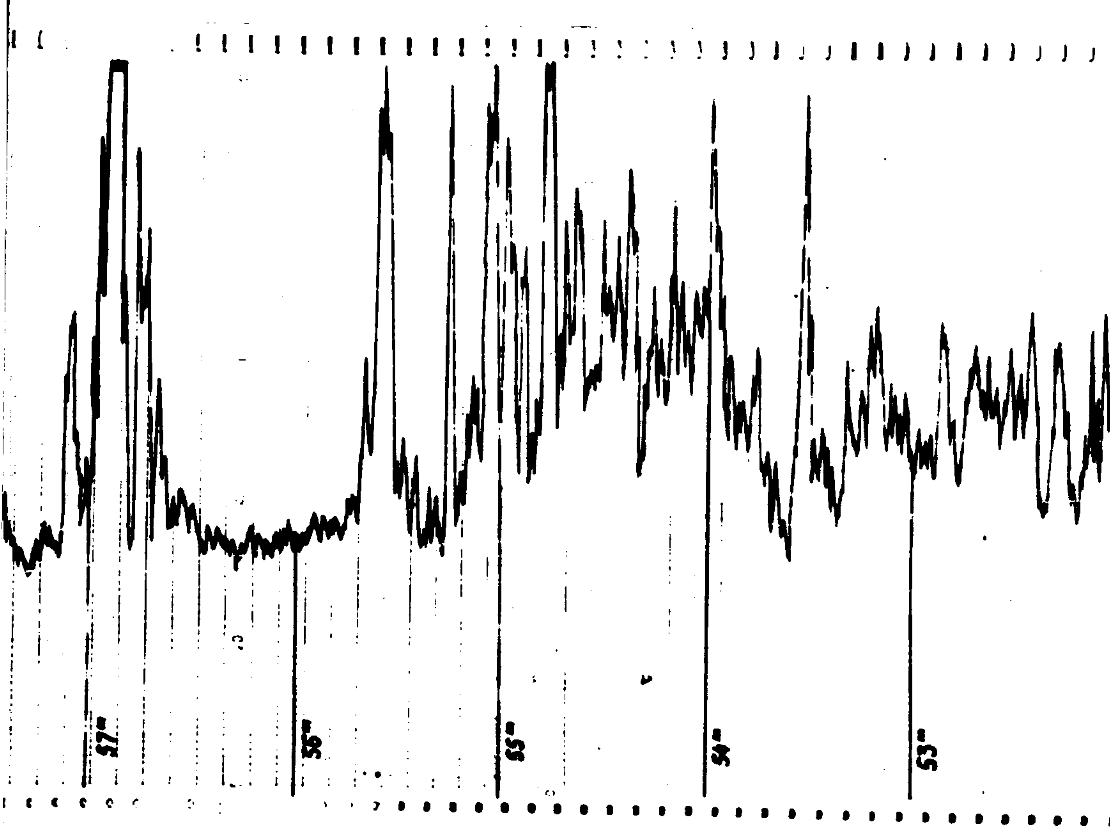

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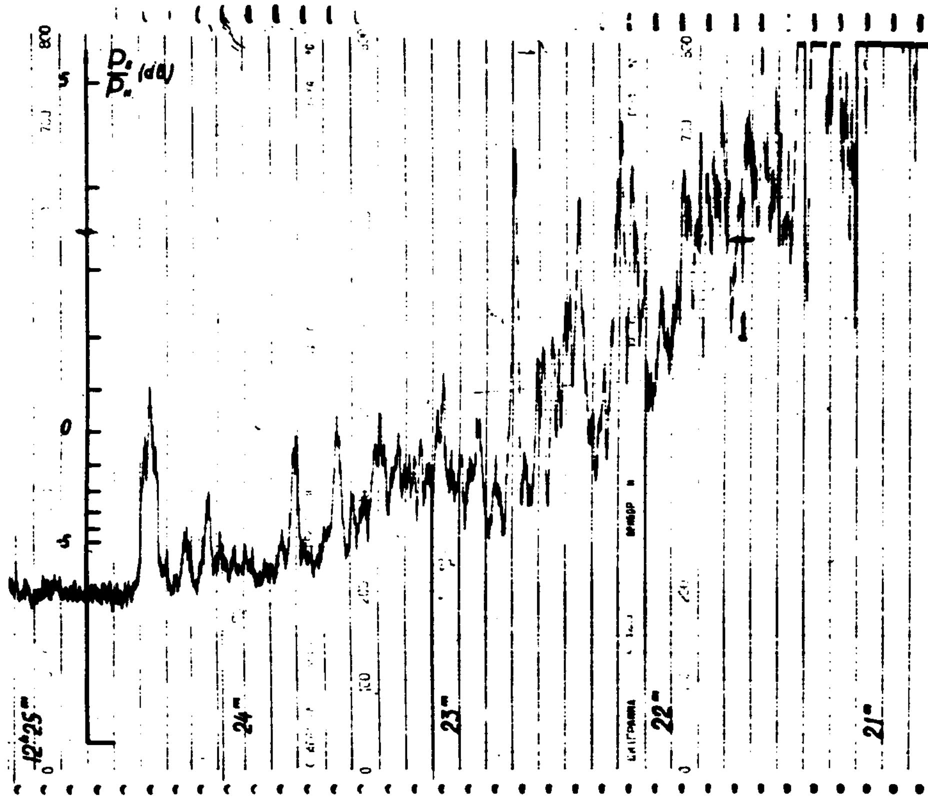

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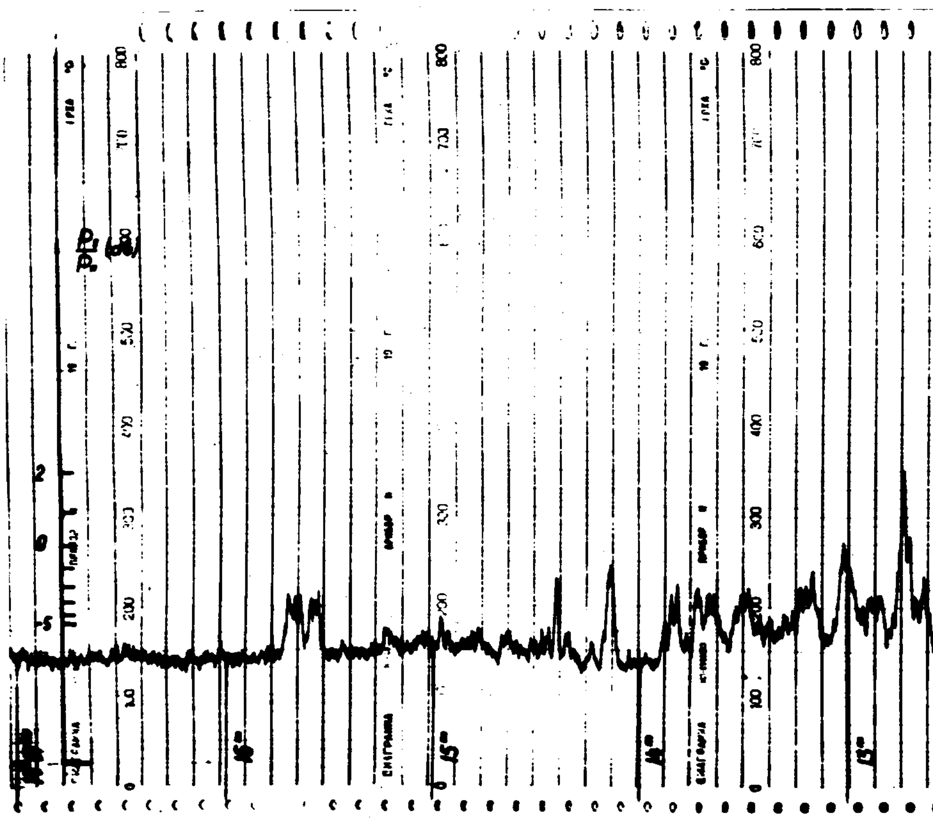
5
0
-5
12h25m
24m
23m
22m
21m



Ps/Pn (dB)
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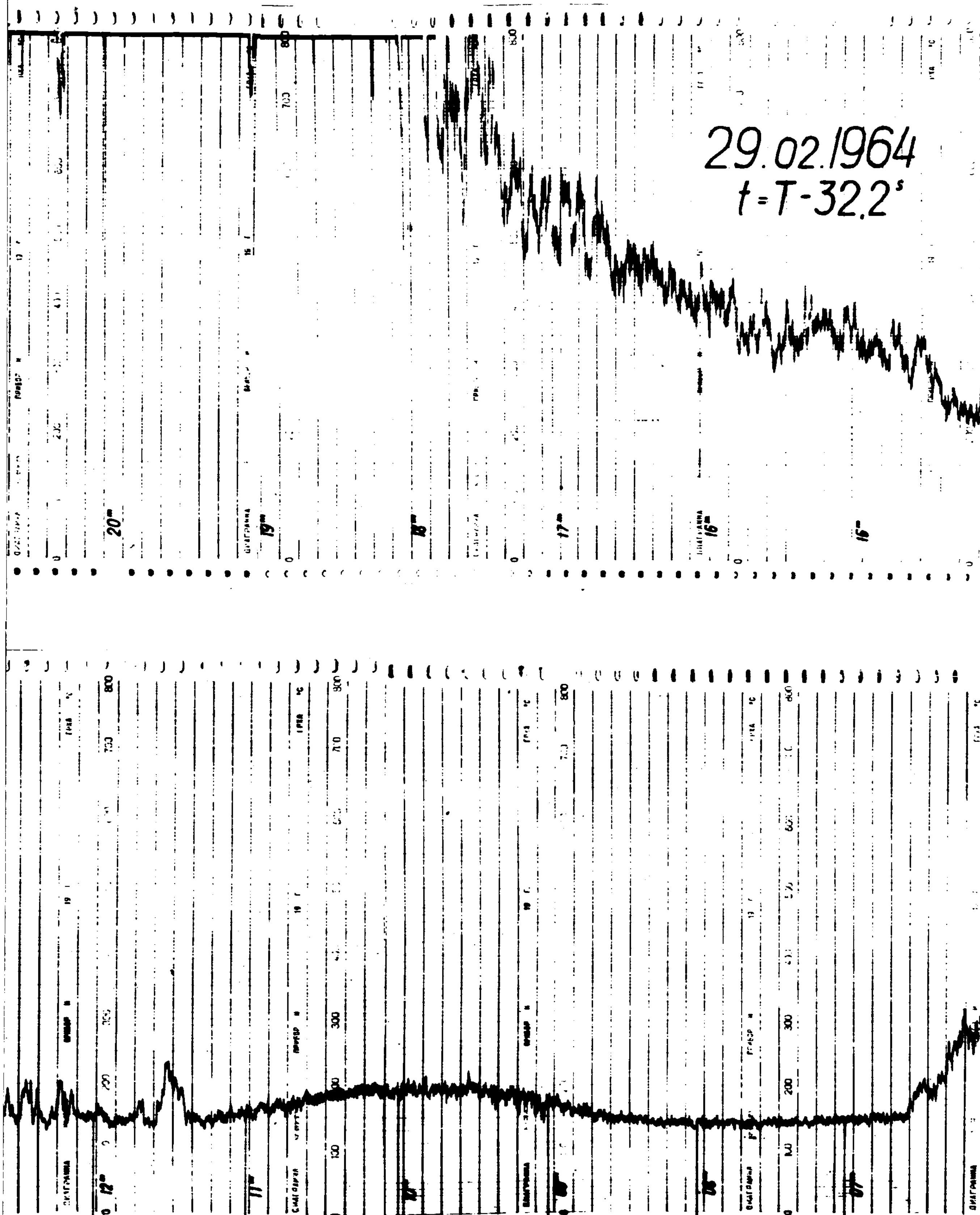
0
-5
16m
15m

2



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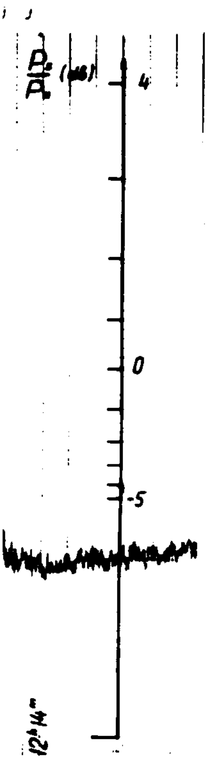

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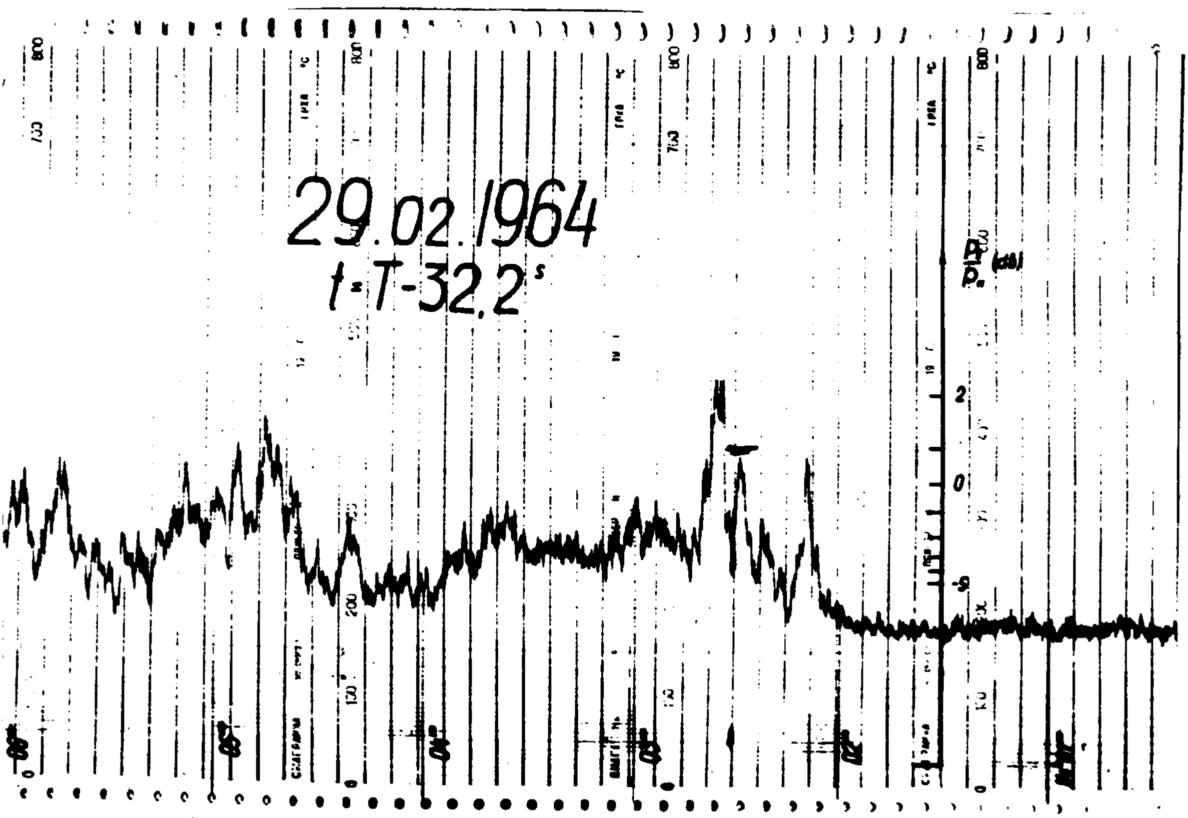

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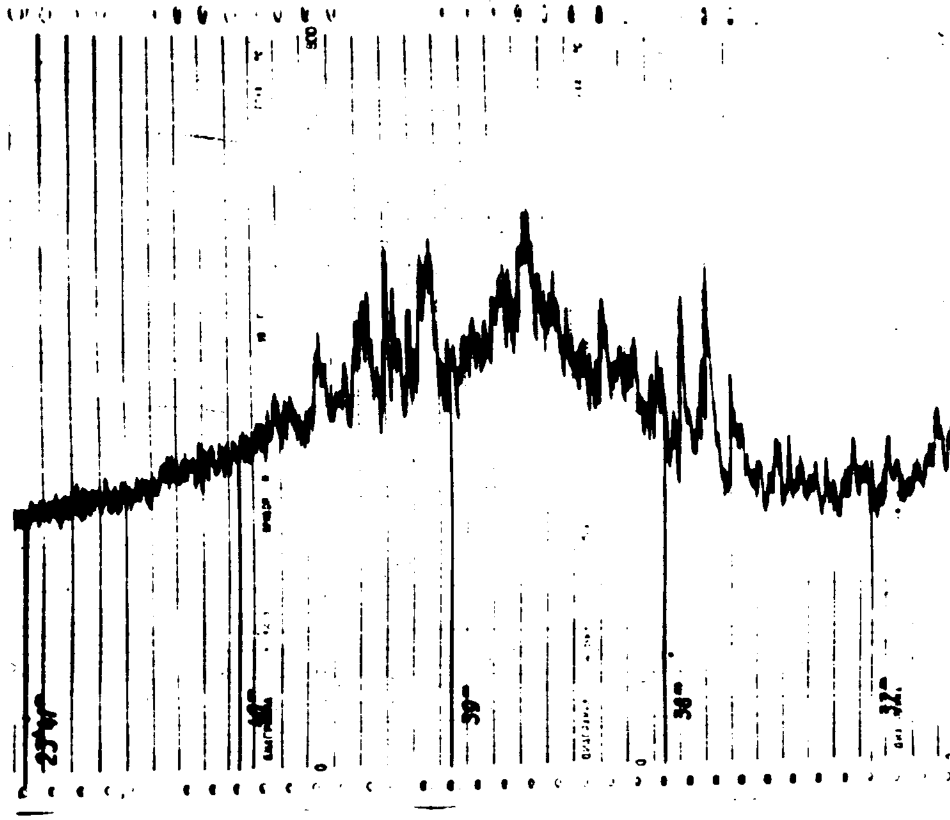

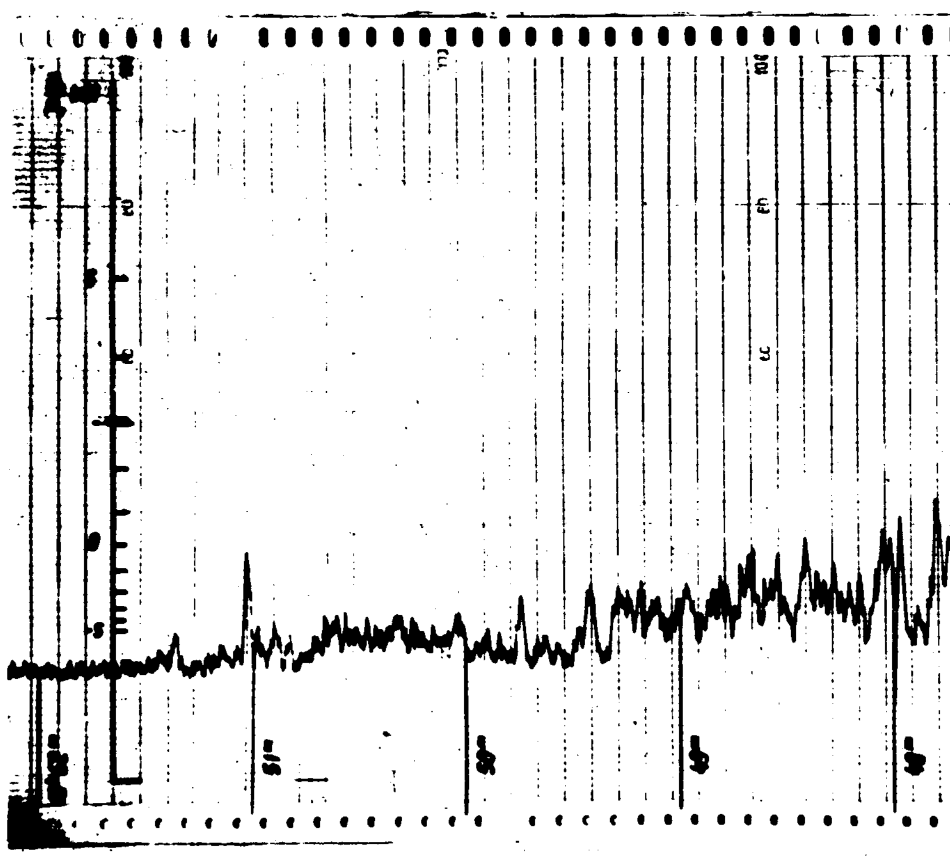

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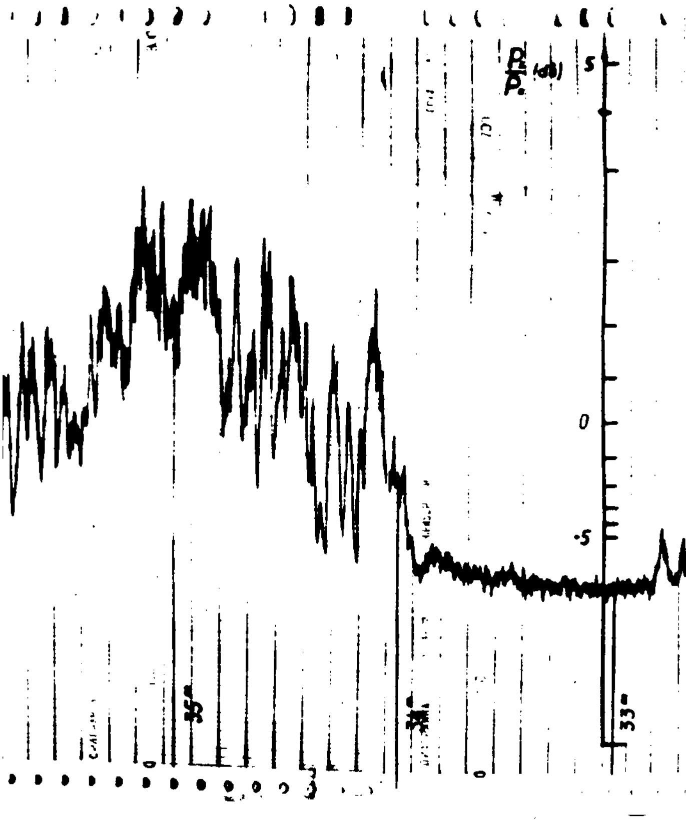

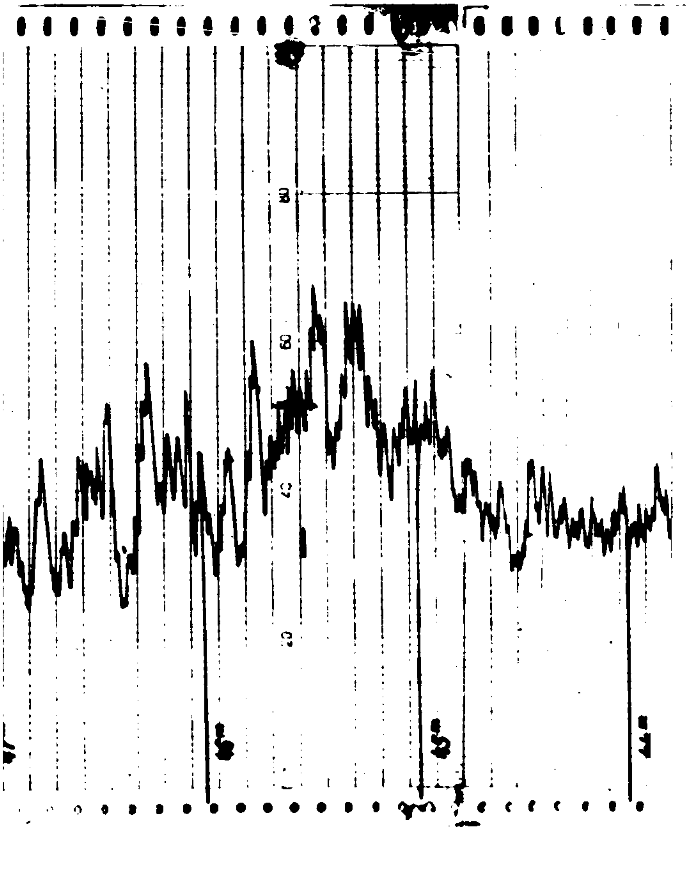

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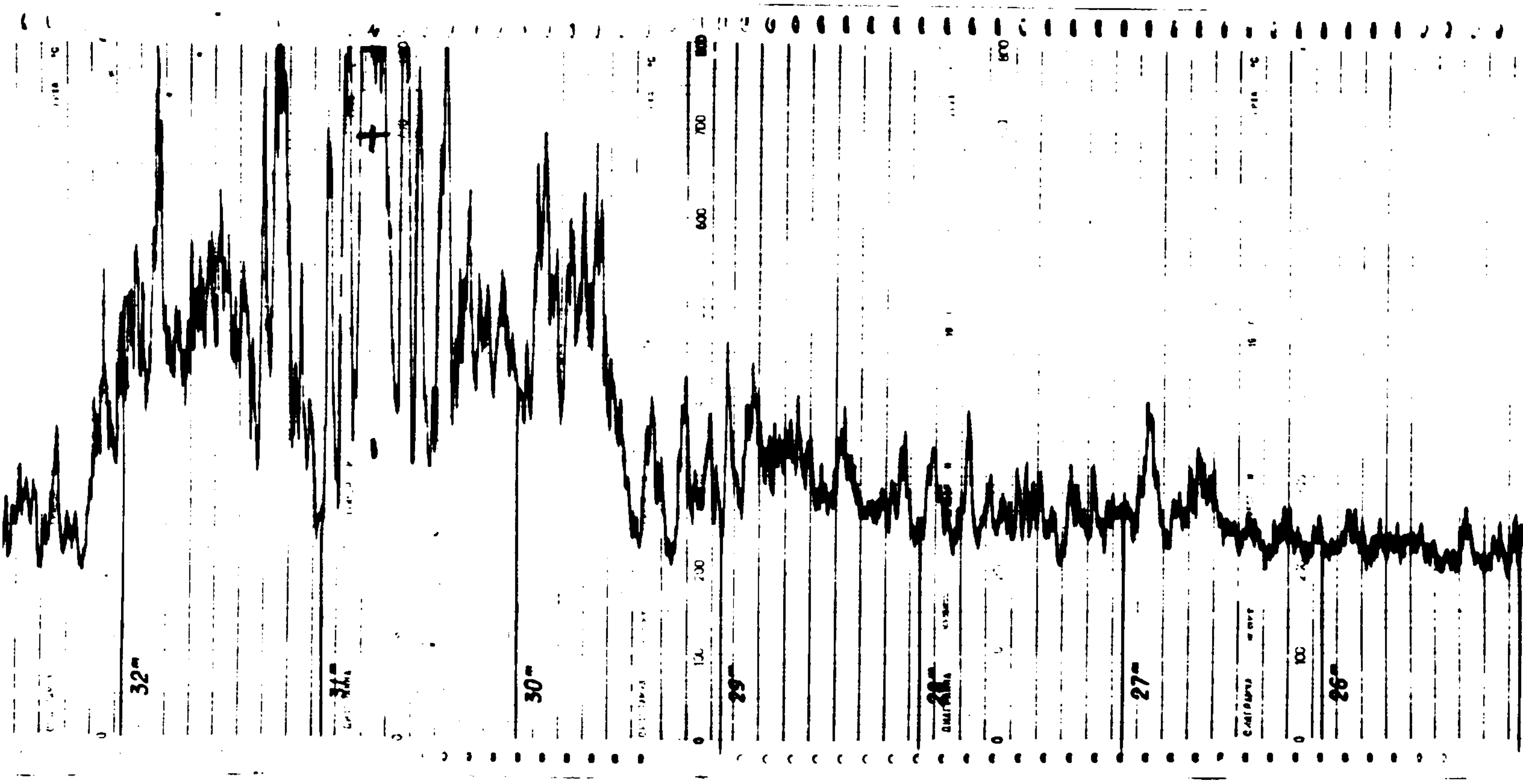
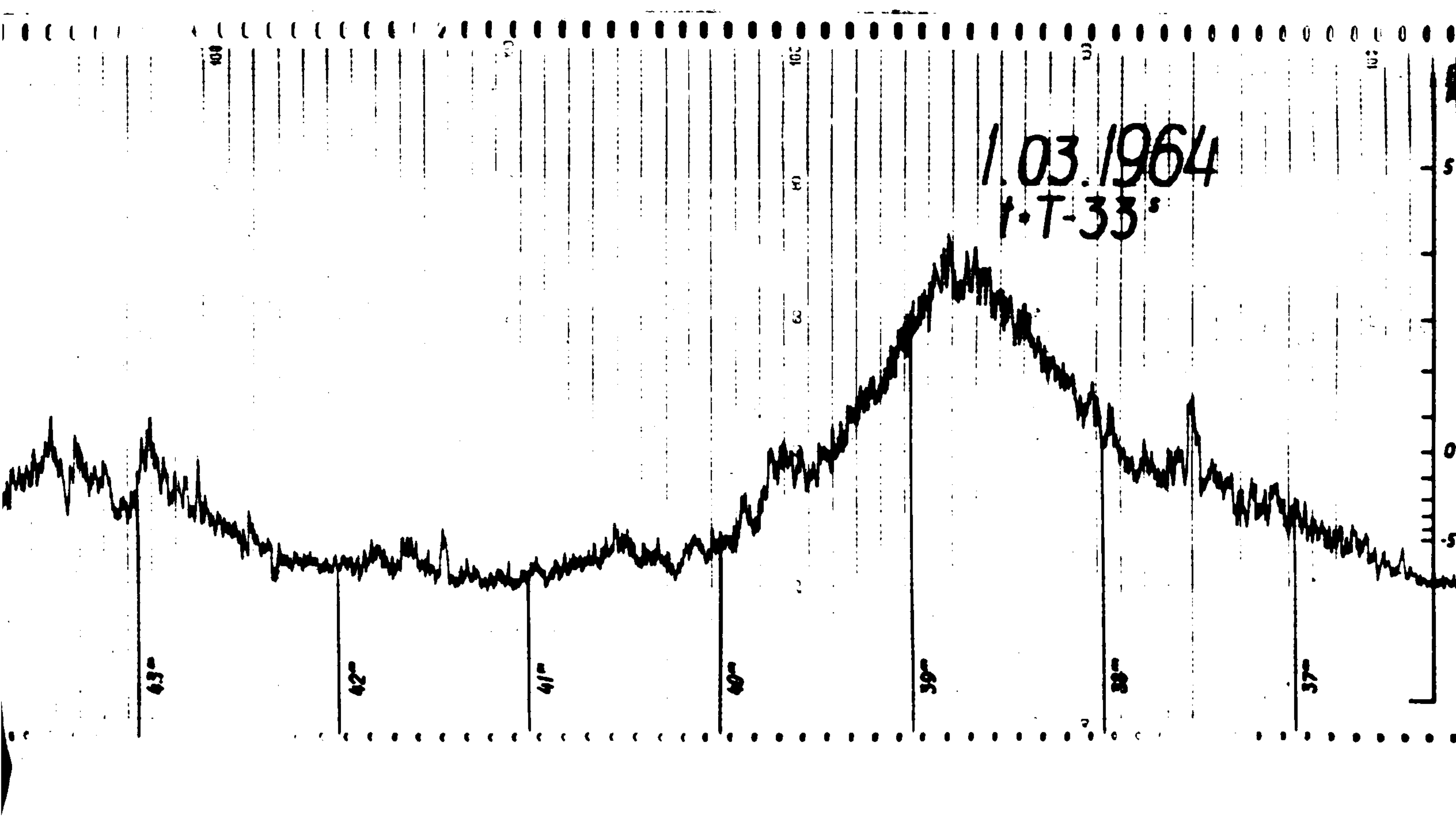

32m
31m
30m
29m
28m
27m
26m


1.03.1964
t·T-33s
43m
42m
41m
40m
39m
38m
37m

4

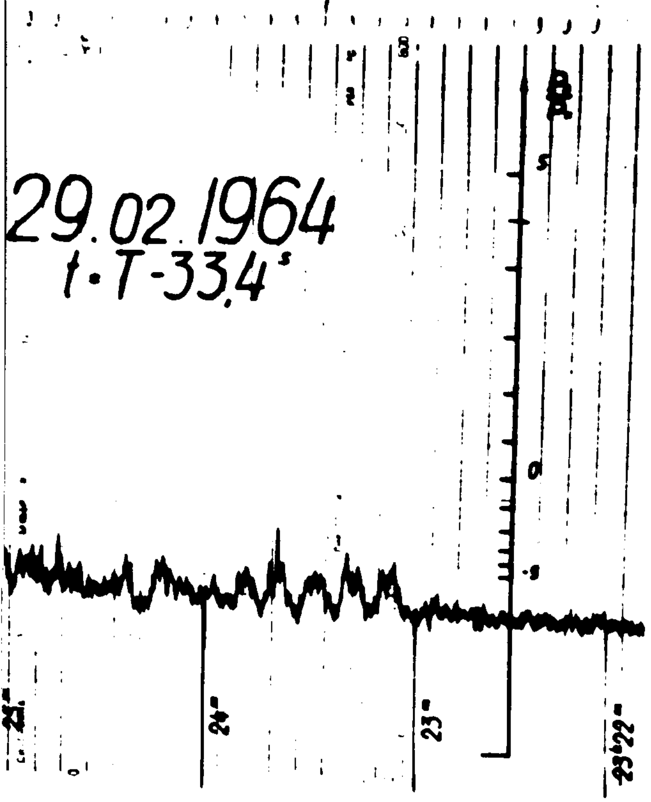


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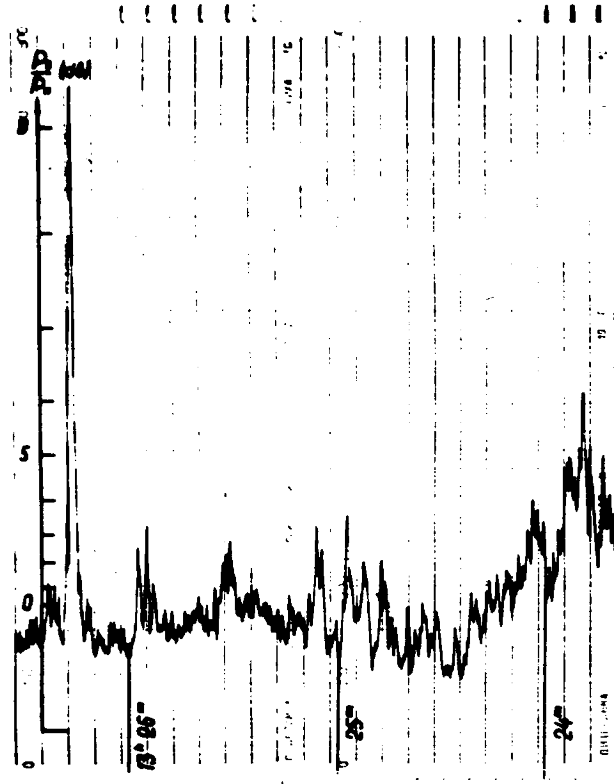
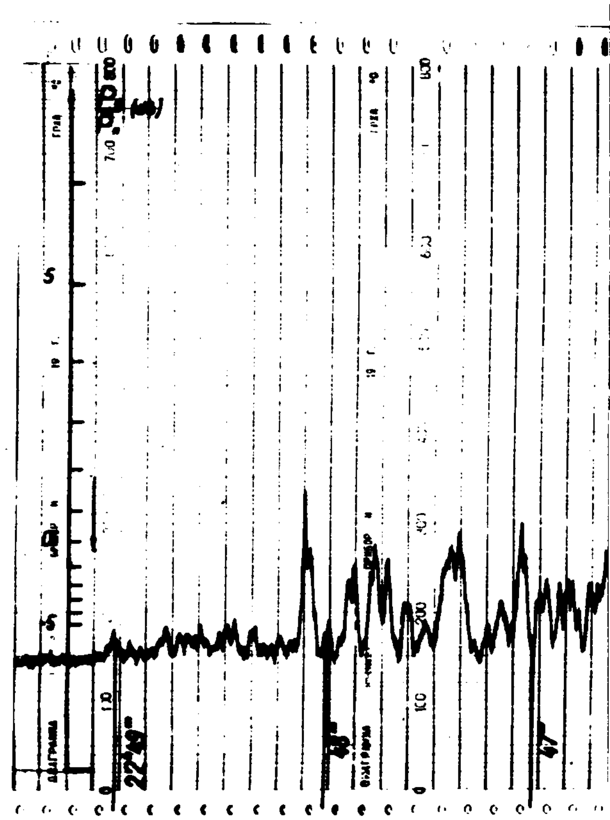
Figure B-25. Pass No. 476





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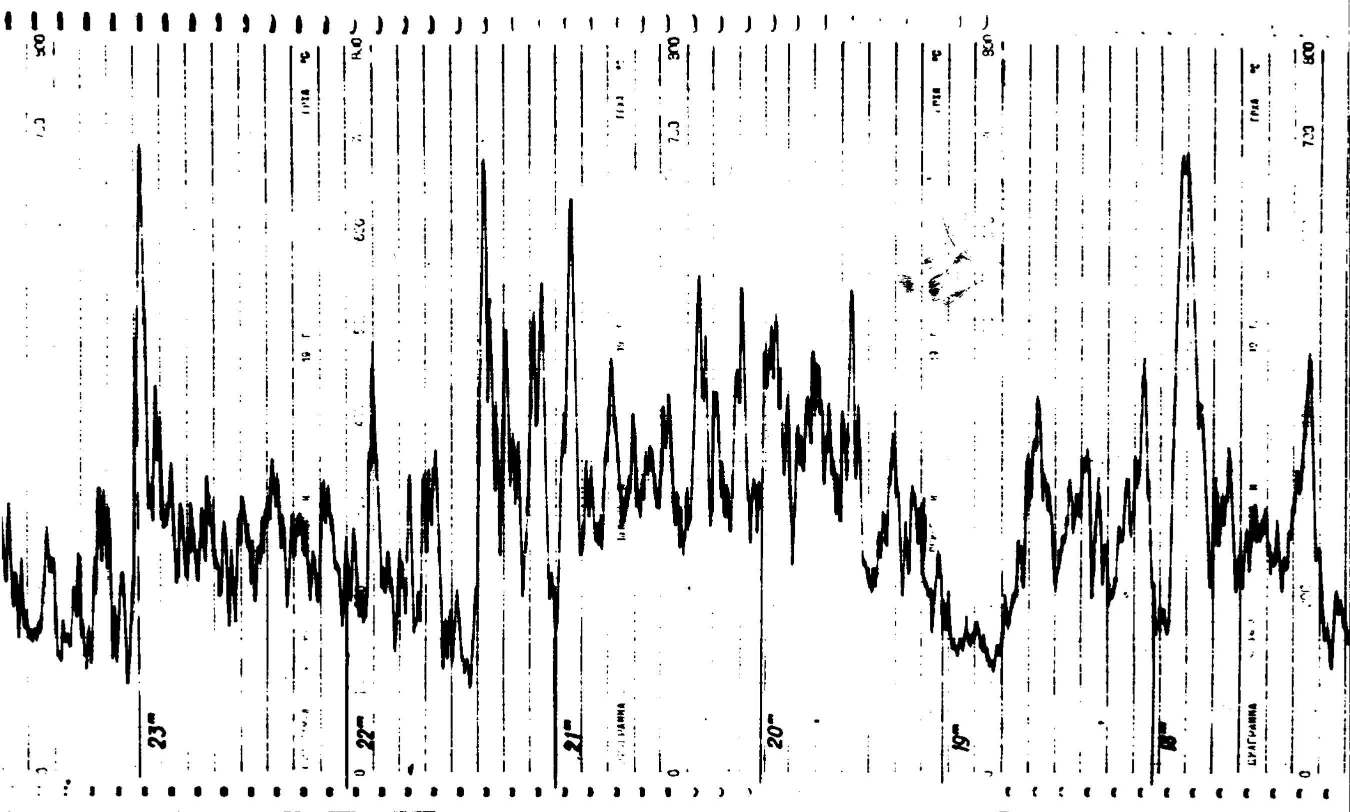

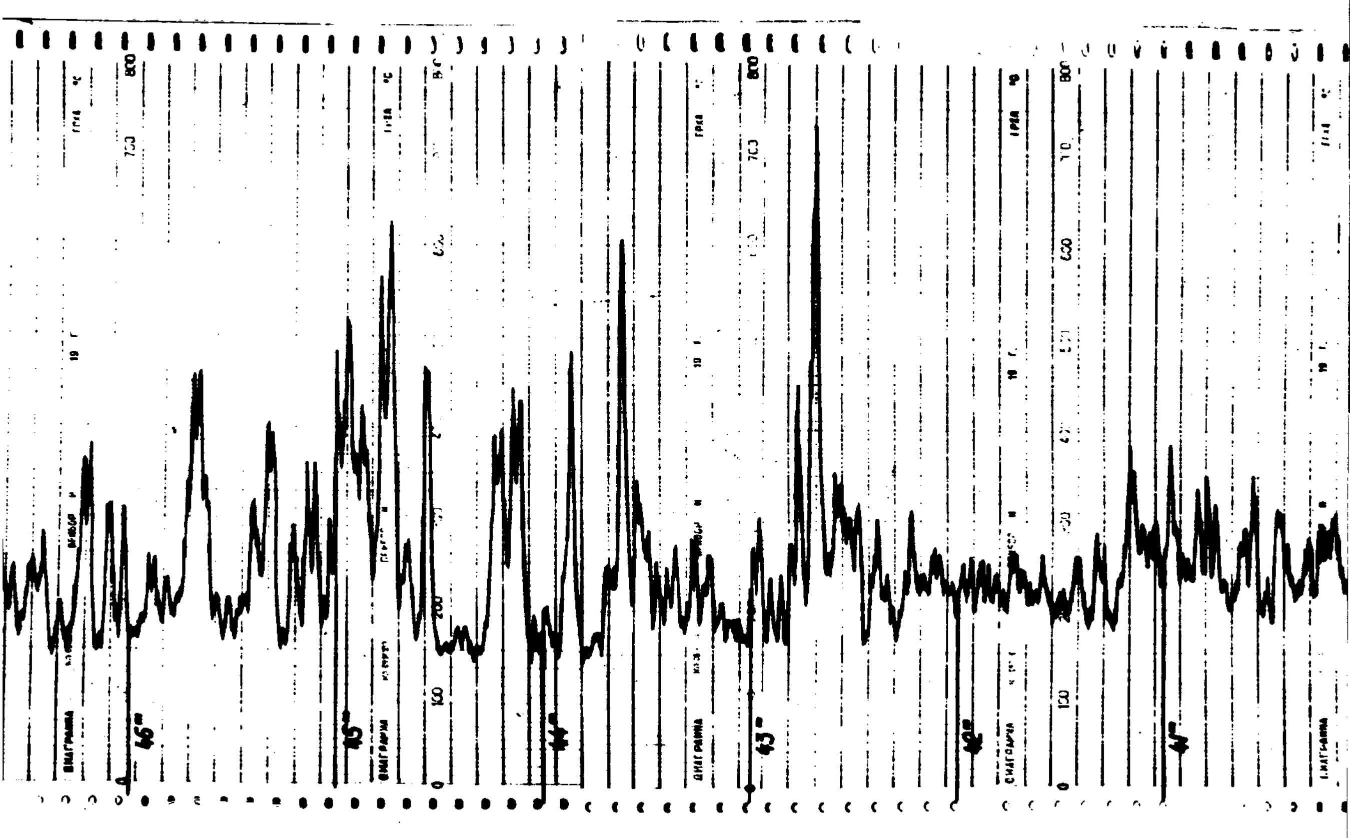

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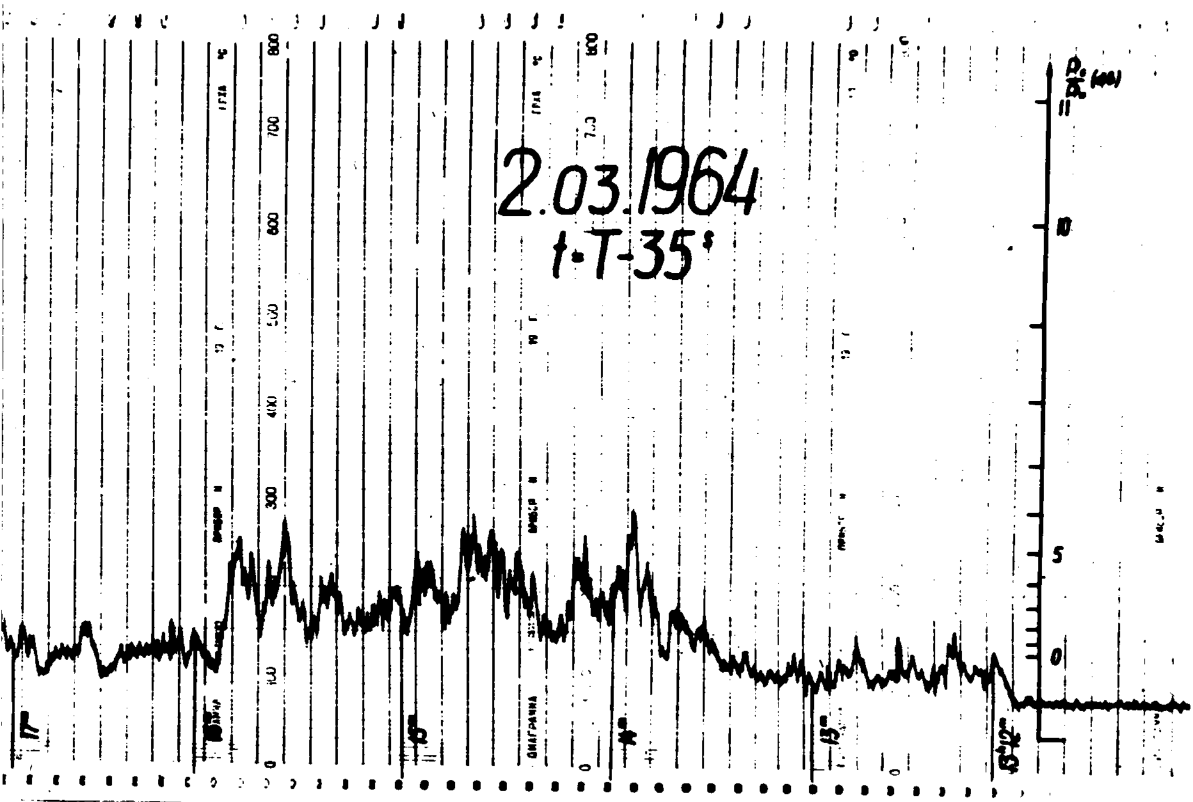

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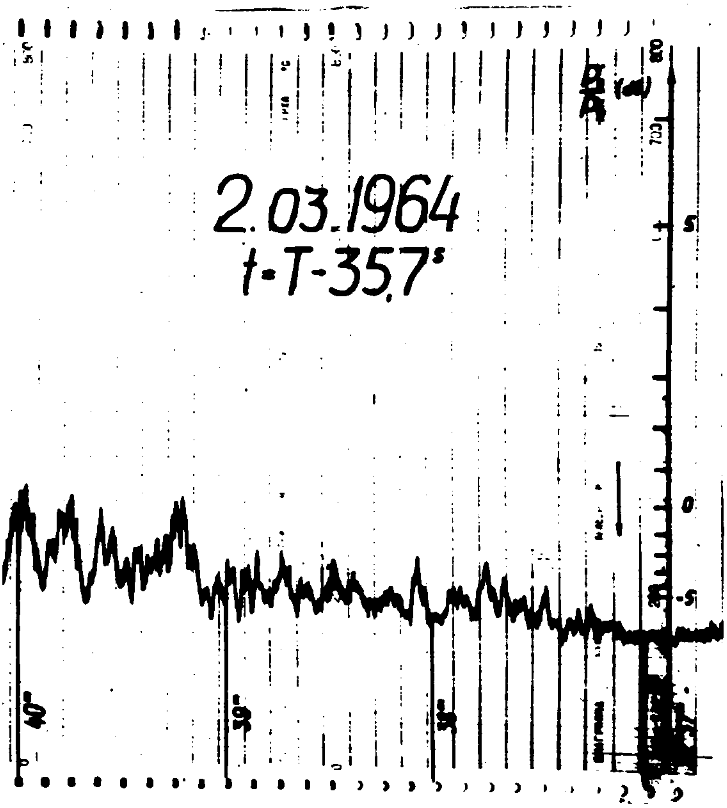

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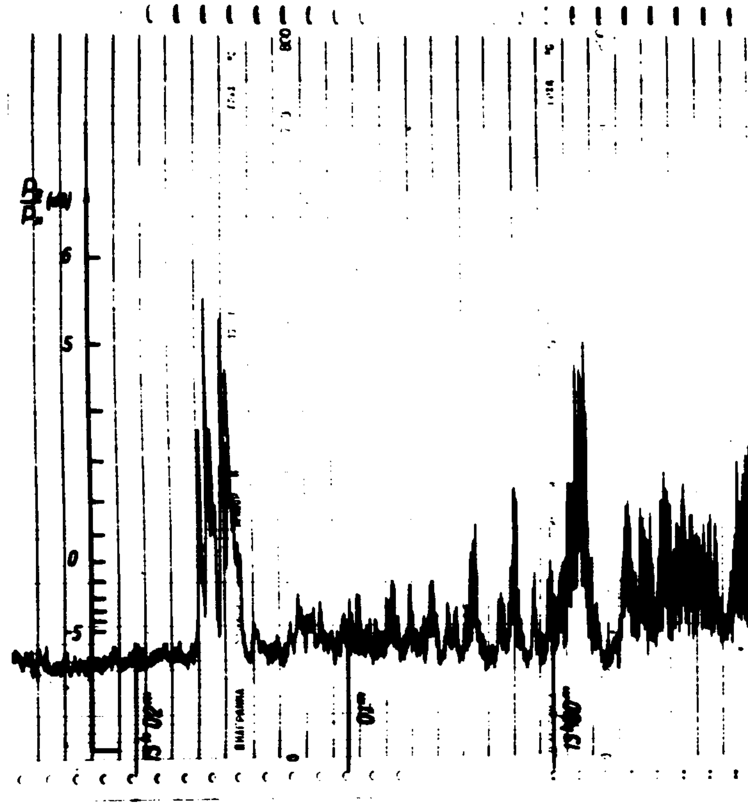

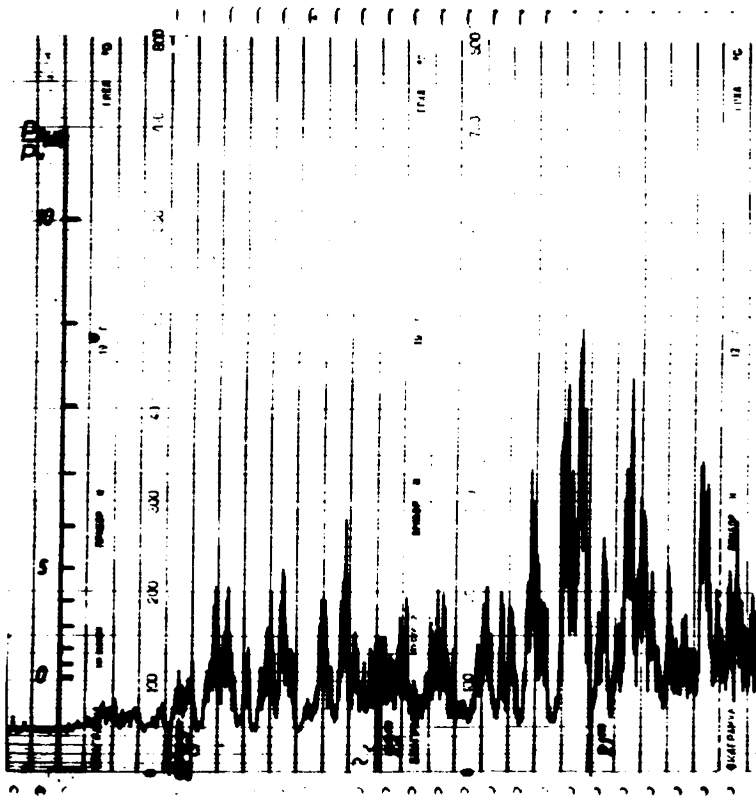

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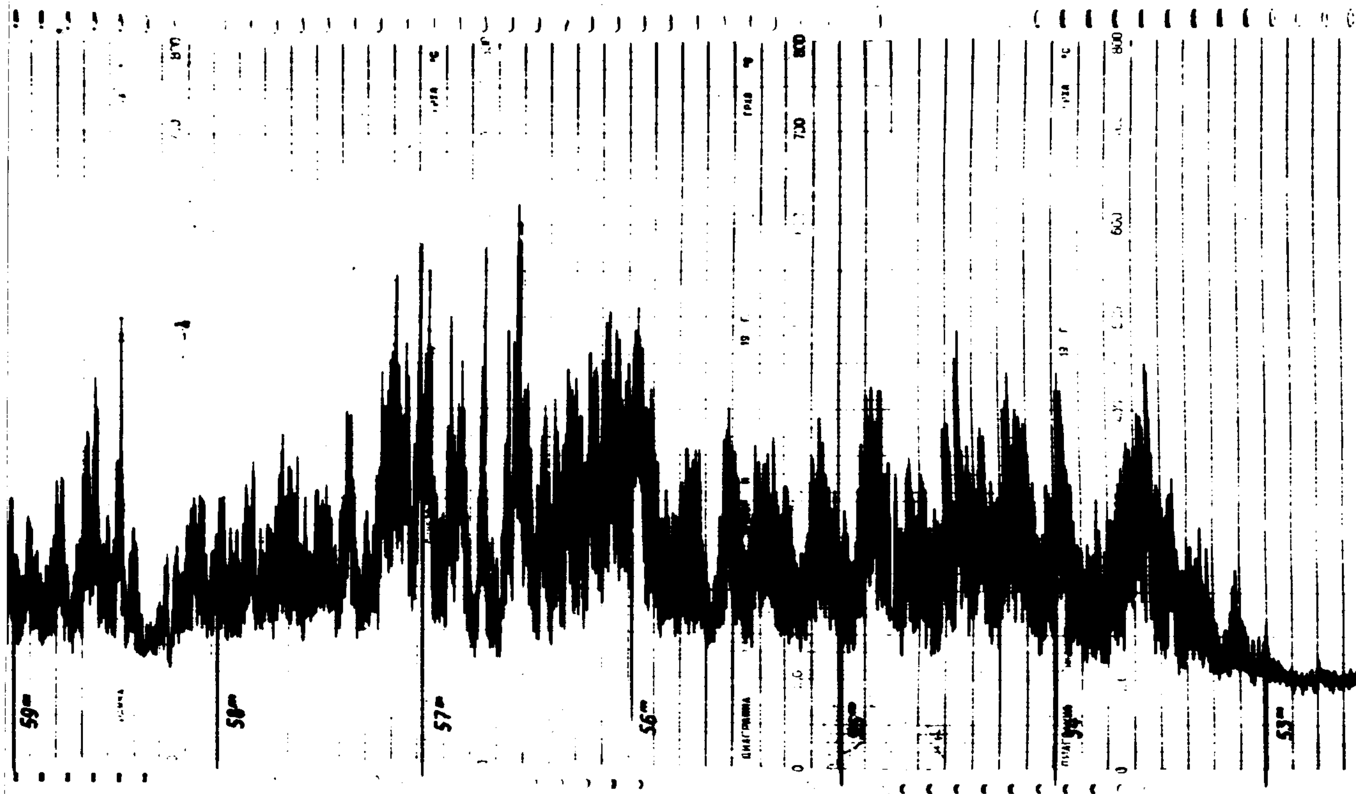

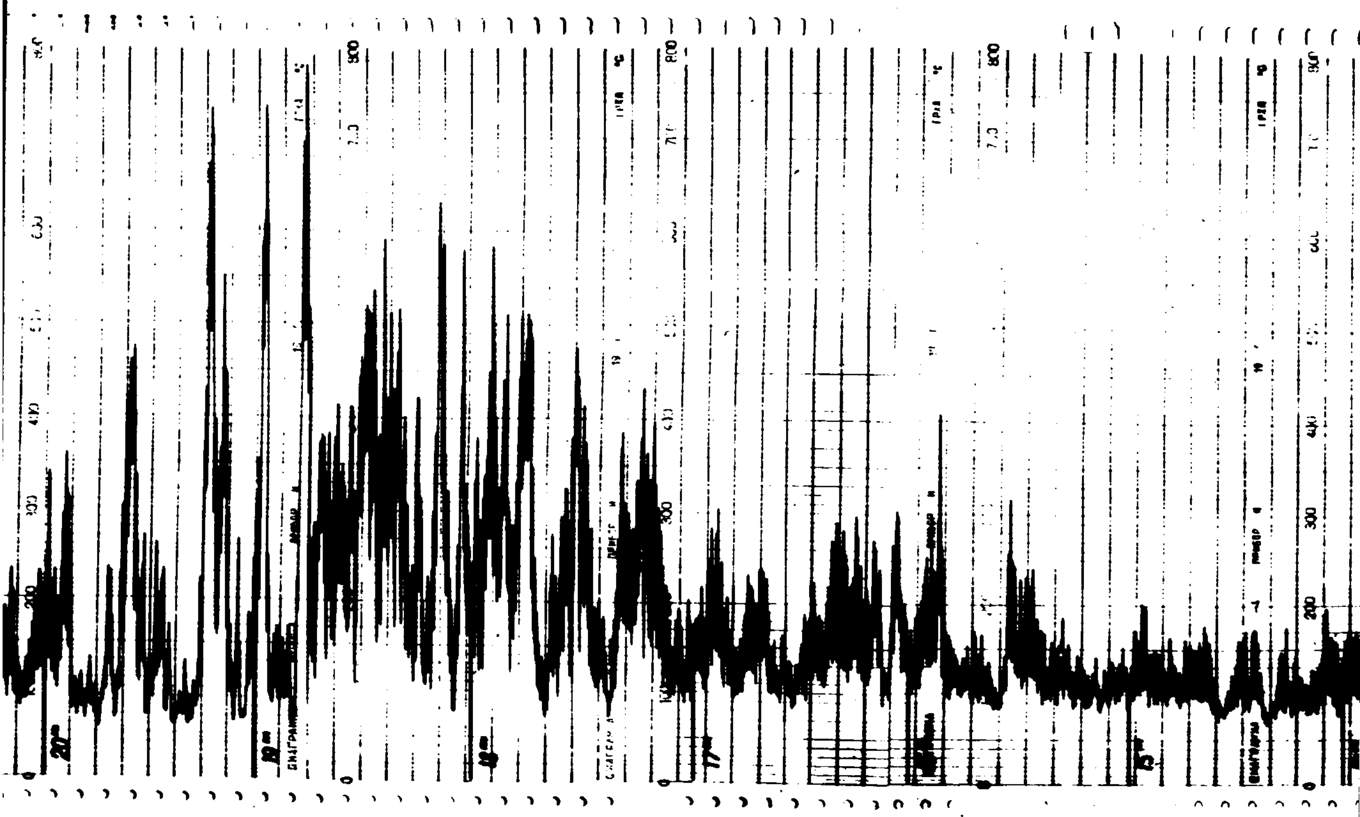

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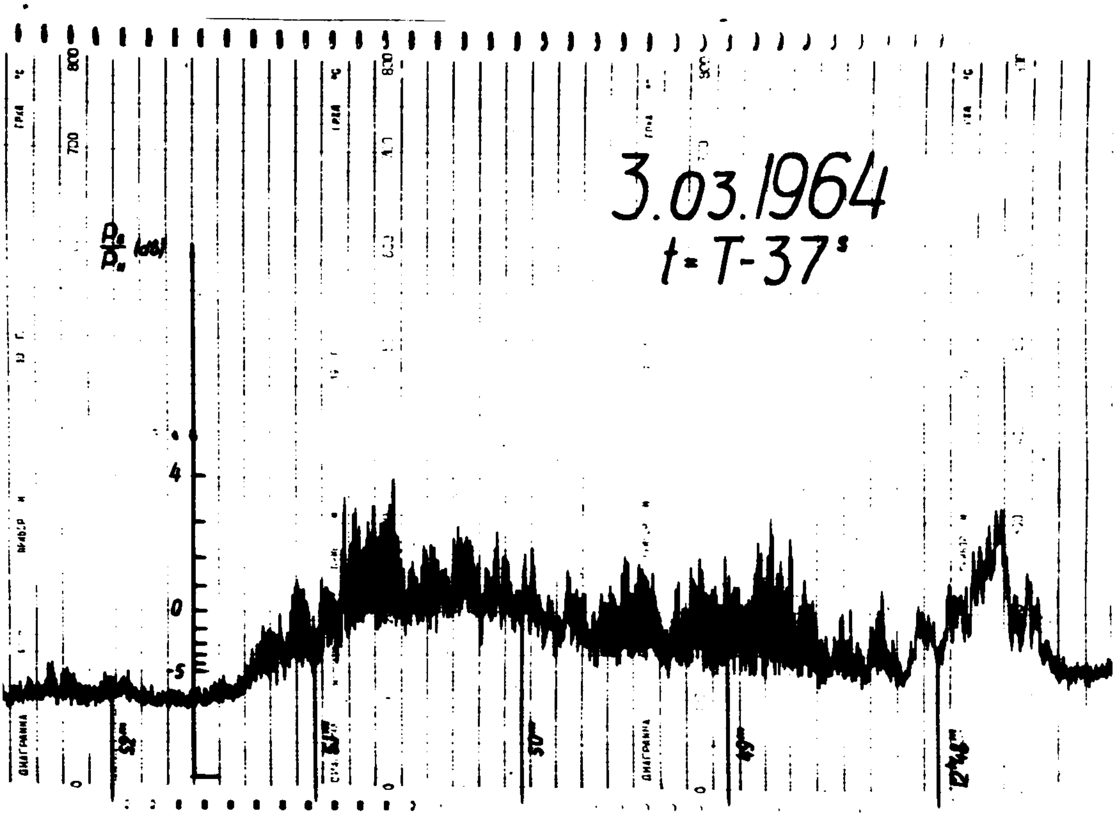

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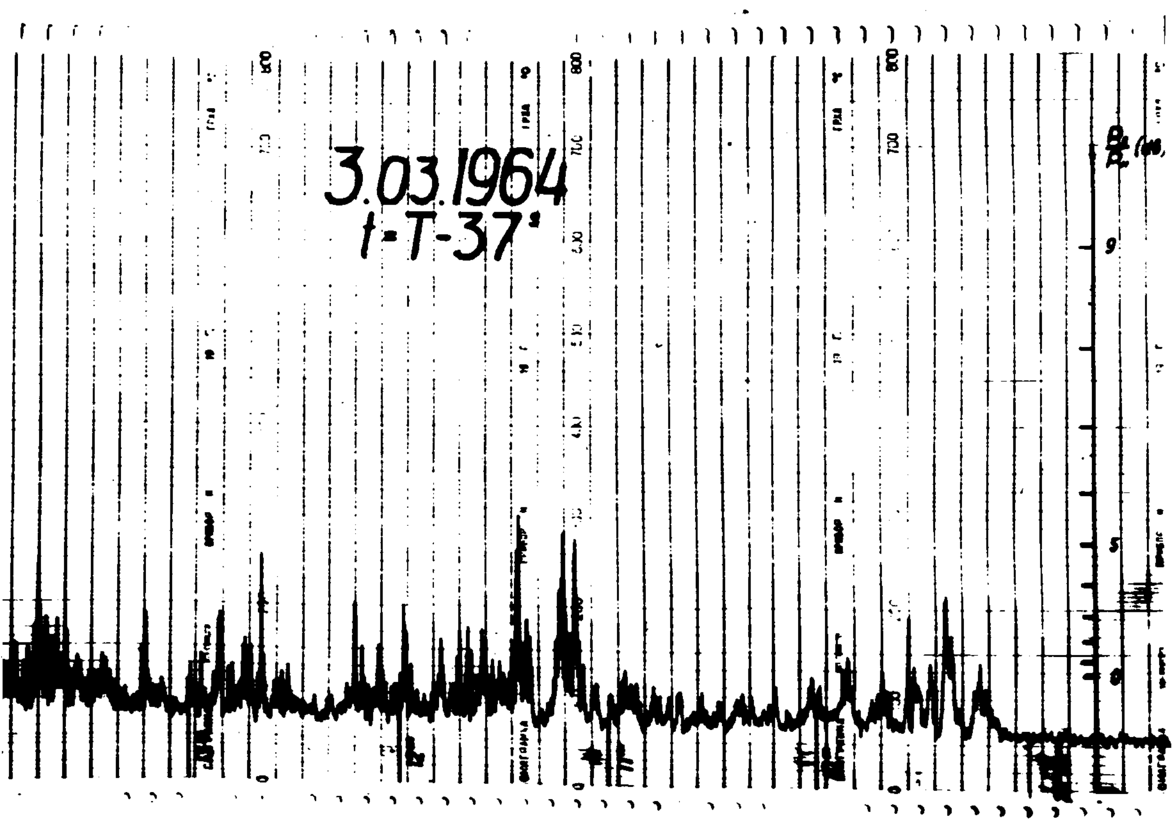

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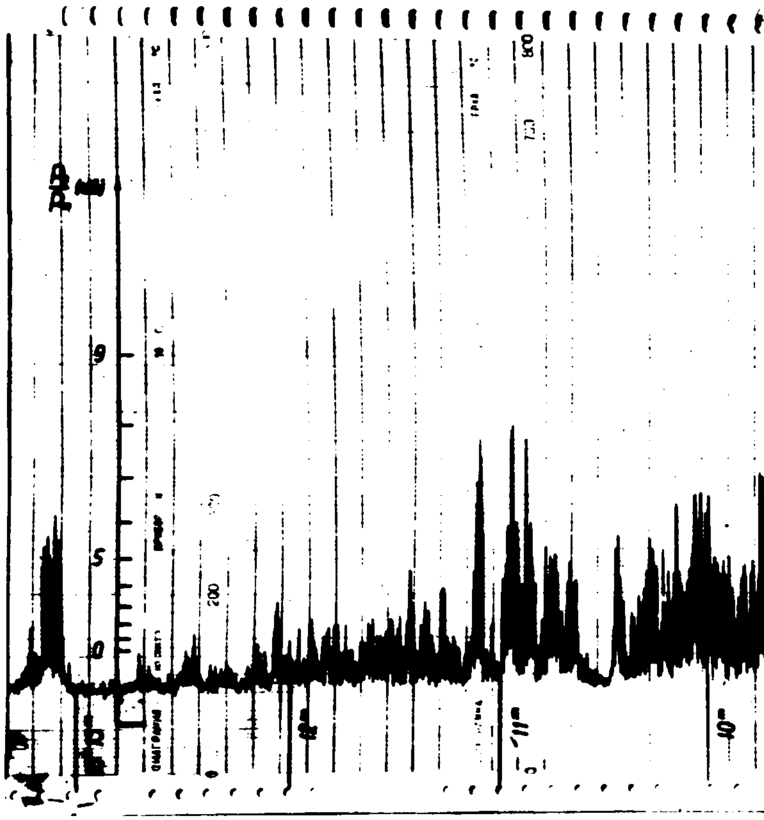

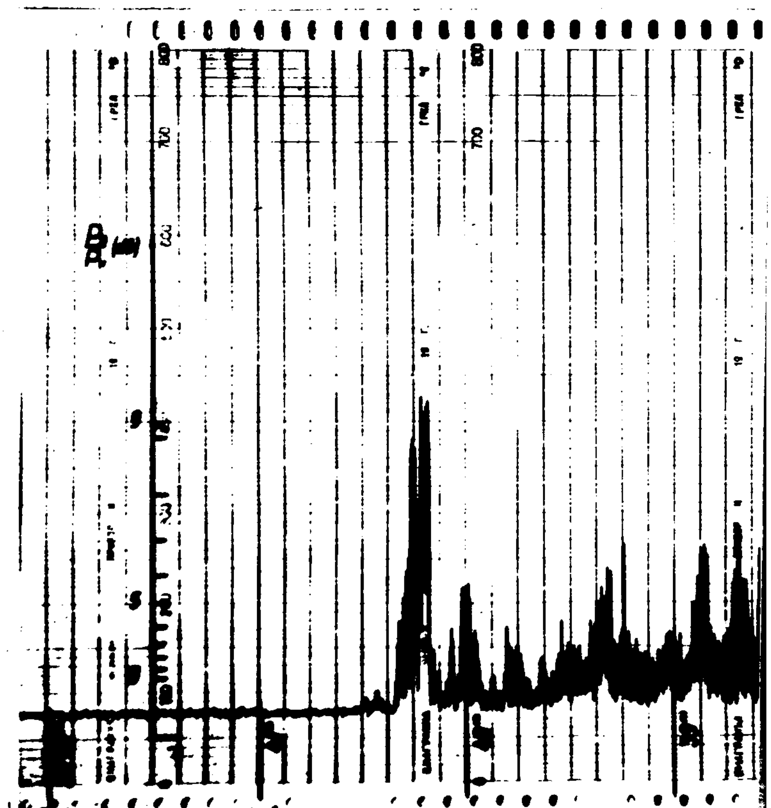

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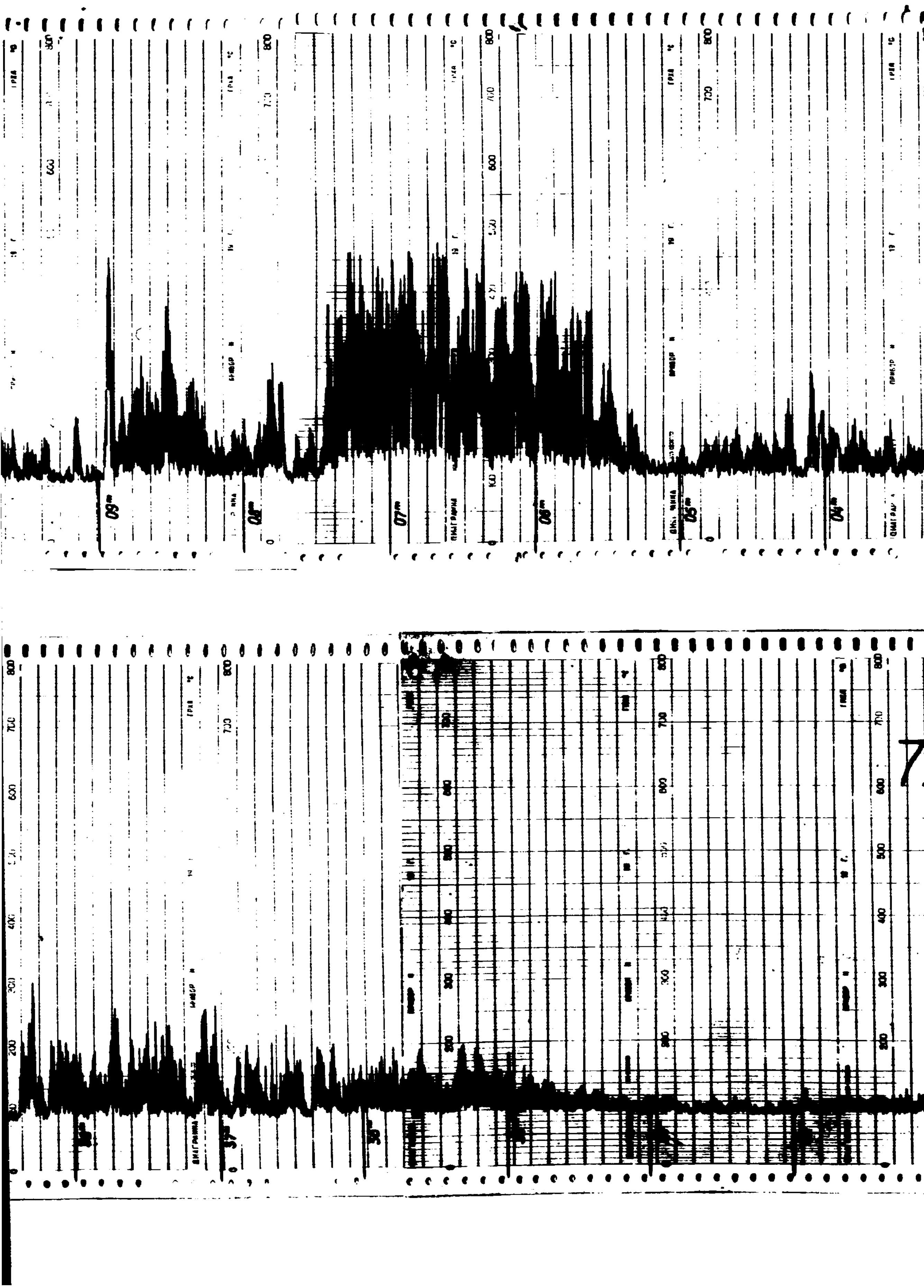

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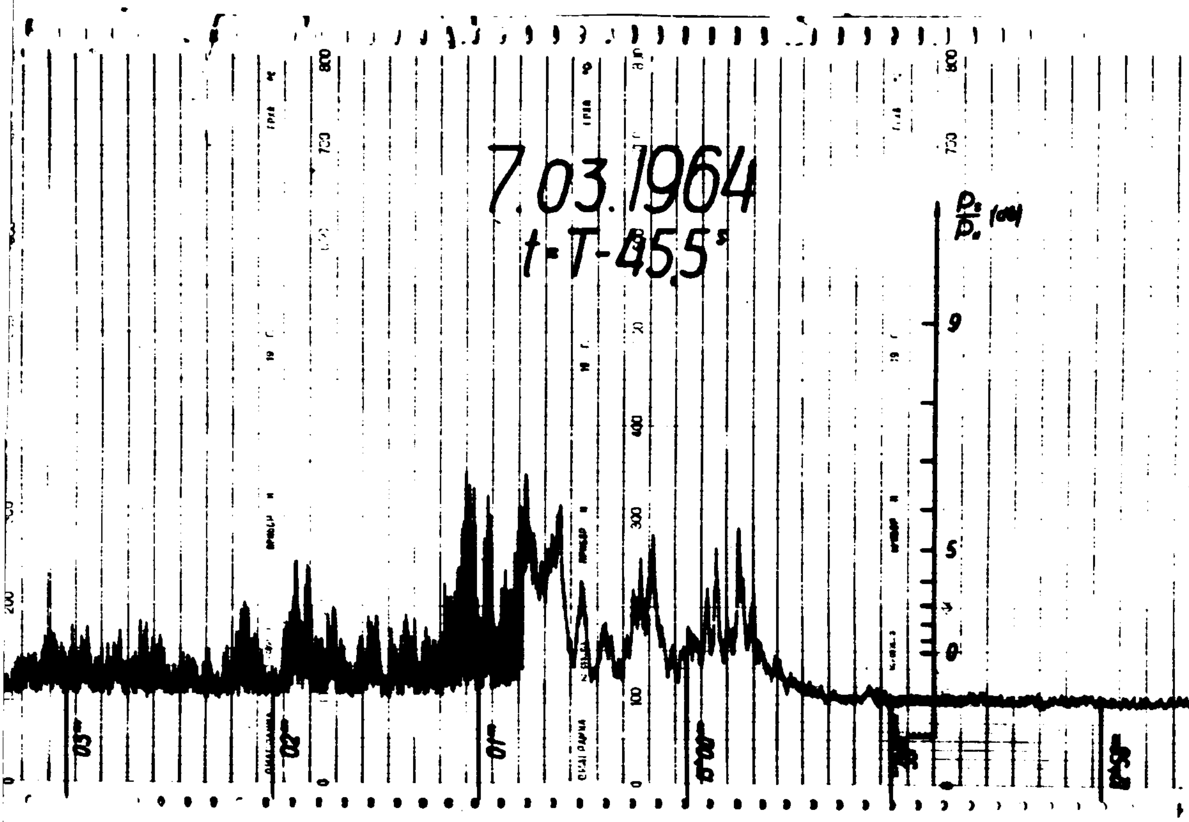

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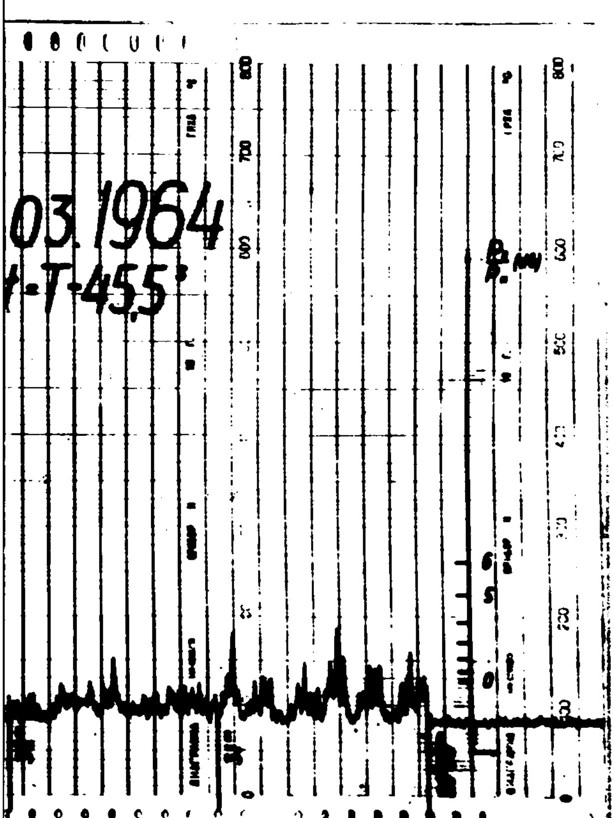

Figure B-31. Pass No. 559

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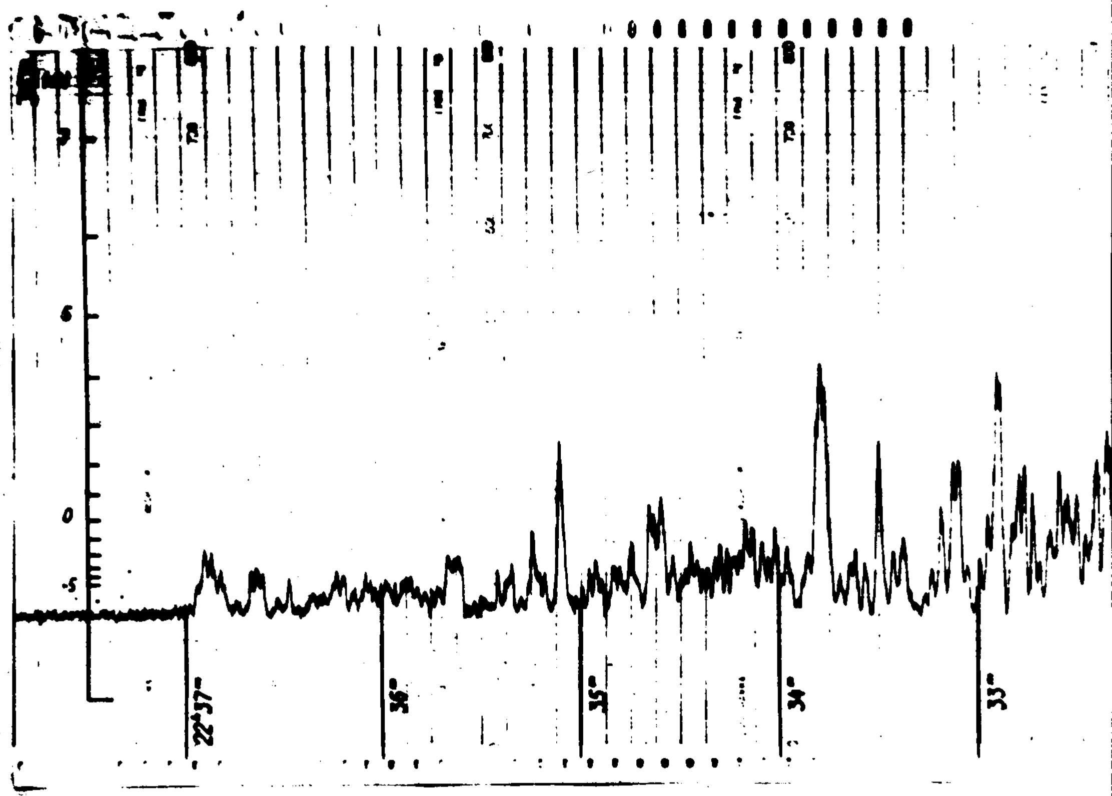

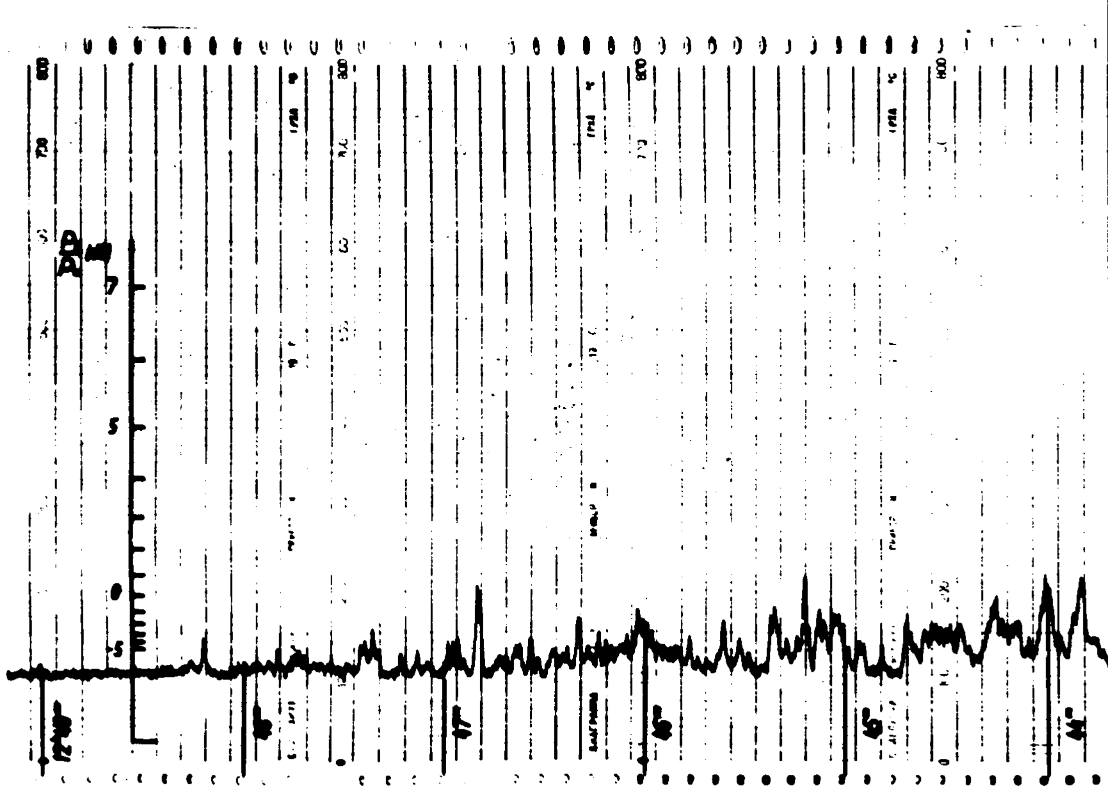

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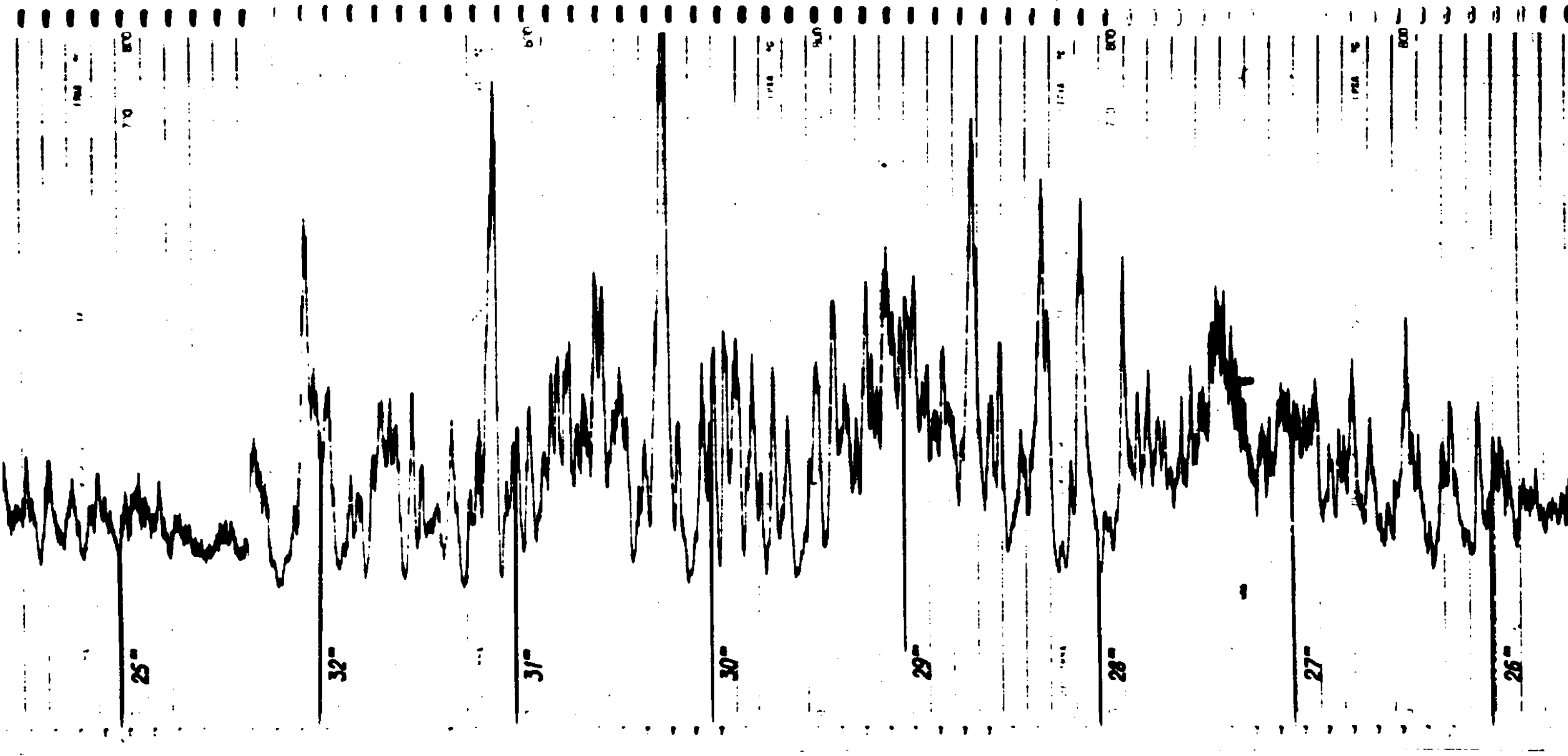

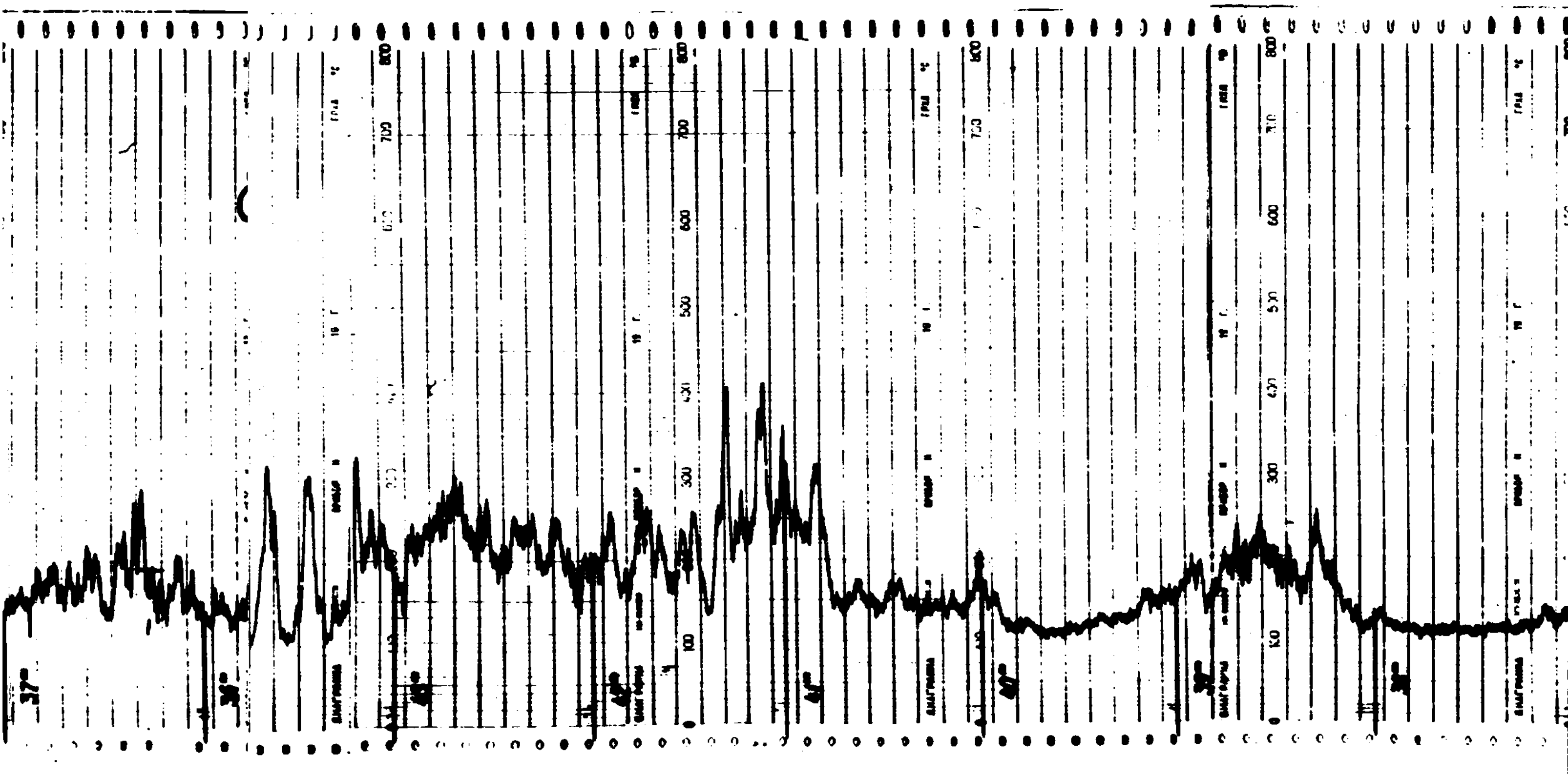

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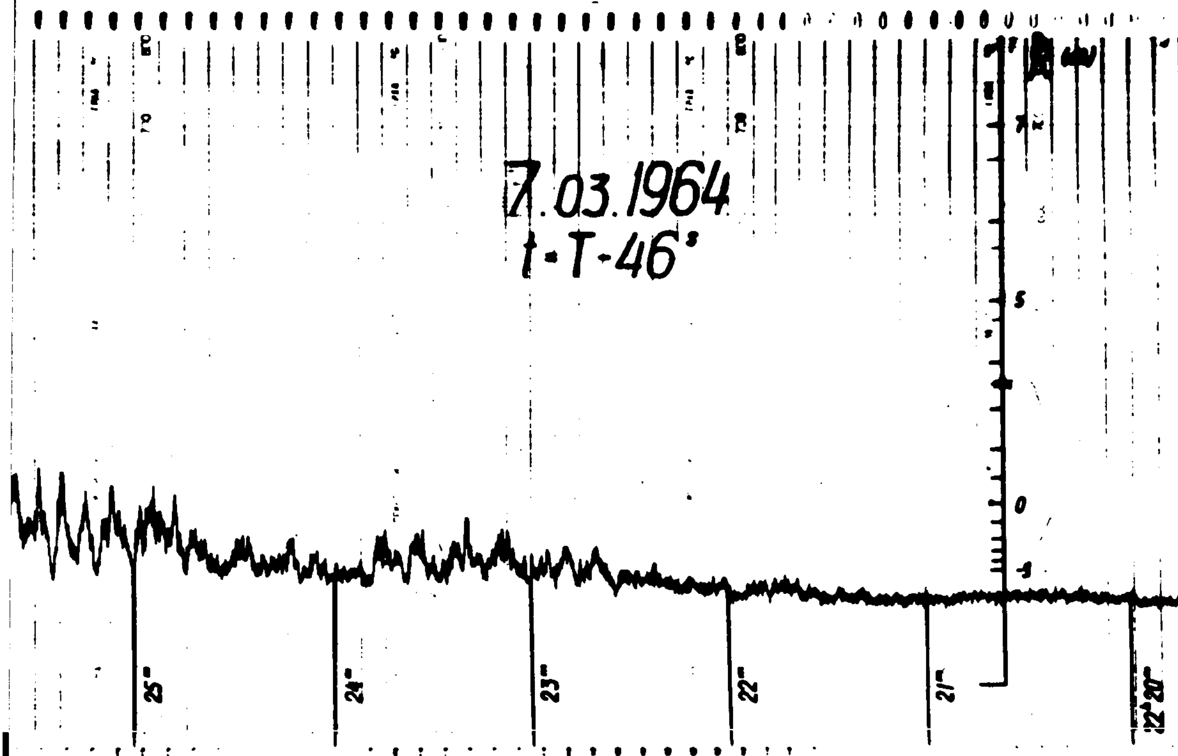

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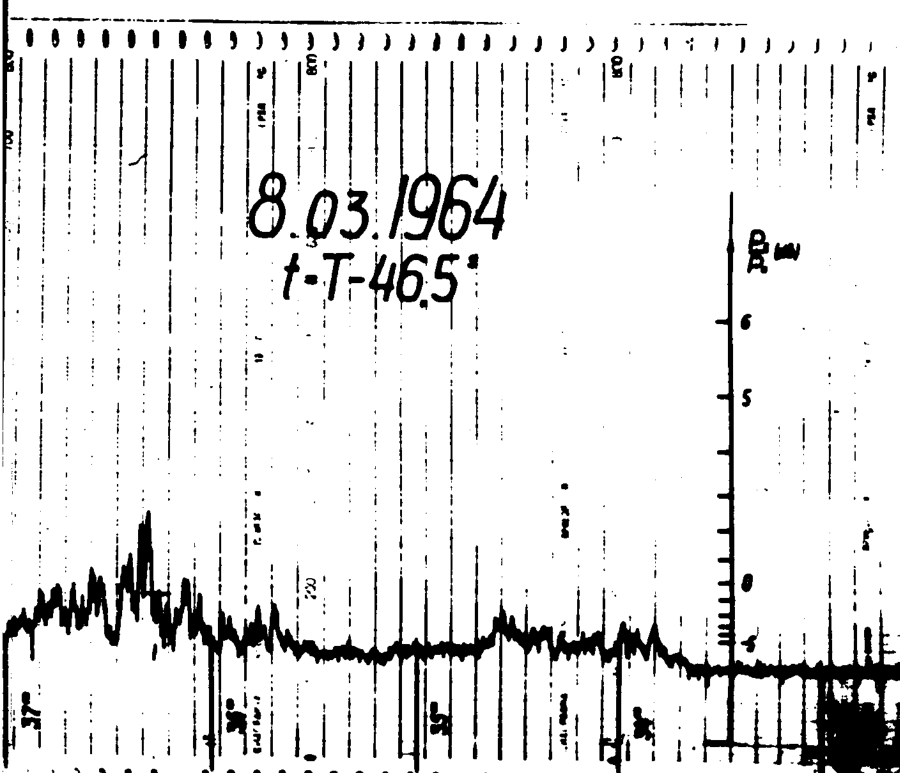

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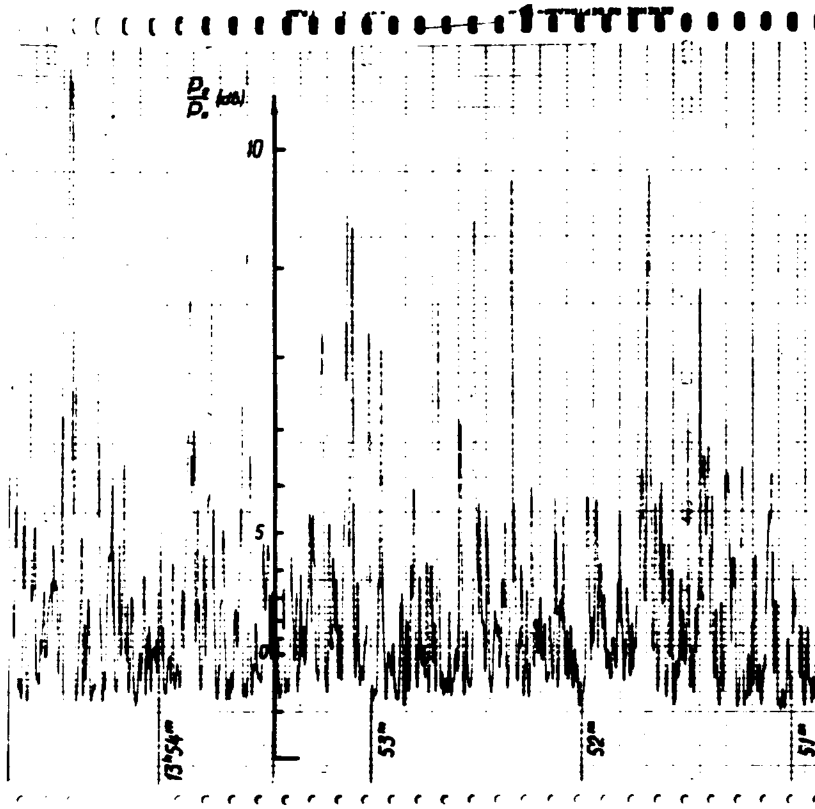
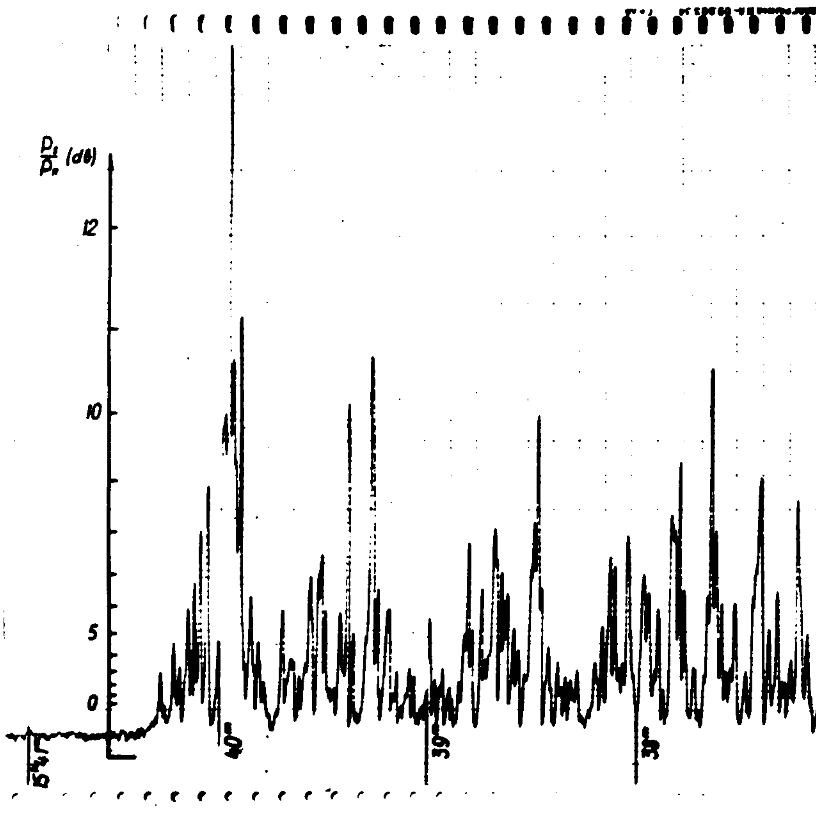

(dB)
10
5
0
13h54m
53m
52m
51m


(dB)
12
10
5
0
40m
39m
38m

2

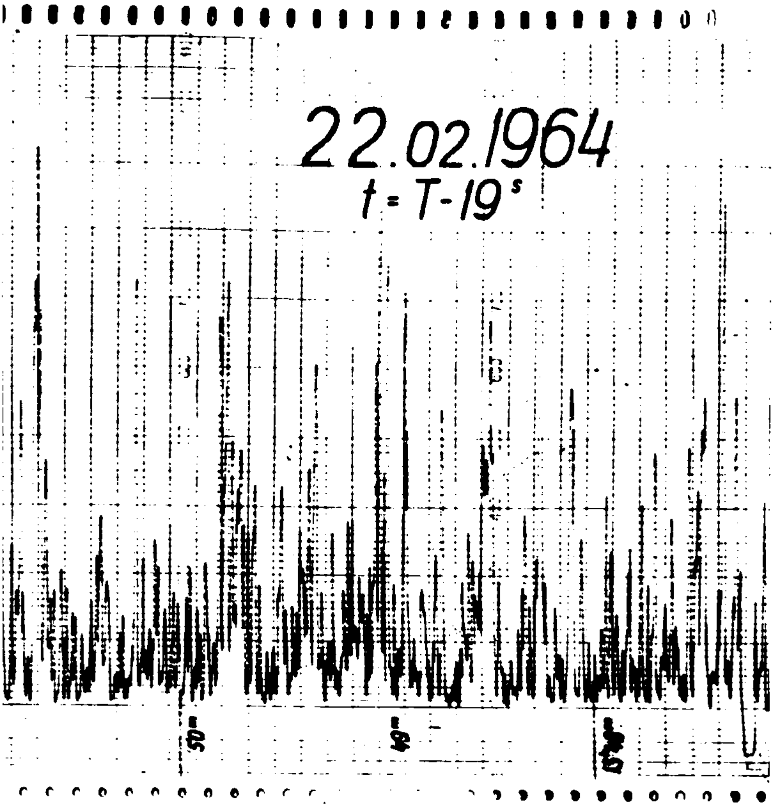
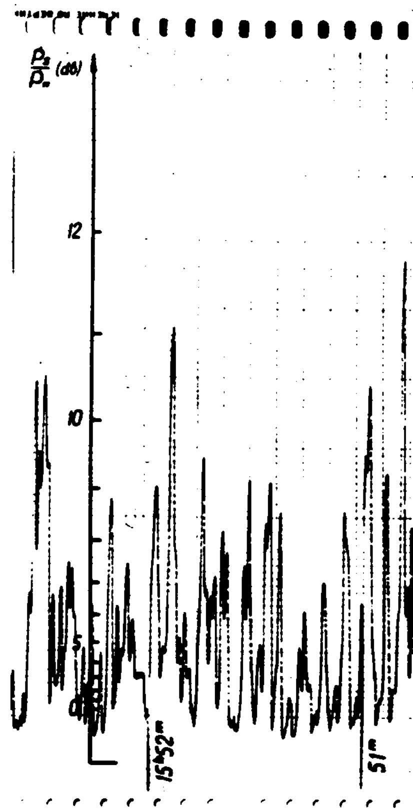


Figure B-34. Session M1



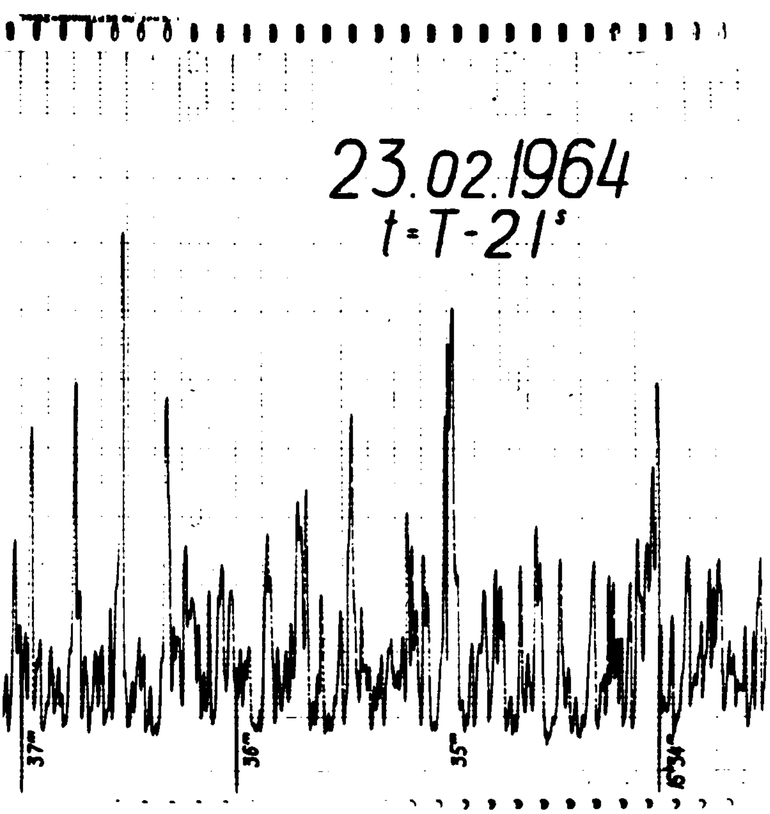
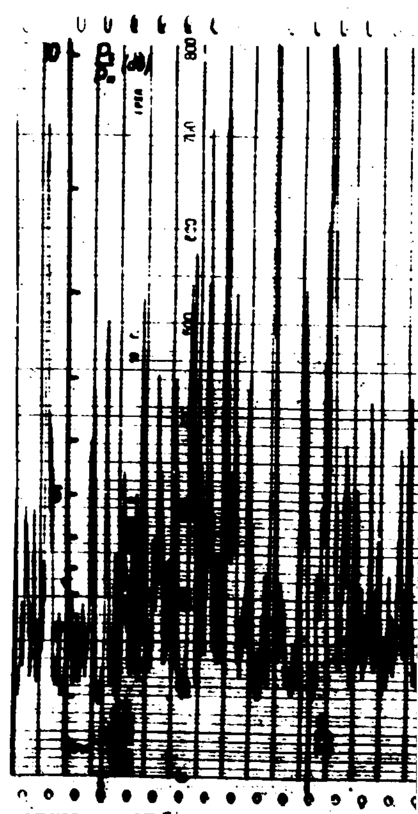


Figure B-35. Session M2A



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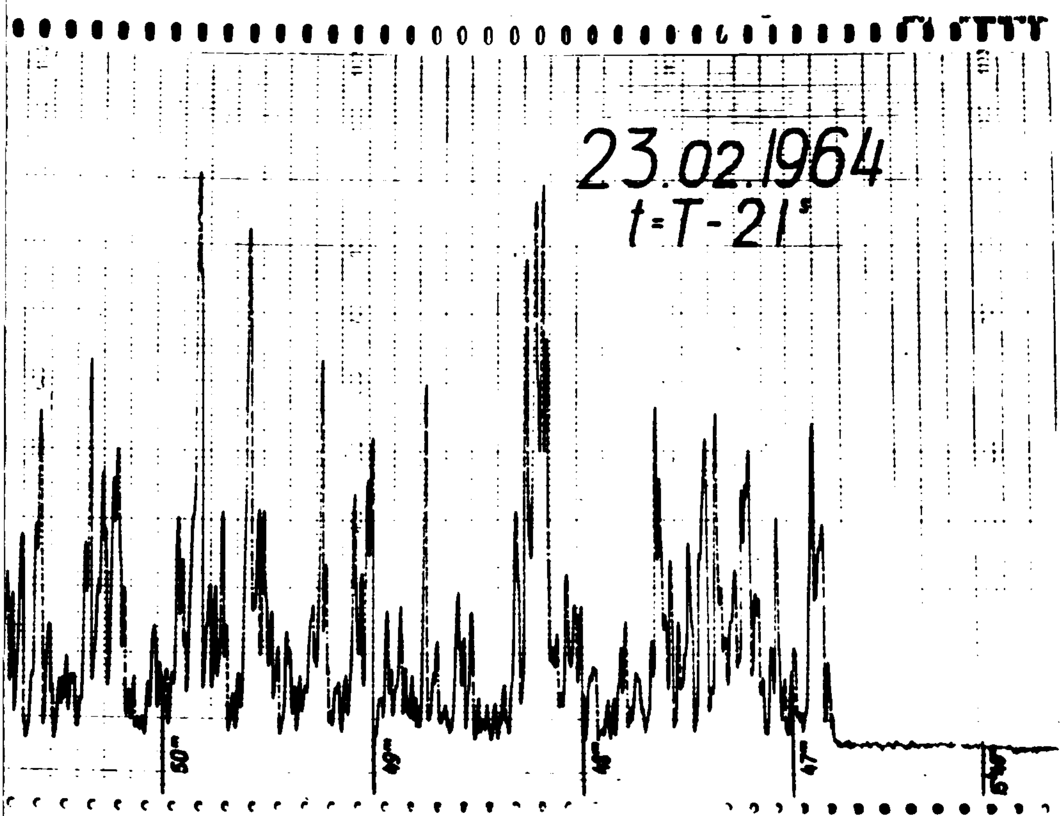


Figure B-36. Session M2B

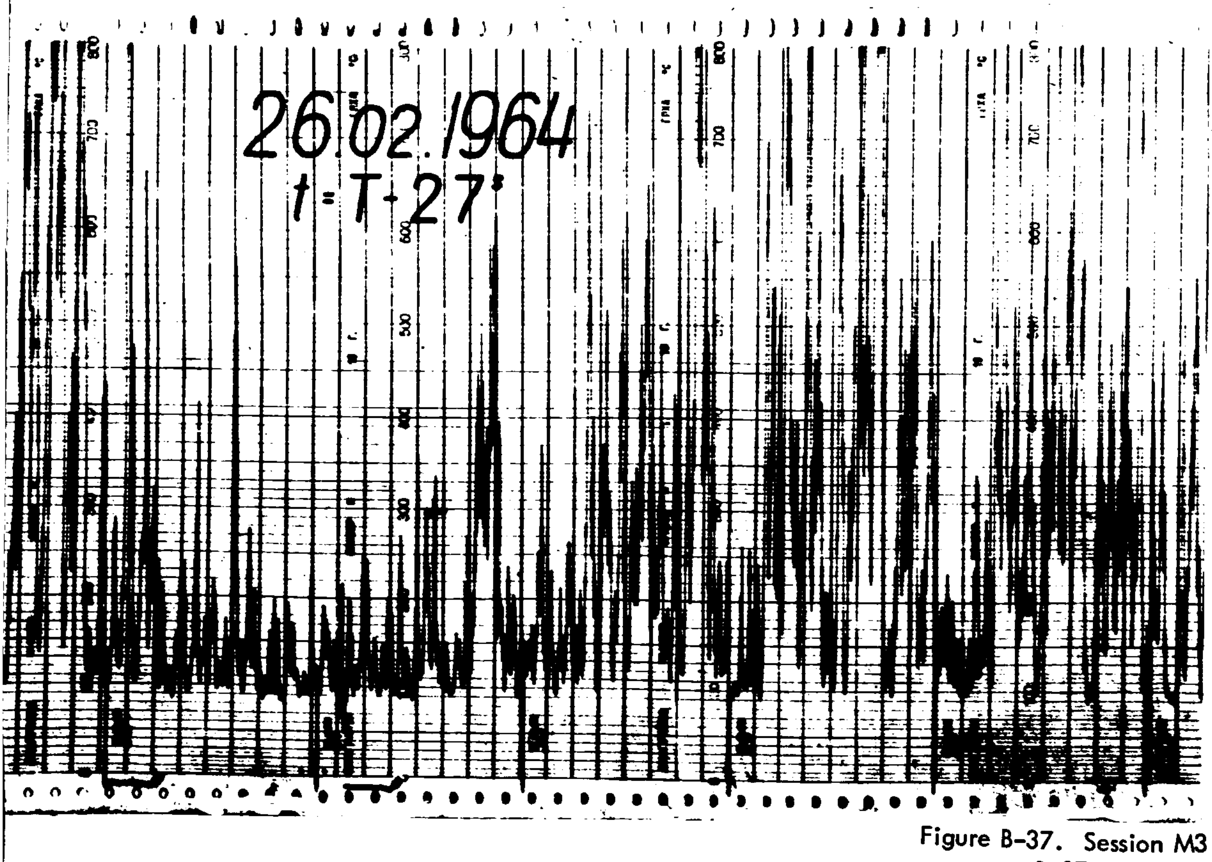
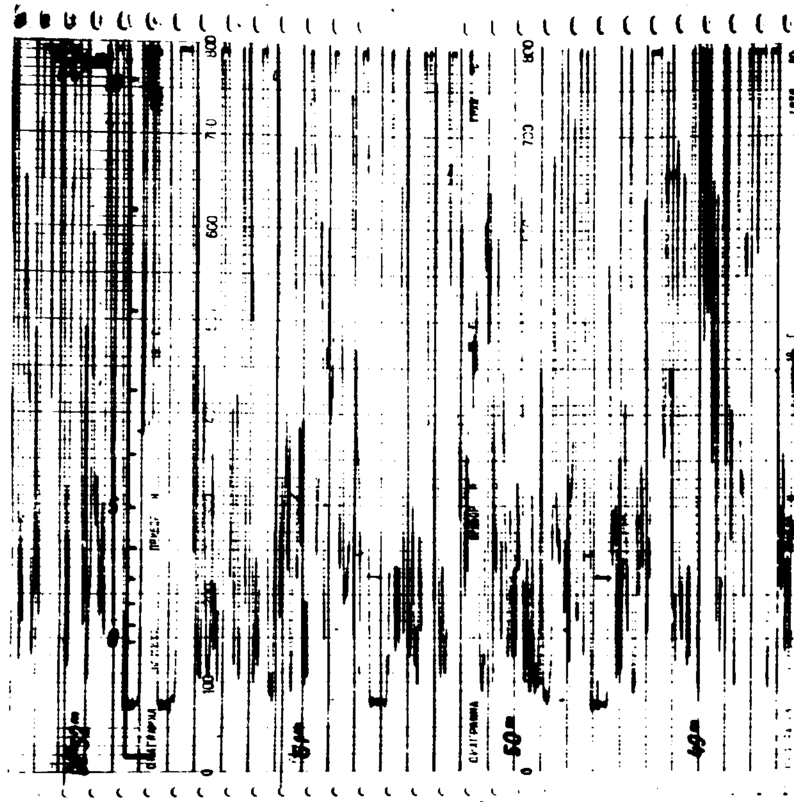
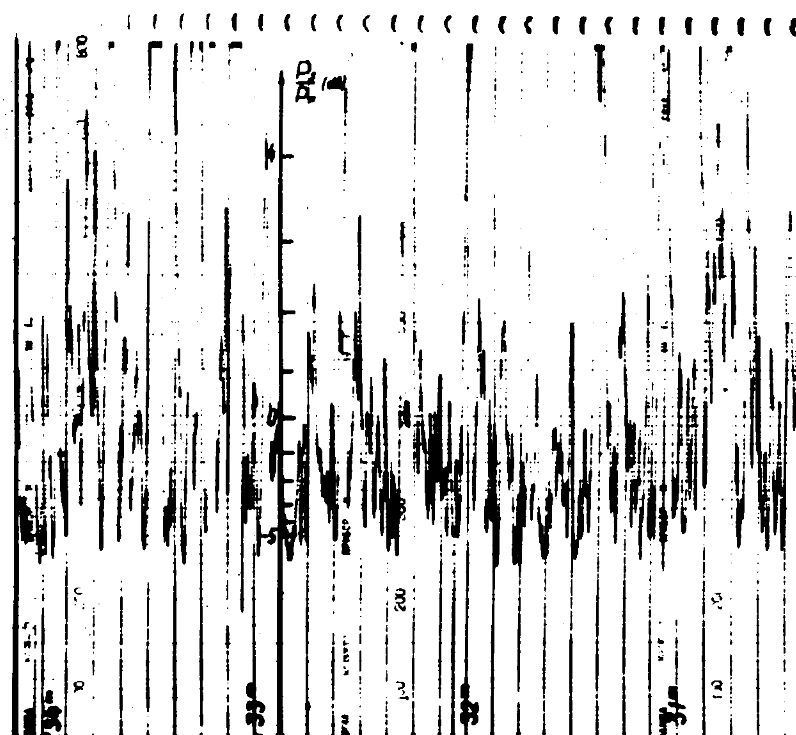


Figure B-37. Session M3





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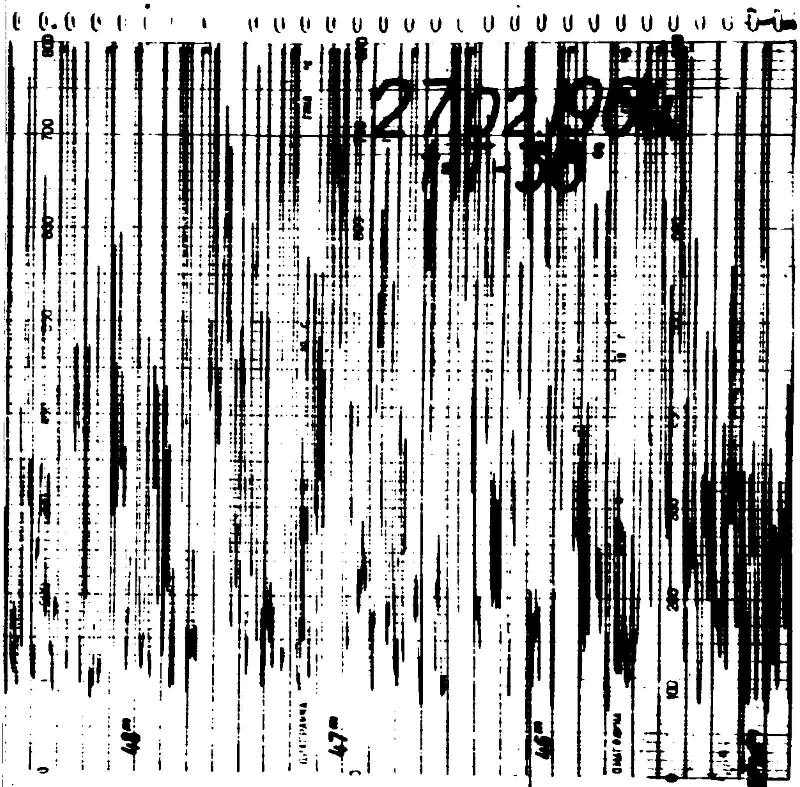
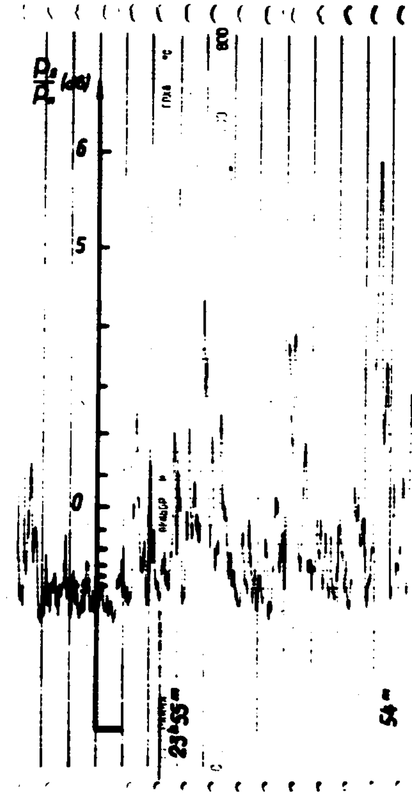


Figure B-38. Session M4



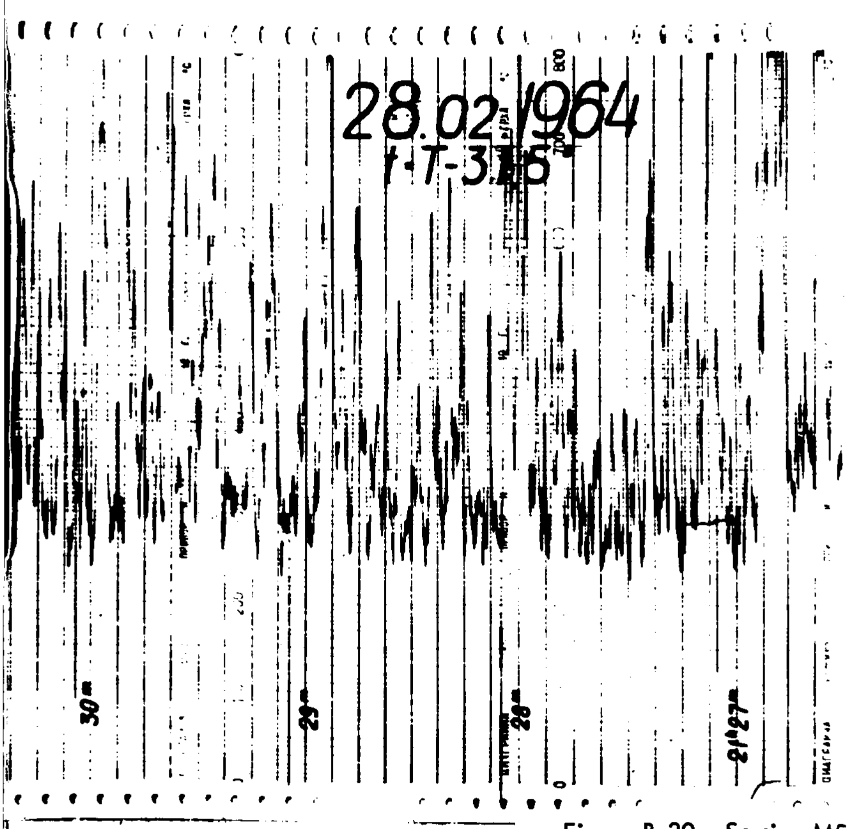
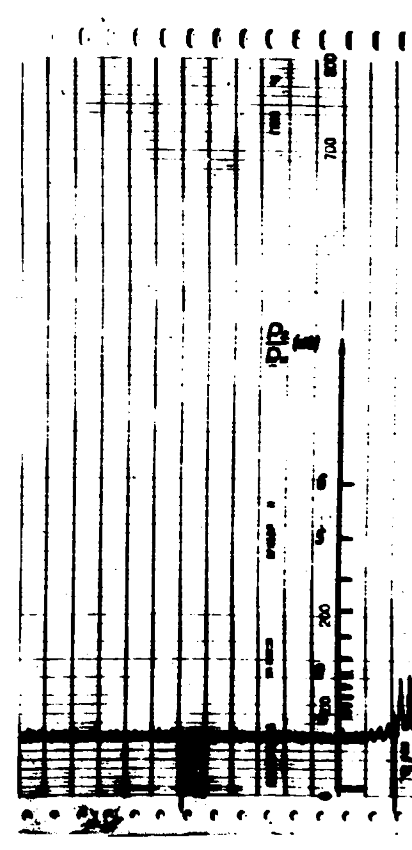


Figure B-39. Session M5



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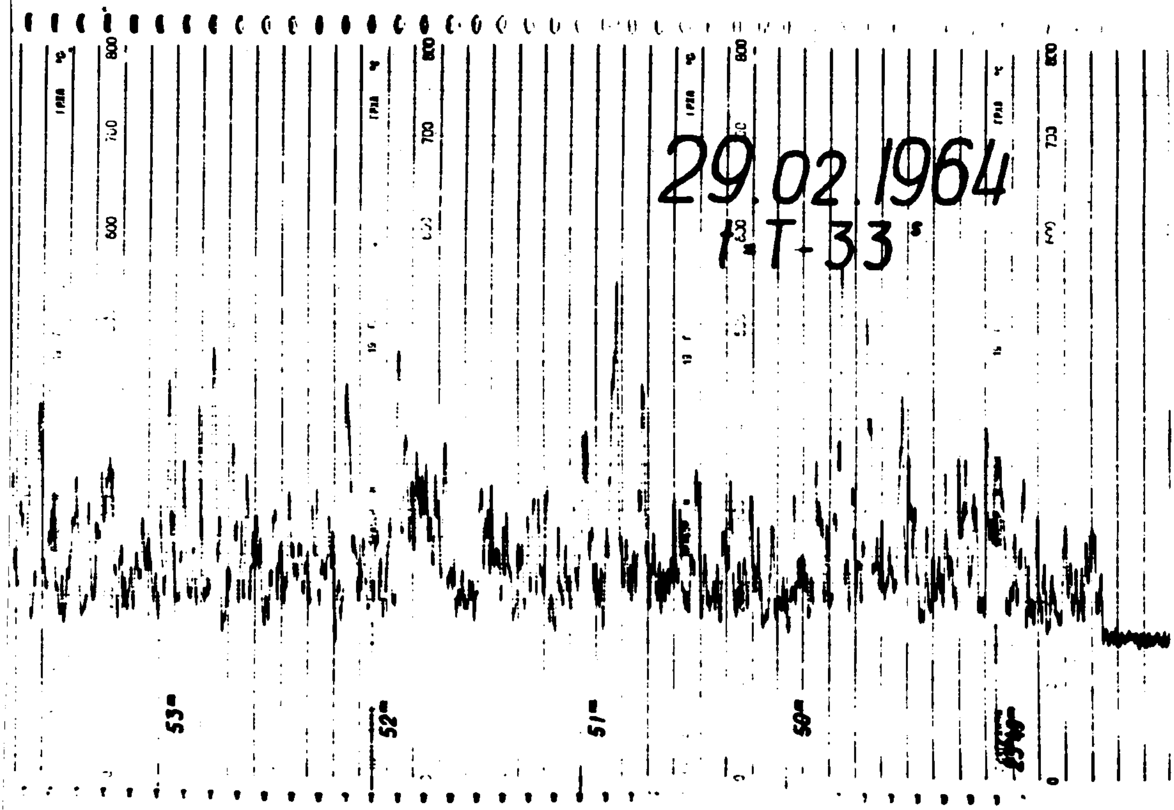

Figure B-40. Session M6

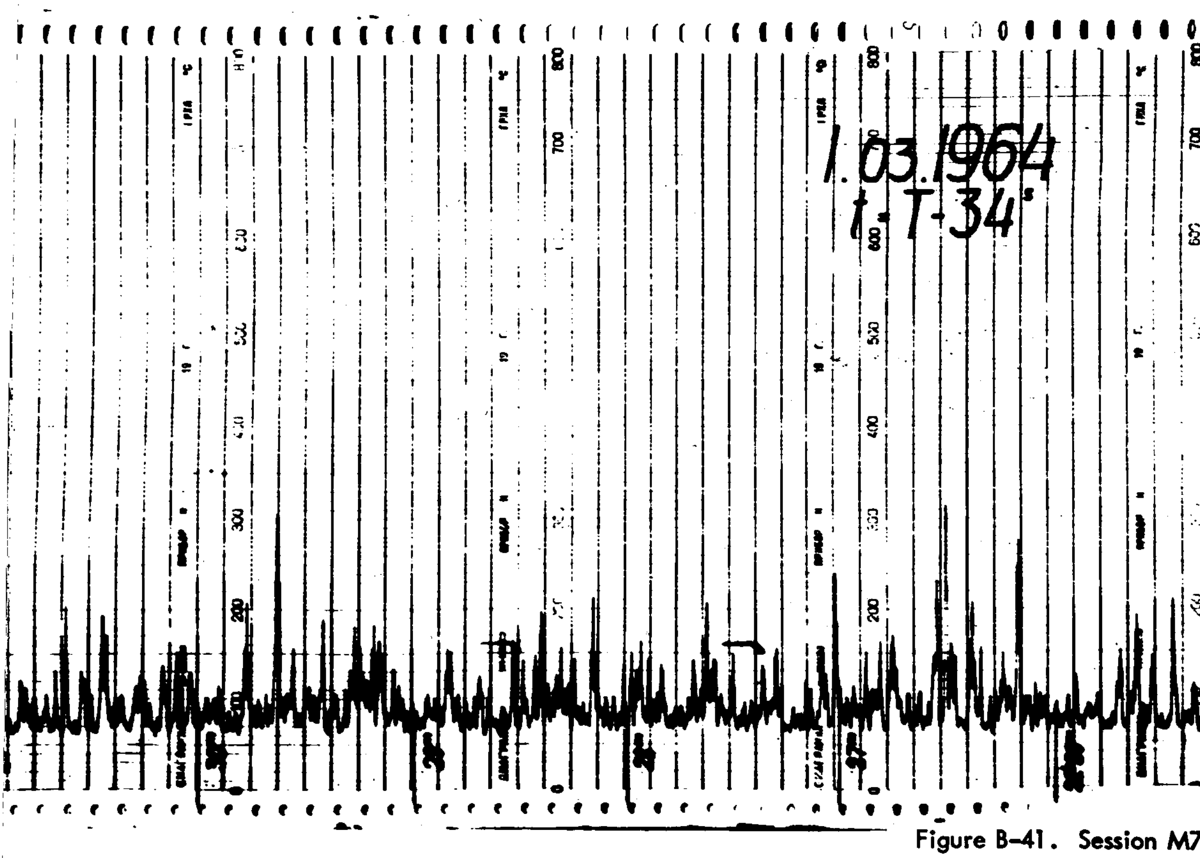

Figure B-41. Session M7

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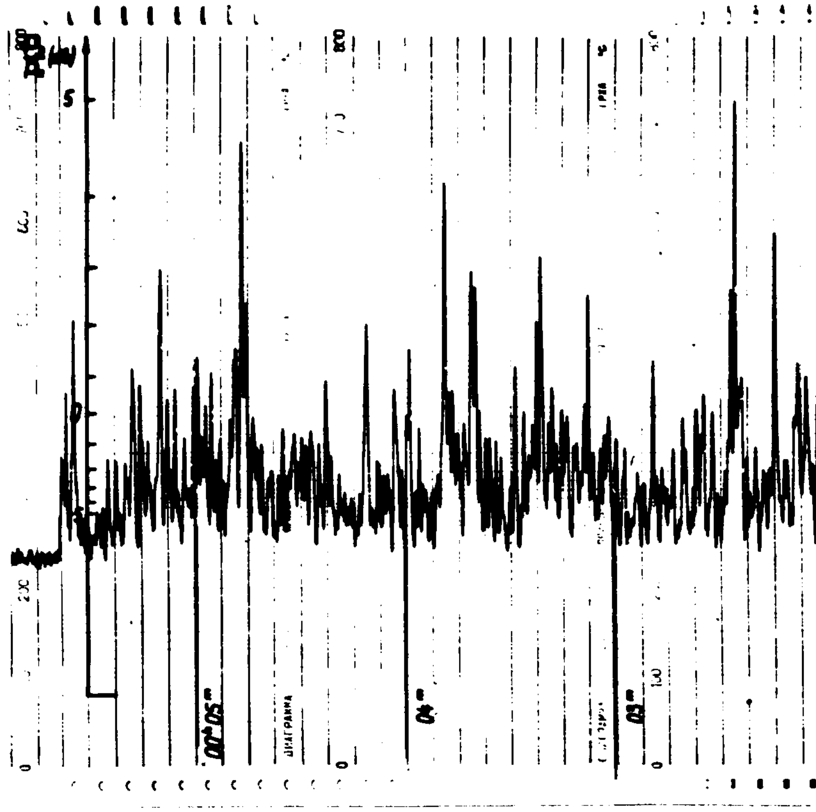

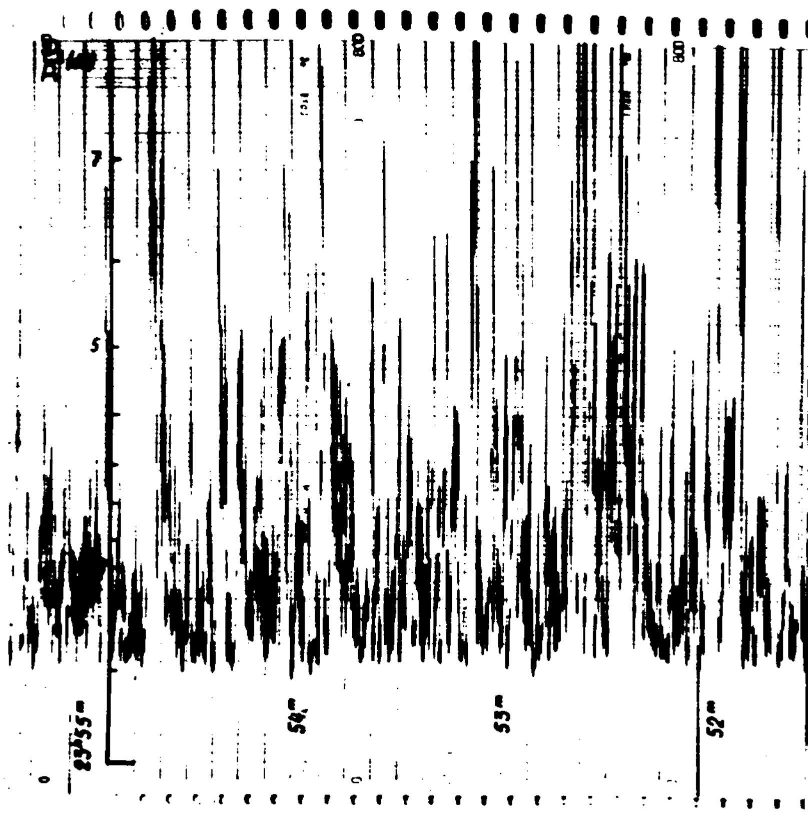

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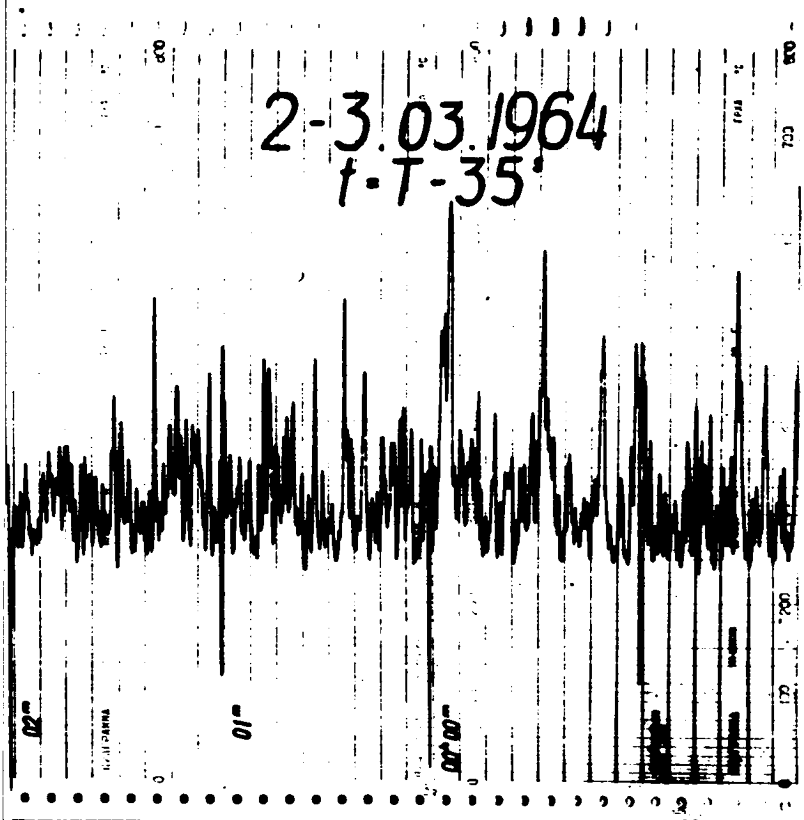

Figure B-42. Session M8

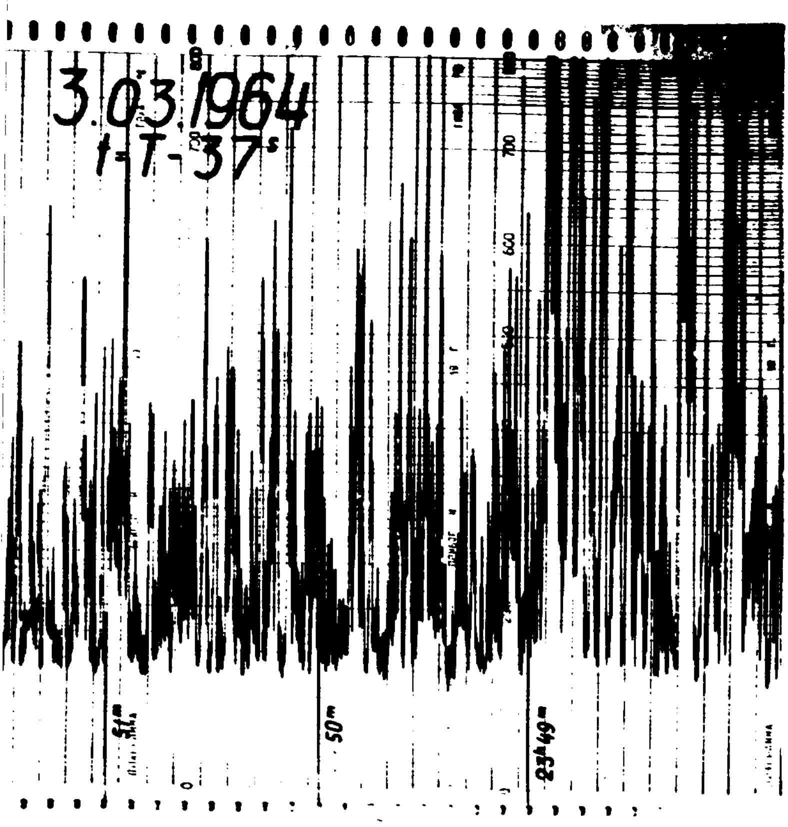

Figure B-43. Session M9

3

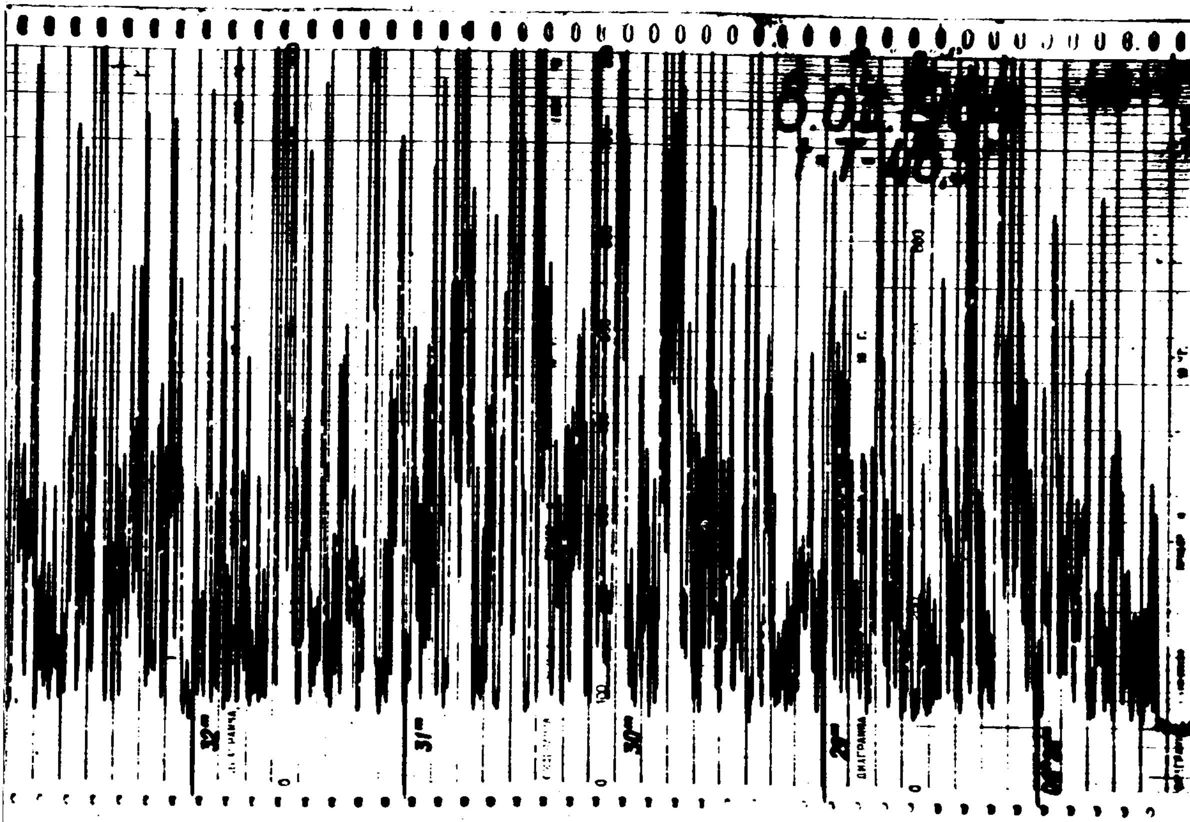

Figure B-44. Session M10

APPENDIX C

EXCERPTS FROM THE "POST LAUNCH ANALYSIS REPORT" PASSIVE COMMUNICATIONS SATELLITE ECHO II, DATED SEPTEMBER 1964, GODDARD SPACE FLIGHT CENTER, GREENBELT, MARYLAND

4.2 RADAR EXPERIMENTS

4.2.1 INTRODUCTION

The primary objective of the Echo II Radar Experiments is to evaluate the shape and surface characteristics of the Echo II satellite as a function of time.

The Echo Project Office made arrangements with certain organizations to conduct the radar observations necessary to meet the primary Radar Experiments' objective. Some of the participating facilities are listed in Table 4-1.

In accordance with these arrangements and the Project Experiment Plan, monostatic radar observations of the orbiting satellite were conducted at selected frequencies from UHF through X-band.

4.2.2 DATA COLLECTION AND PROCESSING

An intensive data collection effort was conducted during the first two weeks after launch. The purpose of this initial intensive effort was to examine the satellite behavior during initial pressurization; during the first continuous sunlit period of eleven days; and during the initial eclipse periods while the satellite was undergoing extreme temperature cycling. Thereafter, radar data was collected on a noninterference basis at the radar sites until observations were again increased during the onset of the second sunlit period which occurred approximately 100 days after launch. After adequate data had been collected, the data collection effort again returned to a non-interference basis when it continued at selected facilities.

Station	Cognizant Agency	Location	Frequency	Peak Power	Pulse Length	PRF	Beam Width	Antenna Size	Antenna Gain	Polarization
Antigua	AMR	Antiqua	C Band	2.8 mw	.25-2.4 us	160	.43°	29'	51 db	Vert-Hor-Cir
Aris Ship (Gen Arnold)	AMR	Ascension Isle	C Band	1 mw	30 us	160	.4°	30'	52 db	Hor-Vert
			L Band	10 mw	30 us	160	1.5°	40'	41 db	Hor-Vert
			X Band	1 mw	30 us	160	.4°	40'	52 db	Hor-Vert
Aris Ship (Gen Vandenburg)	AMR	Cape Kennedy	C Band	1 mw	30 us	160	.4°	30'	52 db	Hor-Vert
			L Band	10 mw	30 us	160	1.5°	40'	51 db	Hor-Vert
			X Band	1 mw	30 us	160	.4°	40'	52 db	Hor-Vert
Cornell Radar Labs	Cornell Univ	Buffalo NY	S Band	25 mw	7 us	125	.24°	60'	51.5 db	Hor
Grand Turk	AMR	Grand Turk Isle	C Band	2.8 mw	.25-2.4 us	160	.43°	29'	51 db	Vert-Hor-Cir
Malvern	RRE	Malvern, England	S Band	3 mw	10 us	200,180	.5°	45'	50 db	Lin
Millstone	L.L.	Westford, Mass.	L Band	5 mw	2 us	15	1.3°	84'	46.5 db	Cir
Patrick AFB	AMR	Patrick AFB, Fla.	C Band	2.8 mw	.25-2.4 us	160	.43°	29'	51 db	Vert-Hor-Cir
Wallops UHF	L.L.	Wallops Isle	.42-4.5 gc	8 mw	2 us	30	2.6°	60'	36 db	Vert-Hor
Wallops S	L.L.	Wallops Isle	S Band	5 mw	2.2 us	320	.39°	60'	52.8 db	Vert
Wallops S	NASA	Wallops Isle	S Band	5 mw	1, 2, 5 us	256,303 328,390	.39°	60'	52.8 db	Vert-Hor-Cir
Wallops C	NASA	Wallops Isle	C Band	2.8 mw	.25-2.4 us	160	.43°	29'	51 db	Vert-Hor-Cir
Wallops X	L.L.	Wallops Isle	X Band	1 mw	2.5 us	320	.12°	30'	60 db	Vert

RADAR FACILITIES

TABLE 4-1

Table 4-1 lists the more pertinent parameters of some of the participating radar facilities.

Data was furnished to GSFC in the form of analog pen records and magnetic tapes. Figure 4-5 illustrates the mode of quick look data flow from these facilities into GSFC. Figure 4-6 illustrates the type of primary data expected and the data flow into GSFC for further processing.

Representatives were stationed at a few selected sites for a brief period during and after launch to provide quick look observations direct to the Project. These representatives were stationed at the following sites:

a) L-band radar at Millstone Hill, Massachusetts

b) S, X and UHF band radars at Wallops Island, Virginia

c) S-band radar at the White Sands Missile Range

The analog pen records (strip charts) were used for quick look analysis. However, the magnetic data tapes provide the primary source of information for investigating the physical characteristics of the orbiting satellite.

A series of computer programs have been prepared for the IBM 7090 computer to permit processing of the collected radar data stored on magnetic tape. Two computer programs, of special interest, provide a means for extracting the radar cross section histories and other statistical information from the collected data. These two computer programs include:

a) A means to convert the collected data received from the various installations into radar cross section. The program extracts from

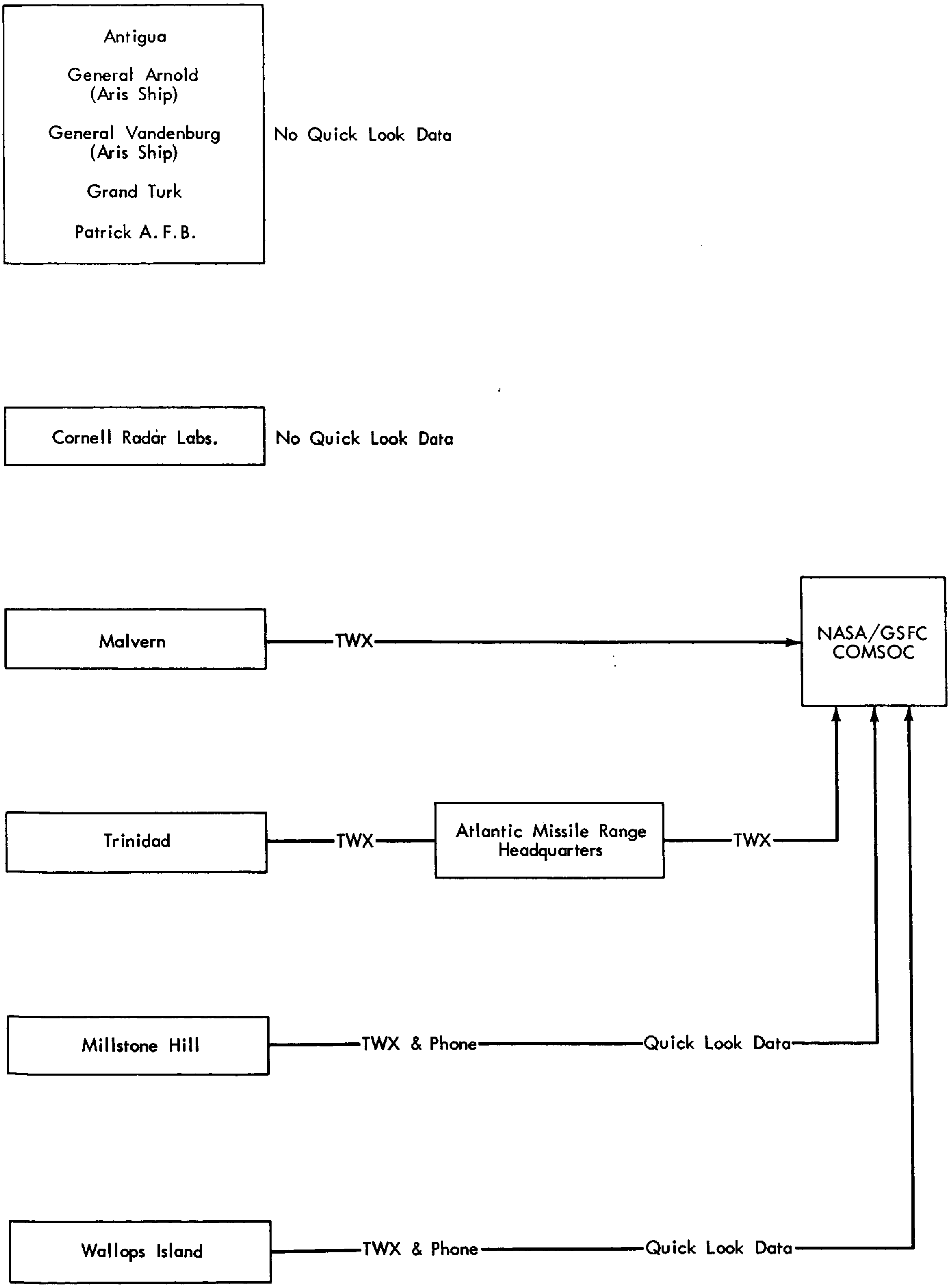

Figure 4-5 QUICK LOOK DATA FLOW PLAN

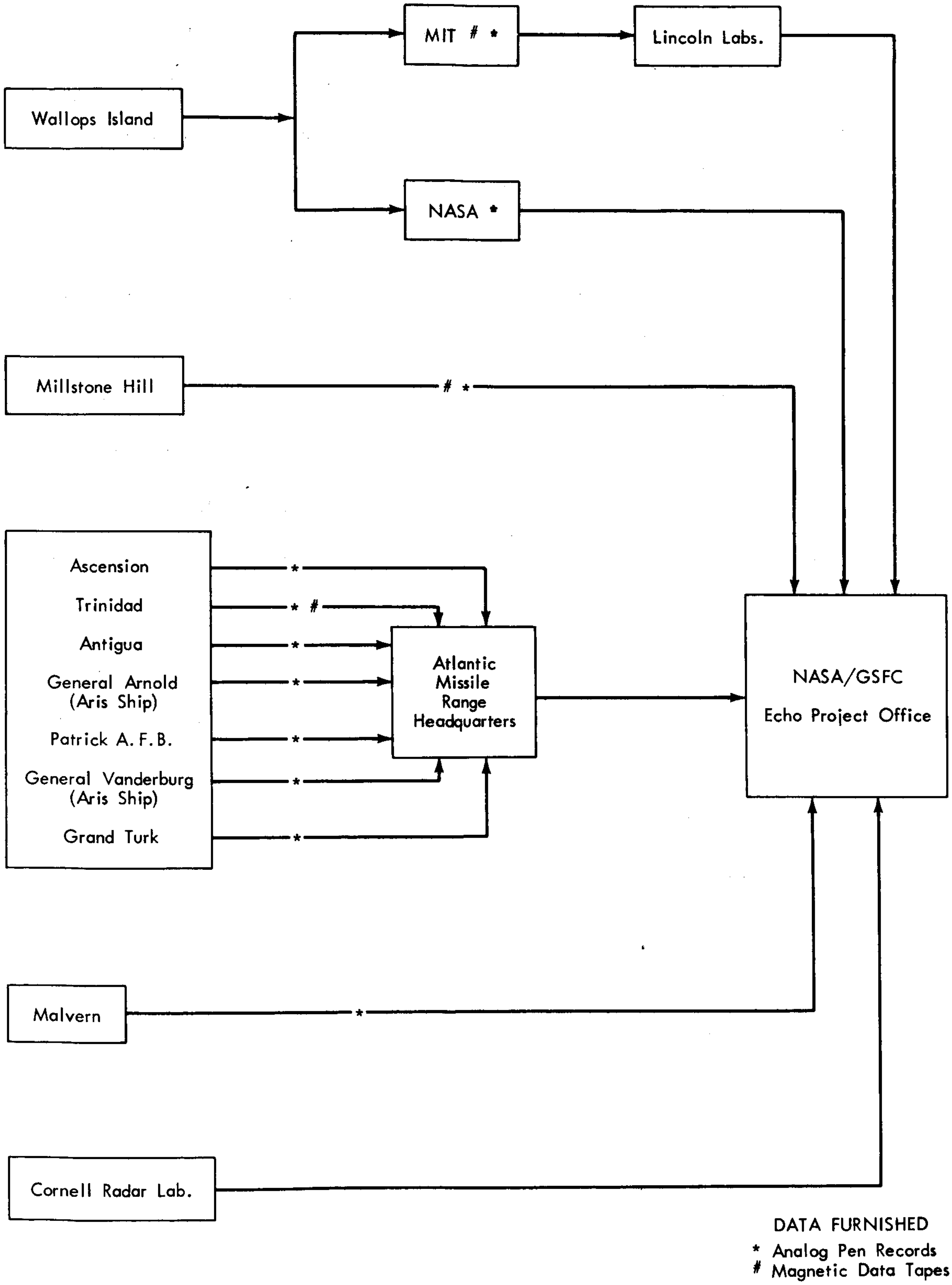

Figure 4-6 PRIMARY DATA FLOW PLAN

the data the received signal level, time, and the slant range to the satellite. These parameters are used in the computation of the radar cross section. From these computations graphs can be plotted of the radar cross section as a function of time.

b) A method of computing a mean or average radar cross section and a standard deviation of the cross section. The mean or average radar cross section provides a measure of the satellite size and the standard deviation provides a measure of the variations in the signal level return. Other parts of this program will provide a histogram of the cross sections and an auto-correlation function of the frequency. This information will allow any periodicity in the signal level variations to be detected.

Due to difficulties encountered with the magnetic tapes (such as data format) received from some of the radar stations listed above, the data processing has been delayed. Therefore, the results of our radar experiments as described in this report are based primarily on analog (strip chart) recordings. Though these recordings form a basis for a quick analysis of the results, the information they contain in some instances restricts one to qualitative judgement. The results from the computer processed data will be included in the Project Echo II Final Report.

4.2.3 DISCUSSION OF RESULTS

4.2.3.1 CHARACTERISTICS OF THE RADAR SIGNALS

The radar return from the Echo II satellite is exhibiting considerably greater scintillations than was anticipated prior to launch. Non-periodic signal fluctuations of approximately ± 6 db (average value) at C band and about ± 5 db (average value) at S band have been observed. In addition, occasional rapid (short duration), non-periodic scintillations of up to 20 db have also been observed.

Figure 4-7 illustrates a sample of radar data collected at Wallops Island at frequencies of 420 mcs (UHF-Band); 1200 mcs (L-band); and 9300 mcs (X-band). This figure indicates that the scintillations vary with frequency. The data illustrated in Figure 4-7 are generally representative of the data collected by the other radar stations.

Quick look reports immediately following the launch indicated that signal dropouts of up to 8-10 seconds in duration, with a periodicity of a multiple of approximately 50 seconds, were being observed. However, examination and processing of received data does not verify this reported condition with any consistency. For example, there are several stations that have never observed this type of dropout (attributable to the satellite). In view of the large amount of data collected and the accompanying difficulty of visually reducing the data, more definitive statements regarding the nature and cause of such dropouts cannot be made at this time.

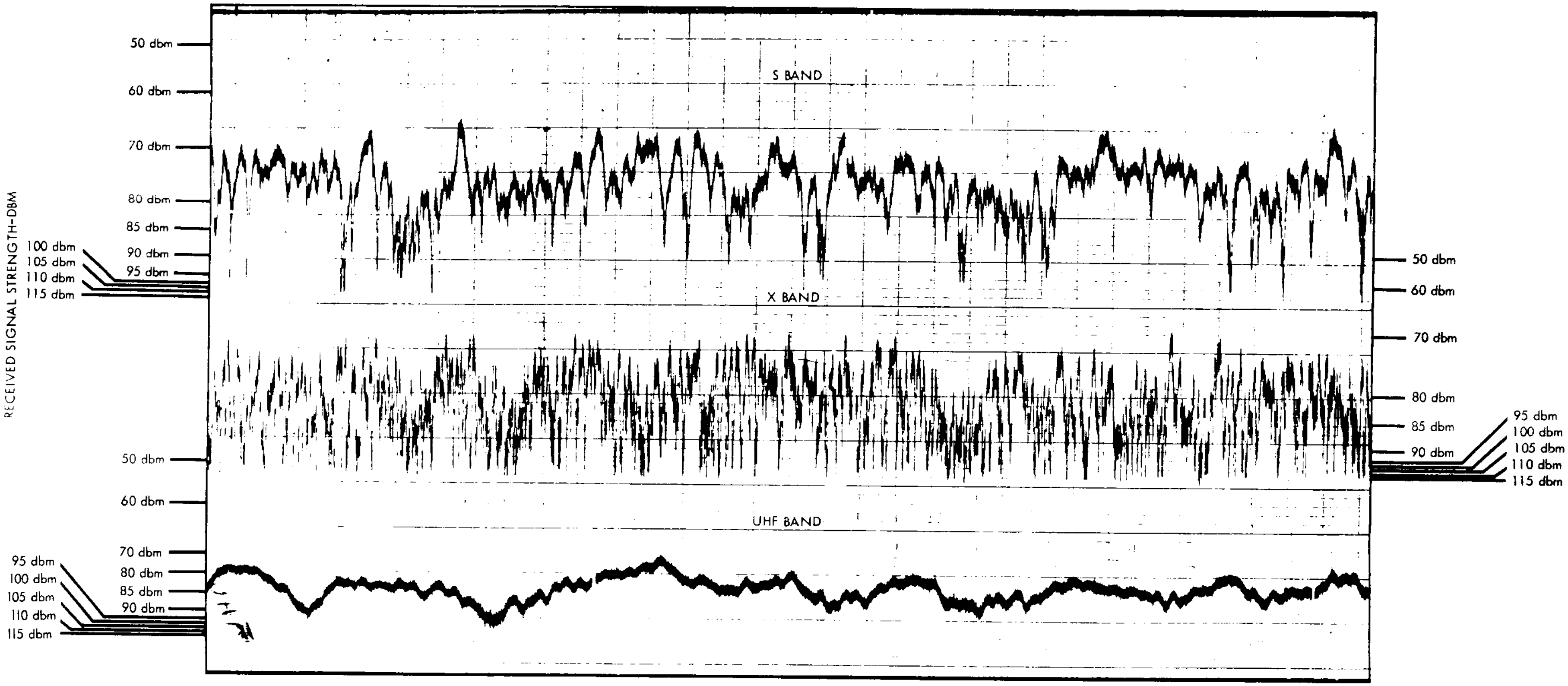

FIGURE 4-7 SAMPLE RADAR DATA
RECEIVED SIGNAL STRENGTH VS. TIME

A number of theories have been advanced to explain the signal dropouts observed in some of the radar signatures. This is discussed in more detail in paragraph 4.2.3.3.

4.2.3.2. <u>RADAR CROSS SECTION</u>

Analysis of the radar data collected for the first four months after launch indicates an overall average cross section of approximately 29 db above a square meter, as compared to the theoretical cross section of 31.2 db. This is well within the calibration tolerances of the various radar systems, and agrees with the average cross sections of 29 db obtained in our communication experiments. (See Section IV). There has been no discernible change in the satellite average cross section since launch.

4.2.3.3 <u>SATELLITE SHAPE AND SURFACE CHARACTERISTICS</u>

As a result of inspection of the analog pen records and preliminary processing of a part of the magnetic tapes, certain preliminary conclusions concerning the satellites shape and surface can be made at this time. However, as previously indicated, this is subject to further validation through the continued data processing and analysis efforts.

Radar returns verify that the satellite achieved a spherical shape having the design radius of approximately 67.5 feet. The scintillations observed at all radar frequencies indicate a sphere with minor surface wrinkles.

It is difficult to describe the various patterns which a surface of this type could include to cause scintillation of the nature observed. However, a comparative analysis of the radar return exhibited by the orbital satellite can be compared with similar returns obtained during the Static Inflation Tests (S.I.T.) at Lakehurst, New Jersey.

Figure 4-8 is an overall photograph of sphere #9, one of the test spheres used at the Static Inflation Tests. The photograph was taken while the sphere was at a skin stress level of approximately 500 psi, after it had been previously stressed to a level of about 1500 psi. Although this sphere was not considered of flight quality (such as spheres No. 13 and 16), it did exhibit radar return characteristics similar to those now being observed on Echo II. Figure 4-8 is provided to give an overall view of the test sphere as seen from the radar test station. The two reinforced gores on which the beacons are normally mounted are rather vividly illustrated by their more wrinkled condition.

Figure 4-9 is a close up of photograph of the sphere, under the same test conditions as described above for Figure 4-8. The radar test arrangement was such that the radar beam swept the sphere area from gore #55 across the reinforced gores (53-54) and continued on to about gore #50. The radar return at C-band frequencies from the reinforced area was typified by scintillations on the order of ± 9-10 db. The area to the right of the reinforced gores exhibited scintillations of approximately ± 6 db. It is this latter condition which is considered representative of the orbital case (± 6 db). From the photograph it is estimated that the wrinkles in the reinforced area vary from about 1/4" to 1" in depth and in the non-reinforced area from 1/4" to perhaps 1/2" in depth.

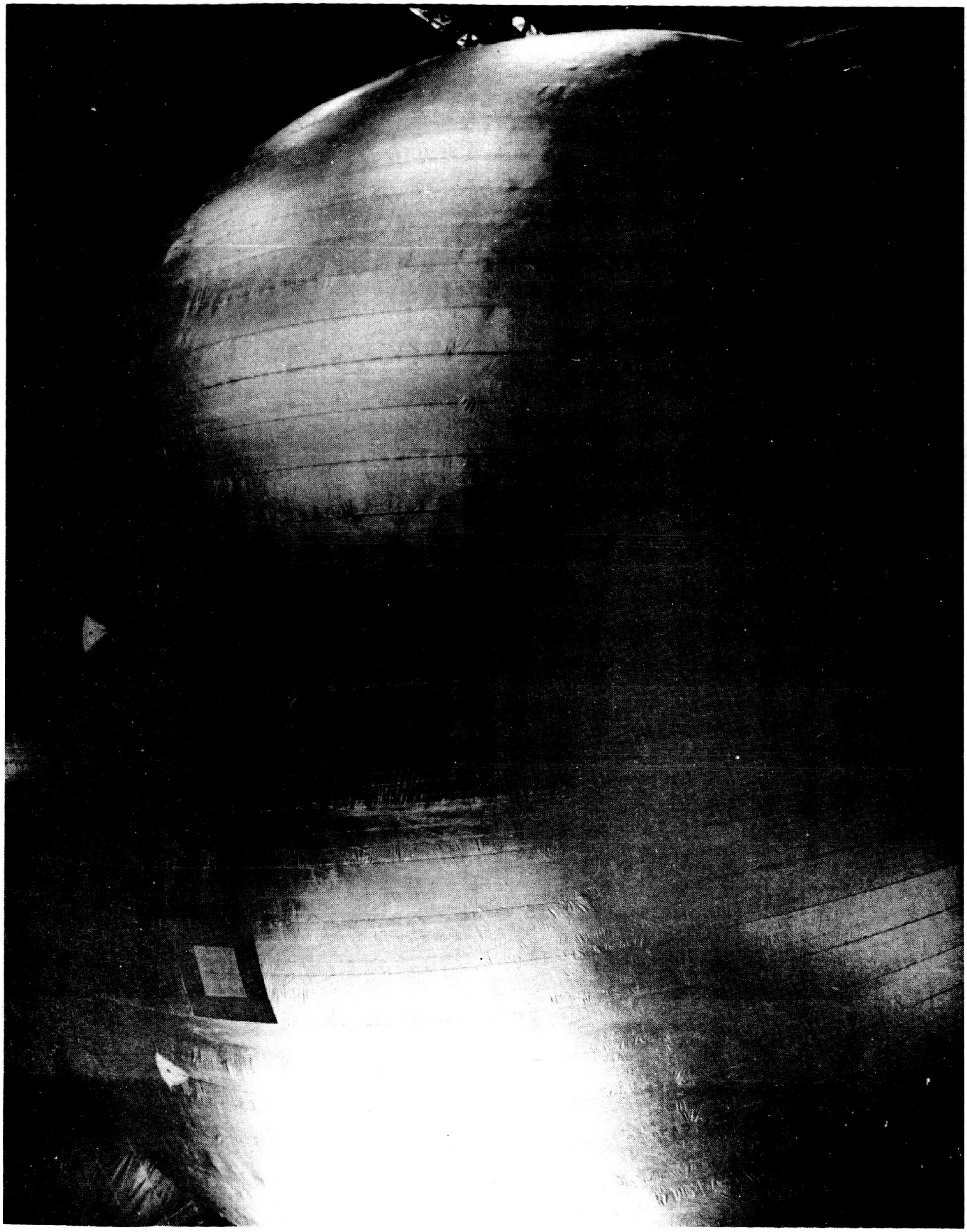

FIGURE 4 - 8 SIT SPHERE #9

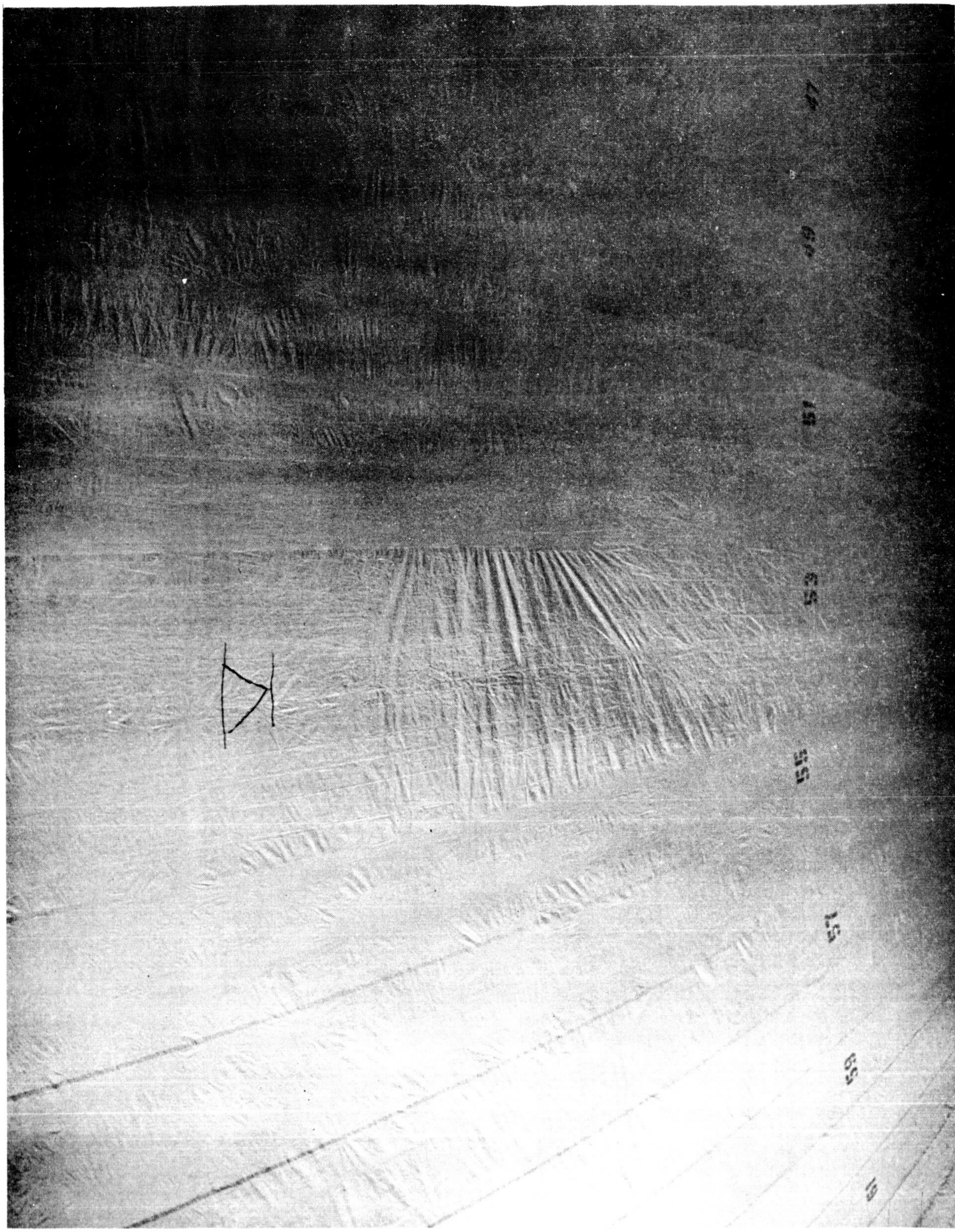

FIGURE 4 - 9 CLOSE UP OF SPHERE #9

When surface perturbations, as pictured above, are related to the Echo II satellite spinning with a period of approximately 100 seconds, a better understanding of the orbital condition is provided. When one considers that the satellite is spinning at a rate of approximately one gore per second, the observed scintillation rate is more easily understood.

While the type of structure discussed above gives an indication of the type of surface which would cause a mean scintillation of approximately ± 6 db (at C band) it does not indicate the shape and surface characteristics necessary for the signal dropout previously referred to.

As stated earlier, a number of theories have been advanced to explain the condition required to cause the observed dropouts. These have been examined in some detail and only the following two are considered in this report.

a. Wedge Effect

After visually examining some of the analog pen records it was noted that there was a correlation in time between the rotation period and the periodicity of the signal dropouts. There is one example noted when this condition existed on a record which contained both radar data and telemetry beacon data. This would seem to indicate that the scattering cross section of the satellite near the telemetry beacons and solar panels is different, causing a signal dropout effect when this area is illuminated. This possibility was examined and it was concluded that a change in the scattering cross-section does occur under such a condition and could therefore cause a dropout effect.

From this investigation it was determined that as the satellite rotates at a rate of one revolution every 100 seconds, an outward directed force is exerted on the gores of the sphere in the area where the solar panels and telemetry beacons are mounted. It was found that this force could be great enough to cause a cylindrical wedge to be formed with a scattering cross section considerably lower than that of the nominal sphere cross section. Figure 4-10 illustrates the shape of the cylindrical wedge.

From the analog records it was determined that the signal dropout effect occurs in a sphere rotation interval of 18 degrees (angle α Figure 4-10). The 18 degrees is consistent with the minimum dropout interval of 5 seconds $\frac{360}{100}(5) \doteq 18$ degrees. Computations were made to determine the backscattering cross section of the cylindrical wedge with a sphere rotation interval of 18 degrees. It was found that the cross section was approximately 58 meters squared or 18 db above a meter squared.

The backscattering cross section of the cylindrical wedge is approximately equal to:

$$\sigma = \frac{R\lambda}{4} \operatorname{Tan}^2 \frac{\beta}{2}$$

where

R = extended radius $67.5/\mathrm{Cos}\ \frac{\alpha}{2}$

λ = wavelength

β = wedge angle (Figure 4-10)

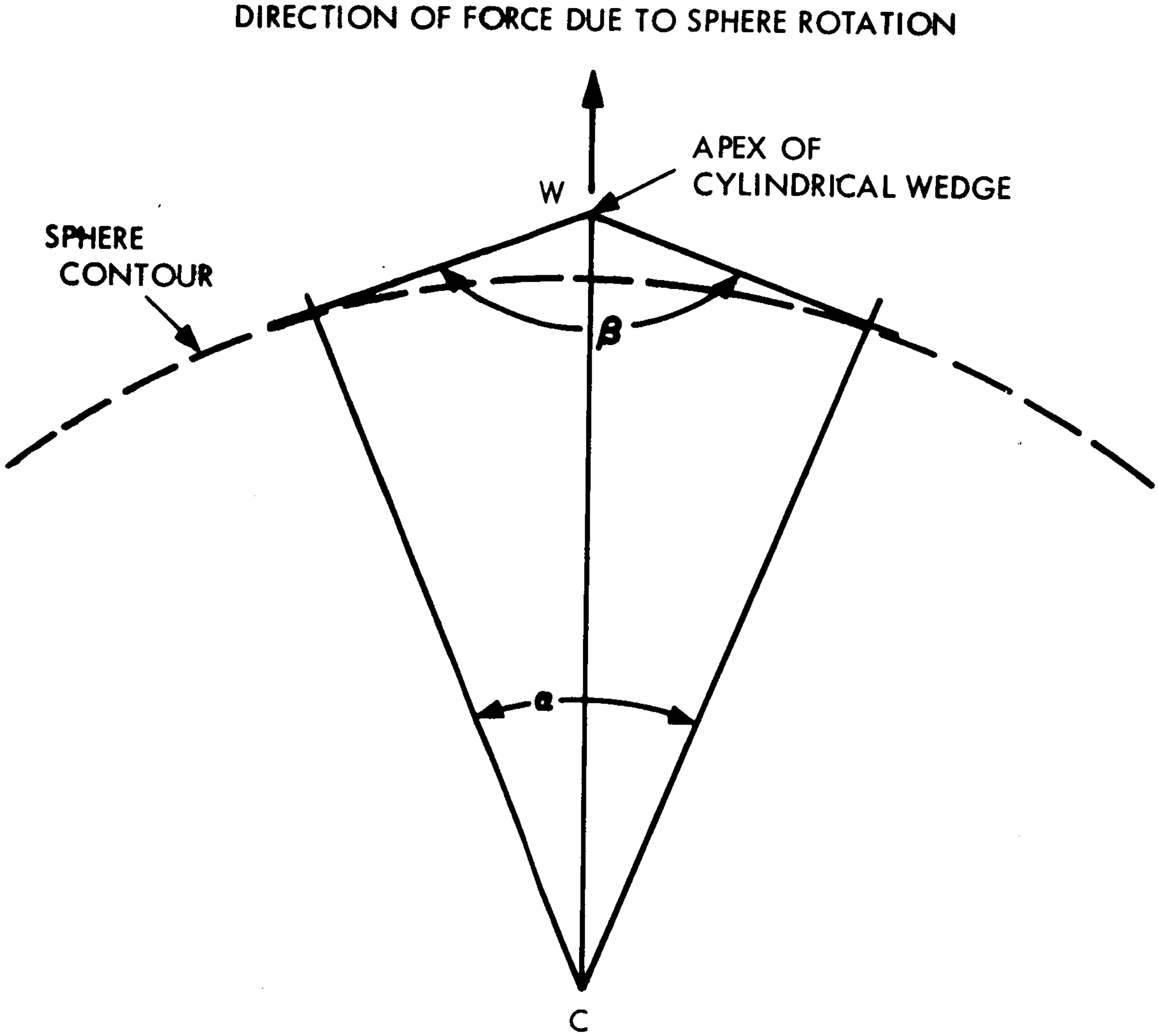
DIRECTION OF FORCE DUE TO SPHERE ROTATION
APEX OF
CYLINDRICAL WEDGE
W
SPHERE
CONTOUR
β
α
C

FIGURE 4-10

From this it was concluded that a signal dropout of 13 db could occur over the 18 degree interval as the incident field traversed from an area having a nominal scattering cross section of 31 db above a meter squared into an area with a cross scattering section of 18 db above a meter squared.

From the above, computations were made to determine the height of the cylindrical wedge. It was determined that the height of the wedge (increase in sphere radius) would be approximately 0.7 foot. (See Figure 4-10 $WC = 67.5/\cos \frac{\alpha}{2}$). This compares very closely with the results of our structural analysis effort. (See Section III, paragraph 4.1)

b. <u>"Echo Box" Effect</u>

If a hole was present in the sphere and the hole was excited by an incident RF field, the inside of the sphere would be excited by reflectionsthat would continue until the energy was depleted by free space attenuation; the hole was re-excited and the normal scattering mechanisms were continued. This is analogous to the familiar "Echo Box" and has been a theory used to explain signal dropouts. As two of the radar facilities have reported the possibility of a hole in the sphere, this theory was investigated and it has been concluded that the "Echo Box" Effect is an improbable cause of the signal dropouts.

From the analog pen records from one station it was determined that subsequent to receiving the main pulse (10 microsecond duration) there is an exponentically decaying train of pulses spaced in order of 10 microseconds at a considerably lower amplitude. This would suggest the presence of a 20-microsecond delay mechanism

The minimum distance energy could travel within the sphere is 270 feet. That is, across the diameter of the sphere 135 feet and back 135 feet before the normal scattering mechanism could continue. The free space time would be approximately $\frac{270}{1 \times 10^9} = 0.27$ microseconds.

The velocity of the propogating mode is therefore $\frac{0.27}{20}$ or approximately $\frac{1}{80}$ of the free space velocity. The "Echo Box" effect would therefore have to be related to a very large number of internal reflections. Computations have shown that the number of reflections would be in excess of 145 for a 20-microsecond delay. It is considered unlikely that this many reflections could be sustained.

A geometric optical approximation was made during the investigation and it was determined that the principal or predominant mode which could exist in this environment would have a velocity of $\frac{1}{\sqrt{2}}$ of the free space velocity.

There is no high order mode known to exist with the mode velocity computed. Further, the geometric optical approximation has shown that the predominant mode has a velocity considerably less than necessary to support a delay mechanism. It was therefore concluded that the "Echo Box" Effect is unlikely to exist and therefore could not cause the signal dropouts.

4.2.4 <u>SUMMARY</u>

The primary objective of the Echo II Radar Experiments is to evaluate the shape and surface characteristics of the Echo II satellite as a function of time.

The Echo Project Office made arrangements with certain organizations to conduct the radar observations necessary to meet the experiment objective.

In accordance with these arrangements, and the Project Experiment Plan, monostatic radar observations of the orbiting satellite were conducted at selected frequencies from UHF through X-band.

Data was furnished to GSFC in the form of analog pen records and magnetic tapes. The analog pen records (strip charts), were used for quick look analysis. However, the magnetic data tapes provide the primary source of information for investigating the physical characteristics of the orbiting satellite.

A series of computer programs have been prepared for the IBM 7090 computer to permit processing of the collected radar data stored on these magnetic tapes.

Due to difficulties encountered (primarily data format) with the magnetic tapes received from some of the radar stations participating, the data processing has been delayed. Therefore, the results of our radar experiments as described in this report are based primarily on analog (strip chart) recordings. Though these recordings form a basis for a quick analysis of the results, the information they contain is of a nature that in some instances restricts one to qualitative judgment.

The results from our computer processed data will be included in the Project Echo II Final Report.

The radar return from the Echo II satellite is exhibiting considerably greater scintillations than was anticipated prior to launch. Non-periodic signal fluctuations of approximately $\pm$ 6 db (average value) at C band and about $\pm$ 5 db (average value) at S band have been observed. In addition, rapid (short duration), non-periodic scintillations of up to 20 db have also been observed.

A comparison of these observed scintillations can be made with selected data collected on the Static Inflation Test (SIT) at Lakehurst, New Jersey for the purpose of relating the surface condition of the orbiting sphere with that of the test sphere. This relation can be made via Figures 4-8 and 4-9.

Quick look reports immediately following the launch indicated that signal dropouts of up to 8-10 seconds in duration, with a periodicity of a multiple of approximately 50 seconds were being observed. However, examination and processing of received data does not verify this reported condition with any consistency. For example, there are several stations which have never observed these type of dropouts (attributable to the satellite). In view of the large amount of data collected, and the accompanying difficulty of visually reducing the data, more definitive statements regarding the nature and course of such dropouts cannot be made at this time.

A number of theories have been investigated to explain these peculiarities in the radar signature. From this investigation it was determined that as the satellite rotates at a rate of one revolution every 100 seconds an outward directed force is exerted on the gores of the sphere in the area where the solar panels and telemetry beacons are mounted. It was found that this force could be great enough to cause a cylindrical wedge to be formed with a scattering cross section considerably lower than that of the nominal sphere cross section. Figure 4-10 illustrates the shape of the cylindrical wedge.

It was estimated that the height of the wedge or the increase in the radius of the sphere due to the outward force would be approximately 0.7 foot. This compares very closely with the results of our structural analysis effort. (See Section III, paragraph 4.1)

Analysis of the radar data collected for the first four months after launch indicates an overall average cross-section of approximately 29 db above a square meter, as compared to the theoretical cross section of 31.2 db. This is well within the calibration tolerances of the various radar systems, and agrees with the average cross sections of 29 db obtained in our communication experiments. (See Section IV). There has been no discernible change in the satellite average cross section since launch.

4.2.5 CONCLUSIONS

On the basis of the data examined to date, it is possible to make the following preliminary conclusions:

a) The satellite inflated to its proper spherical shape.

b) The sphere has minor wrinkles over its surface and possibly two major deformations in the areas of the beacons.

c) These perturbations are causing scintillations in the radar return of approximately ± 6 db at C band and about ± 5 db at L and S band, with occasional very rapid (short duration) scintillations of up to 20 db with a variable period being observed.

d) The satellite surface is considerably smoother than a visual inspection of the radar return indicates due to the effect of satellite rotation.

e) There are indications of signal dropouts varying in length of up to about 10 seconds. An analysis of the radar data in conjunction with a structural analysis of the satellite, indicates that such a signal dropout could be caused by a "wedge effect" created by the outward forces exerted on the satellite in the area of the beacon. However, an absolute determination of the nature and cause of the dropouts cannot be made at this time.

f) An overall average cross-section of approximately 29 db above a square meter has been obtained. There has been no discernible change in the average cross-section of the satellite since it was first observed.

PART IV

COMMUNICATION EXPERIMENTS

LIST OF FIGURES

PART IV

1.0 INTRODUCTION

A Progress Report on the Echo II Communications Experiments, covering the period from launch through July is included herein as Appendix IV-A. The Program Objectives; description of the various facilities involved in the experiment; and test results are included in the Progress Report.

Events and test results since July are outlined in the following paragraphs.

2.0 EXPERIMENT PARTICIPANTS

The Ohio State University, under contract to GSFC began participation in the experiment program in July 1964. For a brief period of time, experiments were conducted between Collins at Dallas (transmitting) and both NRL and OSU receiving. However, due to prior commitments, it became necessary for NRL to cease operations in early September. It is anticipated that NRL will resume limited participation during November and December 1964.

The OSU facility is a four-element array of 30 foot parabolic antennas equipped for receiving at 2260 and 2270 mc. One antenna with a monopulse feed is used for tracking; the other three antennas are slaved to follow the monopulse antenna. An optical telescope is also available for tracking if desired.

The signals from each of the four antennas are summed in anadaptive phase-lock receiver. The output of the receiver is applied to a phase-lock demodulator which gives AM, FM, and PM outputs. Seven channels of magnetic tape recording and sixteen channels of strip chart are available for recording data.

3.0 DATA REDUCTION AND ANALYSIS

3.1 REVISED ECHO II DATA REDUCTION PROGRAM

The scintillations for Echo II have been far more rapid and of greater amplitude than was anticipated prior to launch. As a result with the digital sampling rate specified in the original data reduction and analysis plan, two samples per second (which samples at most, a 0.25 cps sine wave), a considerable amount of high frequency data was discarded. Examination of frequency spectra for several passes showed the distribution to contain frequencies with significant power above 0.25 cps.

Inspection of graphs of cross-section density for a typical Echo II pass using different sampling periods of two seconds per sample and 1/8 second per sample and various averaging times, indicated that the original two second sampling period with a one second averaging time did not provide an adequate representation of the analog data. In view of the results and because of available equipment configurations, it was indicated that a sampling period of 1/4 second and 1/8 second averaging time, would give reasonable data representation without undue increase in data processing time. This sampling rate and averaging time is now being used in the Echo II data reduction being accomplished at Collins Radio Company. In addition, since the characteristics of the signal received from the Echo II satellite are different from those which were anticipated before launch (at the time the original data reduction and analysis plan was formulated), the original scope has been tailored and changed to provide a more thorough and comprehensive data history as follows:

1. The received power is digitized at the rate of four samples per second, and the equivalent cross section is computed for each point.
2. From the cross section data obtained above:
   a) The mean value of cross section is computed for each pass reduced.
   b) A cross section density histogram is computed and plotted for each pass reduced.
   c) The cross section distribution is computed and plotted for each pass reduced.
   d) The upper and lower deviation values are computed.
3. The cross section versus scattering angle is computed and plotted for typical passes.
4. The cross section (20 sec. averages) versus time is computed and plotted for typical passes.
5. The cross correlation coefficient for separate channels on the same magnetic tape (for example, spaced frequency tests, spaced receivers, etc.) is computed.

The mean cross section was added because it can be provided from the stored data with a slight increase in computation time. It provides one more significant number for the designer and user.

The probability density plotted as a histogram indicates the probability that any particular value of equivalent cross-section will occur. Historically, changes in the shape of the histogram when observed on a pass to pass basis reflect the change in character of the faster changes.

The cross-section distribution function shows the probability that any particular value of cross-section is exceeded. Thus, the 50% probability level is the median value by definition. The range over which fading takes place, i.e., from the most probable to least probable occurrences of cross-section, is shown. Historically, the slopes of the curves observed on a pass by pass basis show trending of the faster changes, i.e., changes in the fading ranges.

The deviation from the mean shows the average of cross-section excursions. Averaging excursions both above and below show any tendency for skewness of the equivalent cross-section about the mean. Historically, the deviations observed on a pass by pass basis show longer term variations in the same manner as the mean cross-section when taken pass by pass. Because the cross-section variations may not be necessarily symmetrical about the mean, the average of the deviations above as well as below the mean show the tendency for asymmetry. Because there is such considerable scatter of the 1/4 second values of cross section, a filtering is applied and 20-second averages of cross section will be presented to picture the slow trends.

3.2 DATA REDUCTION AND ANALYSIS AT THE OHIO STATE UNIVERSITY

Ohio State University will reduce and analyze the data it acquires from the experiments conducted with Collins Radio Company in Dallas. Results of the data reduction and analysis will be published by OSU in reports with the following information:

1. Signal Strength Analysis of Signals Reflected from Echo II at 2 Kmc.
2. Apparent Scattering Cross-Section of Echo II.
3. Power Spectral Density of Echo II.
4. A Comparison of Surface Roughness of Echo I and Echo II from Direct and Cross-Polarized Components on 2 Kmc.
5. The Long Term Auto-Correlation Function for Echo I.
6. The Long Term Auto-Correlation Function for Echo II.
7. The Short Term Auto-Correlation Function for Echo I and Echo II.
8. The Amplitude Fading Statistics of Echo II Reflected Signals.

The results from these experiments will be included in the Project Final Report.

4.0 DISCUSSION OF TEST RESULTS

4.1 GENERAL

For results of the experiment program covering the period from launch to July 15, 1964, see "Project Echo II Communications Experiments Progress Report" dated July 15, 1964 included herein in Appendix IV-A.

The Ohio State University began participation in the GSFC Echo II experiment program on July 29 and will continue to participate until the end of the calendar year.

The Naval Research Lab temporarily suspended operations on September 15. It will resume operation in November by participating, as the transmitting station, in a space diversity experiment with Collins Radio Company in Dallas. NRL will also participate in a phase correlation test (Experiment No. 5) in addition to other experiments after it resumes operation.

The operation from July 10 to November 6, 1964 is summarized in Table IV-1.

Some of the significant experiment results obtained since July 15, 1964 are as follows:

4.2 RECEIVED SIGNAL LEVEL (EXPERIMENT NO. 1)

The results of the cross-section data reduction reported in "Communication Experiments Progress Report", dated July 15, 1964 included in Appendix IV-A, are based on the two second sampling period discussed in the preceding section, 3.1.

Table IV-2 shows results of cross-section data reduction using the 1/4 second sampling period outlined in Section 3.1. The average of the mean cross-sections listed in the table is approximately 29.0 db relative to one square meter. The mean cross-section is obtained from the cross-section density histogram. A histogram on a typical Echo II pass is shown in Figure IV-1. The fade range is determined when the percentage of useful service is specified. The fade range figures in Table IV-2 are obtained if the upper 10% and lower 10% of time are neglected, i.e., 10% to 90% levels. These values are obtained from the cross-section distribution functions graphs. A cross-section distribution function on a typical pass is shown in Figure IV-2. The median cross-section value (at the 50 percentile) is obtained from the cross-section distribution function graph.

4.3 MEASUREMENT OF POLARIZATION EFFECTS (EXPERIMENT NO. 12)

Measurement of the polarization rotation effects of Echo II is important. Considerable information about the surface roughness of the satellite can be

TABLE IV-1

OPERATIONS SUMMARY FOR THE ECHO COMMUNICATION EXPERIMENTS

JULY 10, 1964 to NOVEMBER 6, 1964

DESCRIPTION	ECHO II	ECHO I
Number of Orbits Scheduled	61	45
Number Tracked	52	33
Optical Tracking	5	2
Radar Tracking	47	31
Number Not Acquired	9	12
Equipment Malfunction	7	5
Reason Unknown	2	7
Type of Operation		
Monostatic	15	5
Bistatic (NRL and/or OSU)	37	28
Received Signal Strength (Dallas Only)		
-91 to -100 dbm peak	3	0
-101 to -110 dbm peak	28	3
-111 to -120 dbm peak	11	22
-121 to -130 dbm peak	2	3
-131 to -140 dbm peak	1	0
Experiments Performed (Bistatic)		
Experiment No. 1	26	19
Experiment No. 3	2	6
Experiment No. 4	13	1
Experiment No. 6	2	0
Experiment No. 7	8	3
Experiment No. 8	1	4

TABLE IV-2

CROSS-SECTION DATA BASED ON 1/4 SECOND SAMPLING PERIOD

PASS NO.	DATE	Median Cross-Section (db)	Fade Range (db)	Mean Cross-Section (db)
6	1-26	28	11	29
25	1-27	28	11	29
46	1-29	28	11	29
1078	4-16	27	10	28
1170	4-23	27	11	28
1197	4-25	27	13	28
1519	5-10	27	12	29

derived from measurements of the cross-polarized reflected signal. Increasing roughness of the surface is indicated by a decreasing difference between the direct and cross-polarized components of the received signal. Also, from the standpoint of using Echo II as a communication channel, it is desirable to know how much depolarization occurs.

The procedure for such experiments will be to transmit an unmodulated CW carrier using a circularly polarized transmitting antenna. The signal from Echo II will then be received at OSU on four antennas simultaneously; one antenna will receive vertical linear, one horizontal linear, one RCP, and one LCP. From these four measurements the complete polarization rotation properties of Echo II can be determined. Reduction of data from this experiment conducted with the moon, Echo I and Echo II are shown in Table IV-3.

TABLE IV-3

DIFFERENCE BETWEEN DIRECT AND CROSS-POLARIZED COMPONENTS

Moon	Echo I	Echo II
9 db	11-12 db	18-19 db

These results indicate that Echo I is considerably more irregular than Echo II and that the moon's surface is more irregular than Echo I.

4.4 WIDEBAND SIGNAL AMPLITUDE CORRELATION MEASUREMENTS (EXPERIMENT NO. 4)

For a detailed description of this test, see "Project Echo II Communication Experiments Progress Report" dated July 15, 1964, in Appendix IV-A.

Results of the reduction of data from this experiment, conducted with a frequency separation of 190 mcs and space separation of 2400 feet give a correlation coefficient of 0.10 $\pm$ 0.05. The linearized traces for 2380 mc and 2190 mc, displayed in Figure IV-3, show this very low degree of correlation for this frequency separation and space separation.

The results obtained on this experiment indicate that like conditions, i.e., frequency spacing of 190 mc (or greater) and space diversity of 2400 feet can be successfully employed in Echo II communications circuits. The effect of space diversity on this correlation coefficient will be determined when results from the space diversity test mentioned in section 4.1 with this same space separation are known.

5.0 SUMMARY AND CONCLUSIONS

In addition to the conclusions listed in the "Echo II Communications Experiments Progress Report" dated July 15, 1964 in Appendix IV-A the following are listed:

1. The increased sampling period of 1/4 second per sample is resulting in much improved cross-section data. This increased sampling rate together with the revised scope of the data reduction plan is providing a more thorough and comprehensive history of Echo II.

2. Results of the Antenna Polarization Effects Experiment indicate that the surface of Echo I is considerably more irregular than the surface of Echo II.

3. Results of the Wideband Signal Amplitude Experiment indicate that frequency diversity with 190 mc (or more) separation together with space

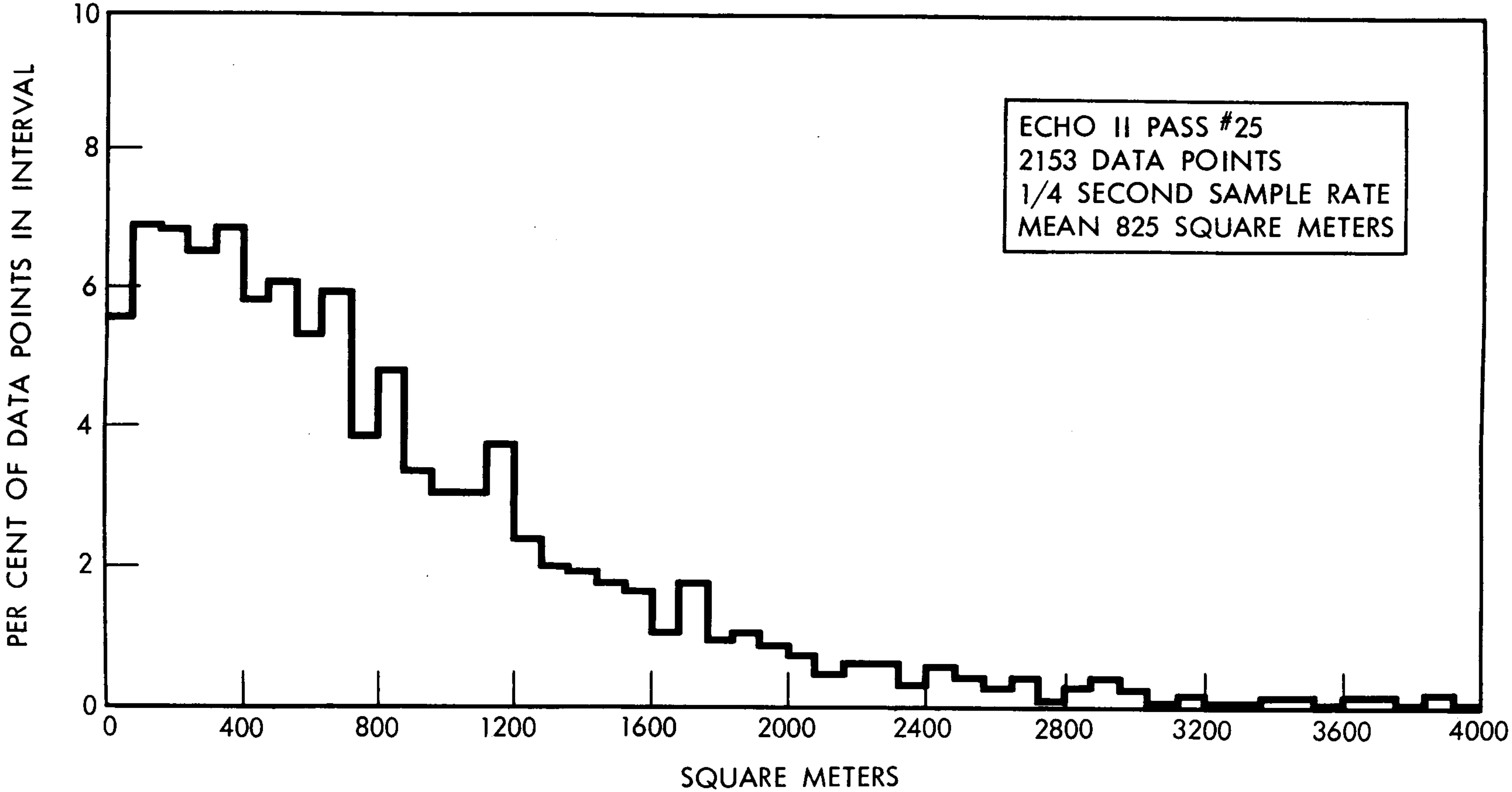

Figure IV- 1 Cross-section density histogram

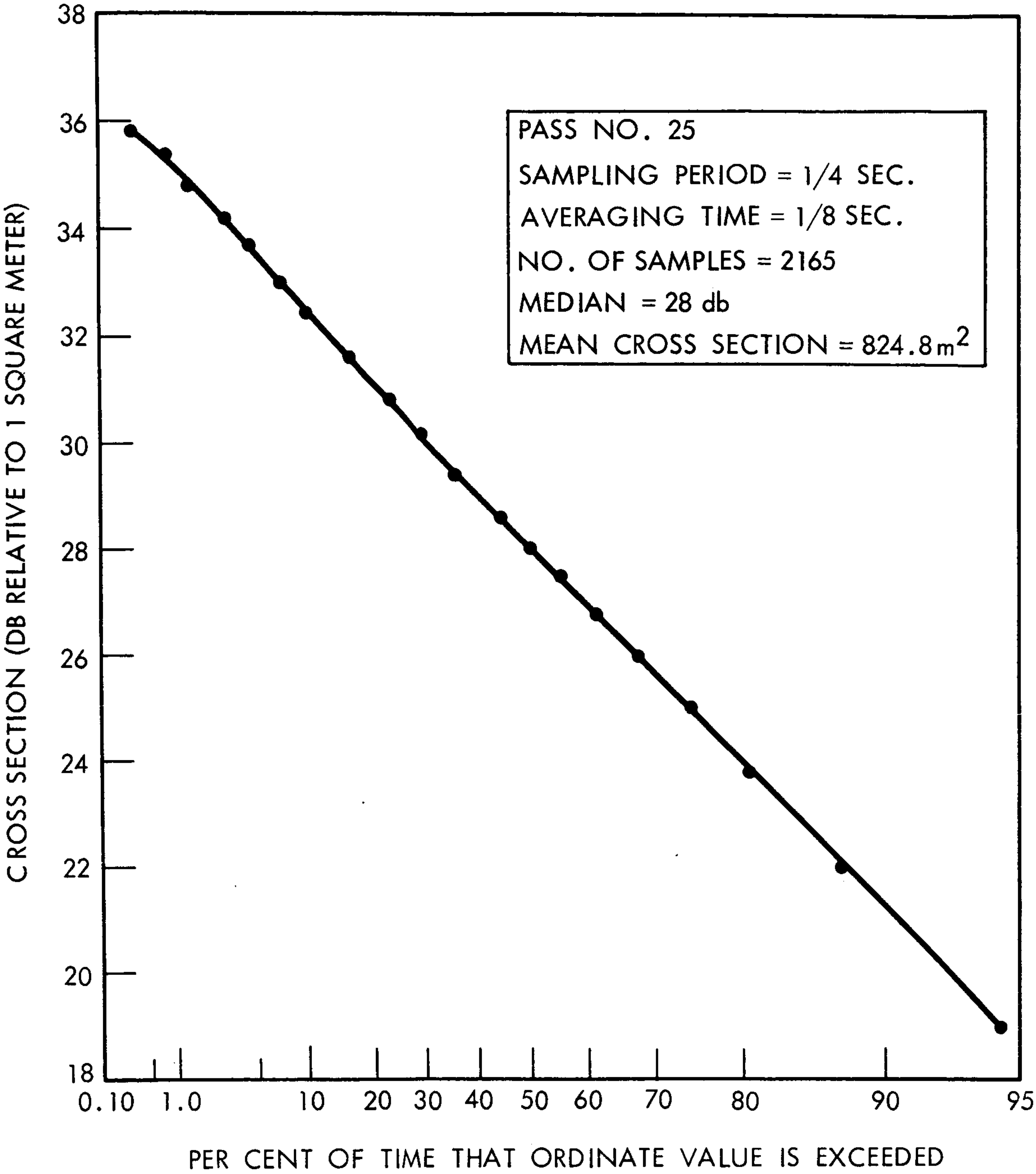

Figure IV- 2 Cross-section distribution

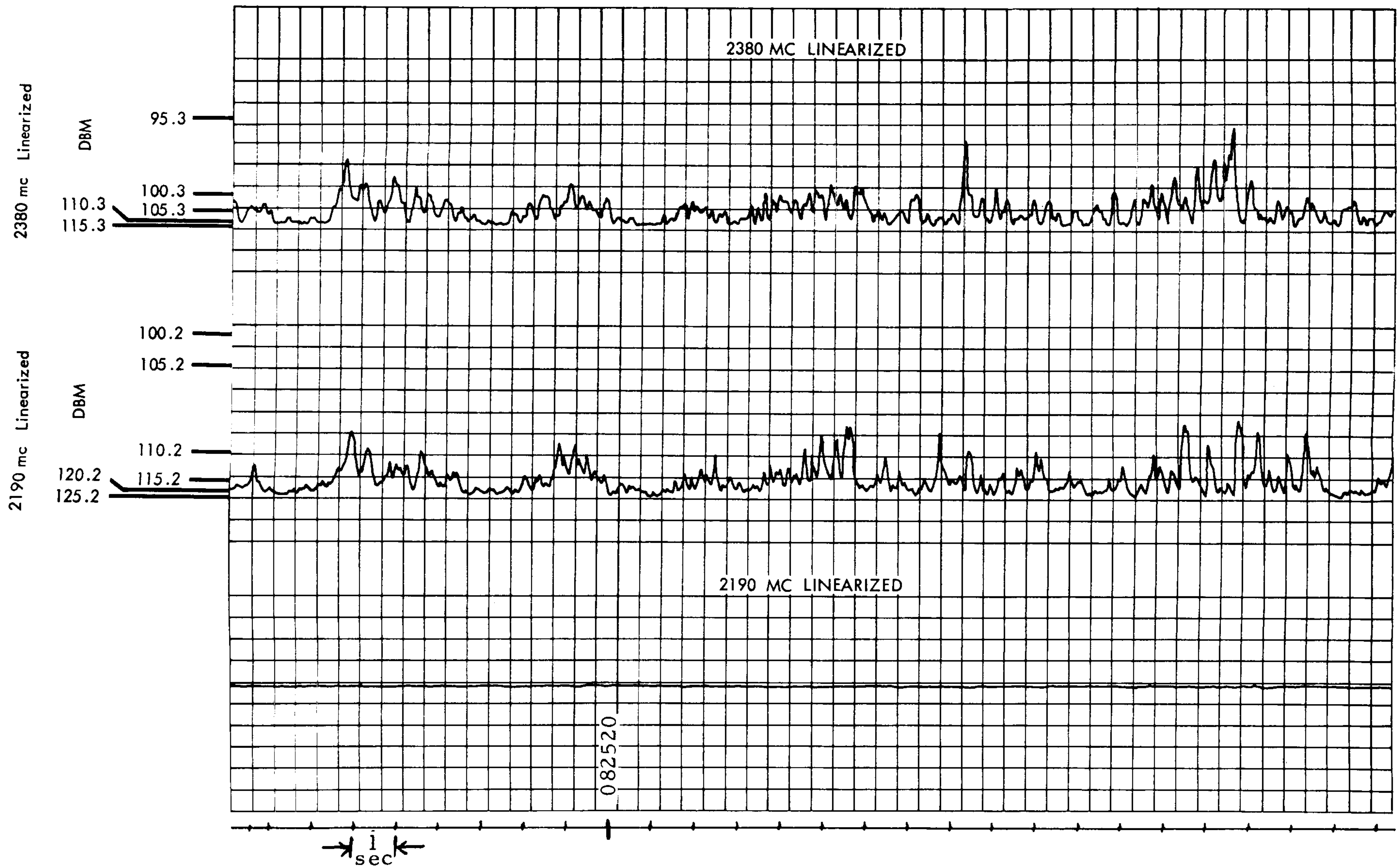

FIG IV-3 WIDEBAND AMPLITUDE CORRELATION MEASUREMENTS (ECHO II) diversity with a 2400 foot separation of receivers can be successfully employed on Echo II communication circuits.

APPENDIX IV-A

PROJECT ECHO II COMMUNICATION EXPERIMENTS PROGRESS REPORT

July 15, 1964

PROJECT ECHO II

COMMUNICATION EXPERIMENTS

PROGRESS REPORT

JULY 15, 1964

PROJECT ECHO II

COMMUNICATION EXPERIMENTS

PROGRESS REPORT

JULY 15, 1964

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I. INTRODUCTION

1.0 PROGRAM OBJECTIVES

1.1 General

The objective of the Echo II experiments is to determine the communication capability of the satellite and to provide information about Echo II's shape and surface characteristics as a function of time.

1.2 Detailed Objectives

The communication capability of the satellite can largely be specified by data on such characteristics as effective reflection cross-section, fading characteristics and bandwidth capability. Its capability is most graphically demonstrated by transmission of various forms of information and examination of the received results. To obtain these results, an experimental configuration was implemented and a specific series of experiments initiated.

The detailed objectives are illustrated most easily by discussion of the specific experiments. The composite results of these experiments, plus one new experiment presently planned, were designed to satisfy the objectives.

2.0 PROGRAM IMPLEMENTATION

2.1 Experiment Participants

Details concerning the implementation of the Echo II communication experiment are outlined in the Echo II Experiments Plan dated 11 January 1964. For completeness, a summary of the experiment participants and the planned experiments is given in the following paragraphs. (It should be noted that, because of technical difficulties experienced with their system, the Navy Electronics Laboratory (NEL) at San Diego, California, has as yet been unable to participate in the experiments as originally planned.)

The participating stations to date have been the Naval Research Laboratory facility at Stump Neck, Maryland, and the Collins Radio Company facility at Dallas, Texas. Figure 1 illustrates the circuit

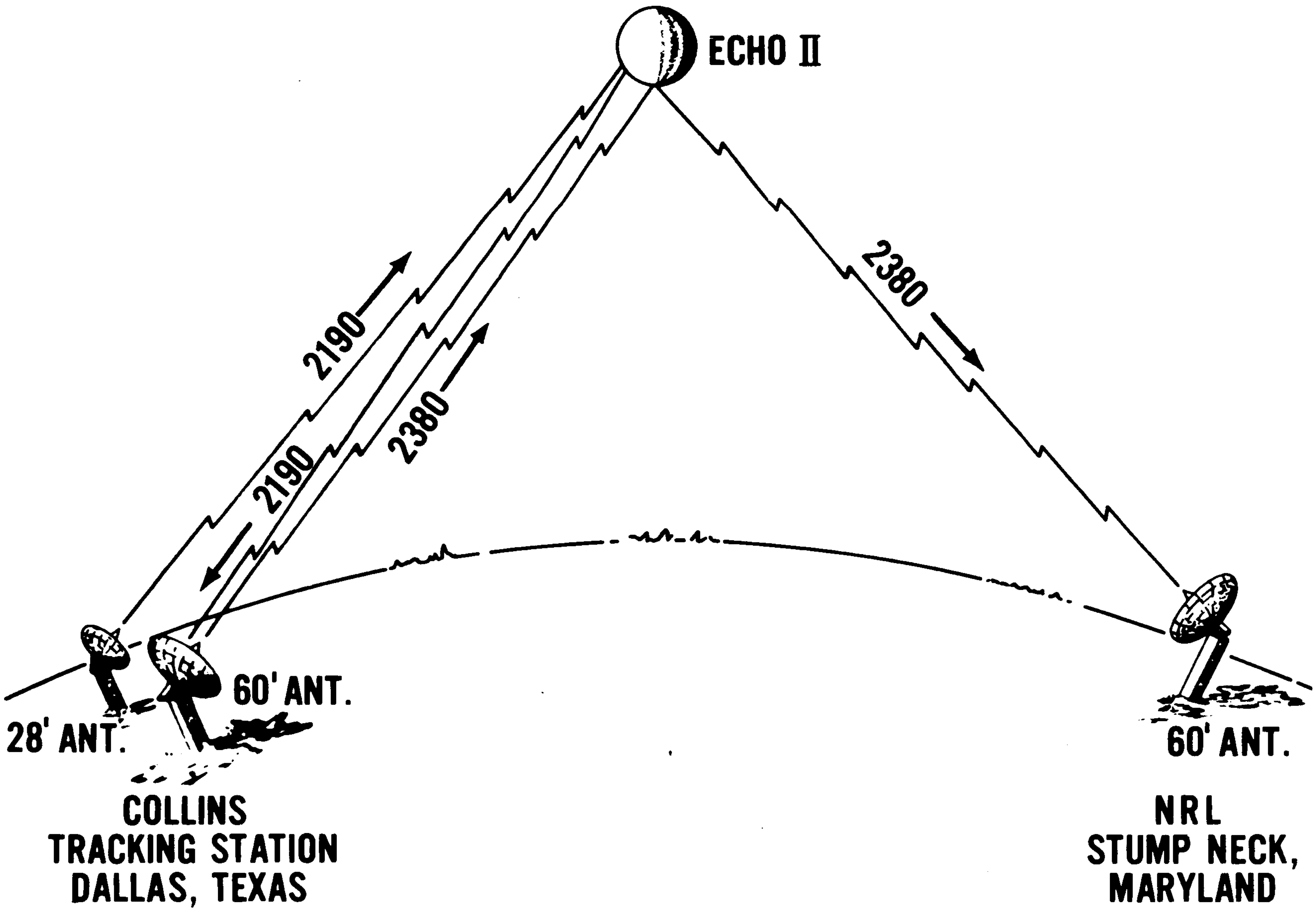

Figure 1 – Circuit Configuration for the Echo II Communication Experiments (Dallas – Stump Neck)

configuration between Dallas and Stump Neck for the Echo II communication experiments. The Collins facility has been serving as the transmitter terminal of the link, while NRL has been serving as the receiving terminal during the past 5 months.

It is anticipated that in the next 6 months of the Echo II communication experiments, the Ohio State University facility at Columbus, Ohio, and the Navy Electronics Laboratory at San Diego, California, will also participate with the NRL and Collins facilities. The detailed descriptions of the NRL and Collins facilities are described in the following paragraphs.

2.1.1 Description of Collins Radio Company Facility, Dallas, Texas

The Collins space communication facility at Dallas is a transmitting-receiving-tracking facility that employs two steerable azimuth/elevation-mounted parabolic reflectors. A plot plan of the facility is shown in Figure 2. The two sites are 2400 feet apart to provide electrical isolation and to eliminate the need for a duplexer when operating in the radar mode. The 28-foot parabolic reflector antenna is equipped with a 10-kw transmitter. This transmitter is capable of operating as a communication transmitter, although the normal operation is for it to be used as an illuminator for self tracking. It is capable of operating anywhere in the 1700- to 2400-mc frequency range. The transmitter, the exciter, and the modulator are housed along with the 28-foot antenna servo-controls in a 900-square-foot brick building.

The 60-foot parabolic reflector is equipped with a phase-lock monopulse tracking radar receiver and a 10-kw S-band transmitter. The power supply and the primary controls are housed in the receiver operations building, while the exciter, power amplifier, and heat exchanger are mounted on the antenna itself. The 60-foot antenna is shown in Figure 3. The receiver is equipped to receive 2190 mc; however, sufficient versatility has been provided in the receiver to allow it to be modified to operate at any S-band frequency. The 60-foot antenna controls, tracking receiver, signal demodulators, and recording equipments are housed in the receiver operations building. The facility is equipped with a 7-channel magnetic tape recorder and a 6-channel stripchart recorder for data recording. In addition, the antenna pointing angles and doppler data are processed into a digital form and are printed and/or punched out in 6-digit numbers on paper tape every 10 seconds. A government-furnished boresight camera is being used to photograph

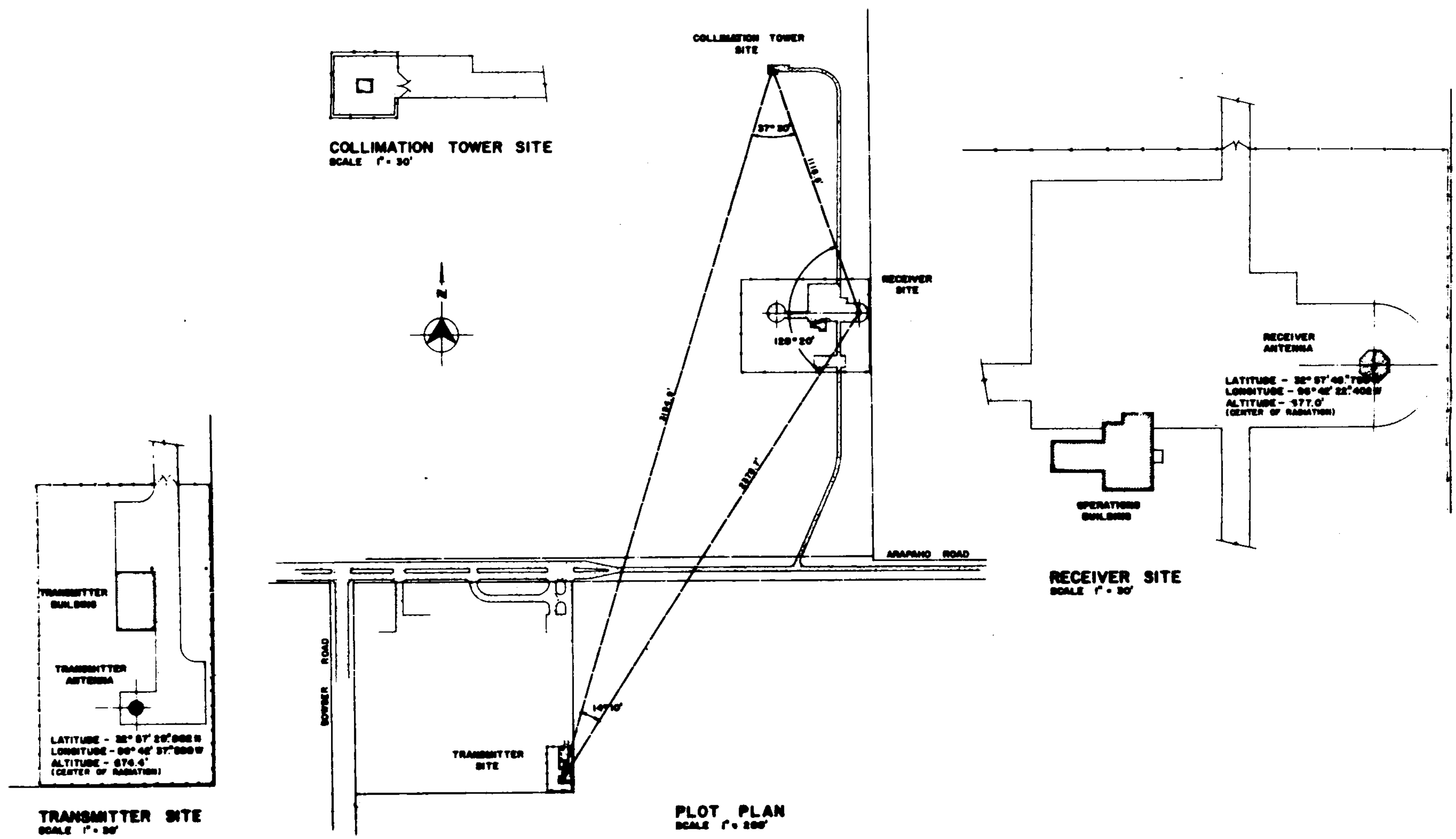

Figure 2 – Site Plot Plan, Collins (Dallas) Facility

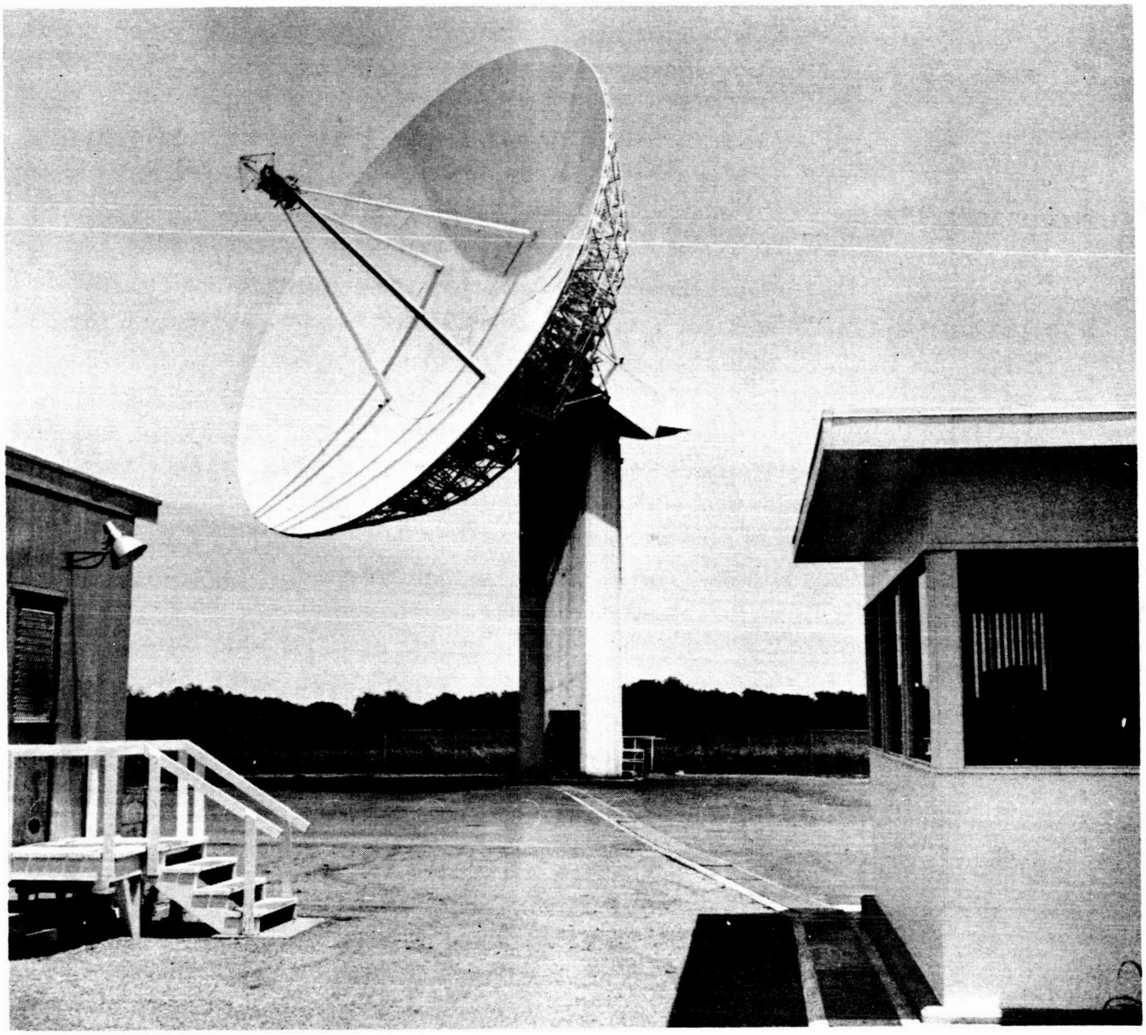

Figure 3 – Collins 69-Foot-Diameter Antenna and Tower, Dallas, Texas

(at a rate of 1 frame every 10 seconds) the satellite and thus allow determination of the antenna boresight errors.

In normal operation for the Echo II experiments, the 28-foot antenna illuminates the satellite with a 50 percent duty cycle at 2190 mc, while the 60-foot antenna serves as the tracking receiver of the radar system and transmits on either 2380 mc or 2260 mc.

The 28-foot antenna, in turn, is slaved to the 60-foot antenna. Figure 4 illustrates the system configuration used in the NASA/GSFC communication experiments with Echo II.

In the normal configuration, the system is capable of automatic self-acquisition and self-tracking. However, when visibility permits, an optical telescope and positioning controls on either antenna can be used to position either or both antennas for acquisition or manually following the trajectory of the satellite. A considerable amount of effort has gone into the system design to provide flexibility and rapid mode changes, as well as rapid changes in the system configuration.

Currently, the Collins space communication research facility has the following modes/configurations:

(1) Twenty-eight-foot antenna only, and optically-visible satellite:
Antenna continuously follows the satellite by means of the optical/manual control system, and simultaneously transmits signal at S-band.

(2) Sixty-foot antenna only, and optically-visible satellite:
Antenna continuously follows the satellite by means of the optical/manual control system, and simultaneously transmits signal at S-band and receives signal at S-band.

(3) Both antennas and optically-visible satellite:
Any combination of (1) and (2) above.

(4) Radar mode:
The 60-foot-antenna tracks at S-band while simultaneously transmitting a communication signal at S-band. The 28-foot antenna is slaved to the 60-foot antenna and simultaneously transmits a radar signal.

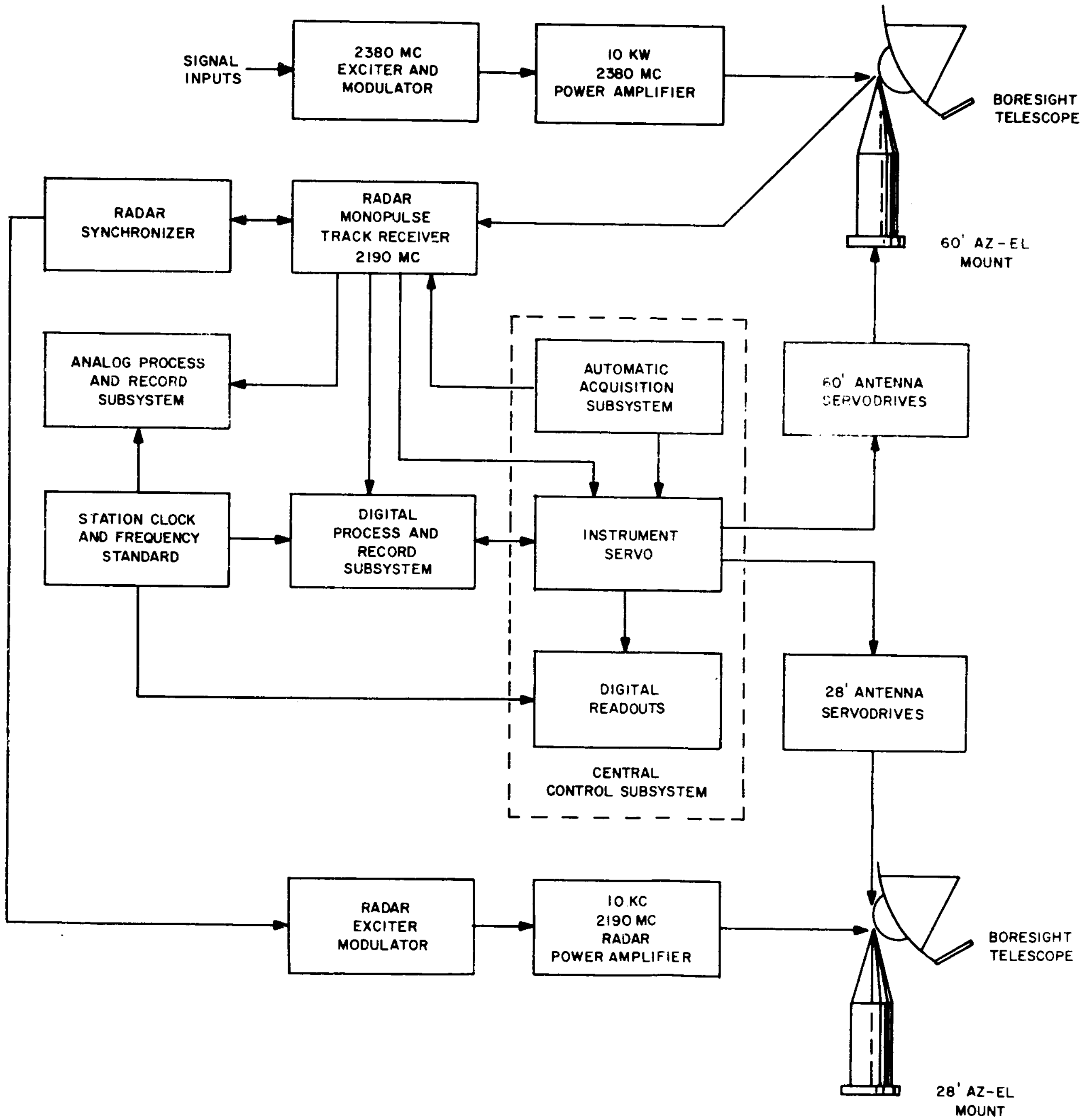

Figure 4 – Collins Space Communication Facility, Dallas, Texas

2.1.2 Description of the Naval Research Facility, Stump Neck, Maryland

The Stump Neck facility of NRL is illustrated in Figure 5. The NRL facility is a transmitting-receiving facility that employs a single 60-foot azimuth/elevation/mounted paraboloid antenna with a feed for 2380-mc operation. The antenna is normally controlled by digital drive tape data. When visibility permits, an optical tracker mounted on the antenna can be used to insert corrections to the antenna drive tape for acquisition and accurate pointing. The transmitter is capable of 10-kw output at a frequency of 2380 mc. The receiver employs a low-noise traveling wave amplifier. Additional sensitivity is obtained by the use of an IF phase-lock loop at 60 mc. Communication reception is provided by R-390A/URR and R-220/URR receivers. The facility is equipped with a 7-channel magnetic tape recorder and an 8-channel strip-chart recorder for data recording. In addition, the optical tracker system includes a recording camera to record the position relative to the antenna pointing of the satellite when it is optically visible. Figure 6 is a photograph of the NRL site.

The NRL facility has the following modes of operation:

(1) For Optically-Visible Satellite:

(a) Antenna continuously follows the satellite using drive tapes derived from GSFC computing center data. The optical tracker inserts offsets necessary to obtain precise tracking of the satellite.

(b) Transmit information or CW signal at 2380 mc or receive information at 2380 mc, as required.

(2) For Optically-Obscure Satellite:

(a) Antenna continuously follows the satellite using drive tapes derived from GSFC computing center data. Corrections can be inserted which are based on scanning the antenna for maximum signal.

(b) Transmit information or CW signal at 2380 mc or receive information at 2380 mc, as required.

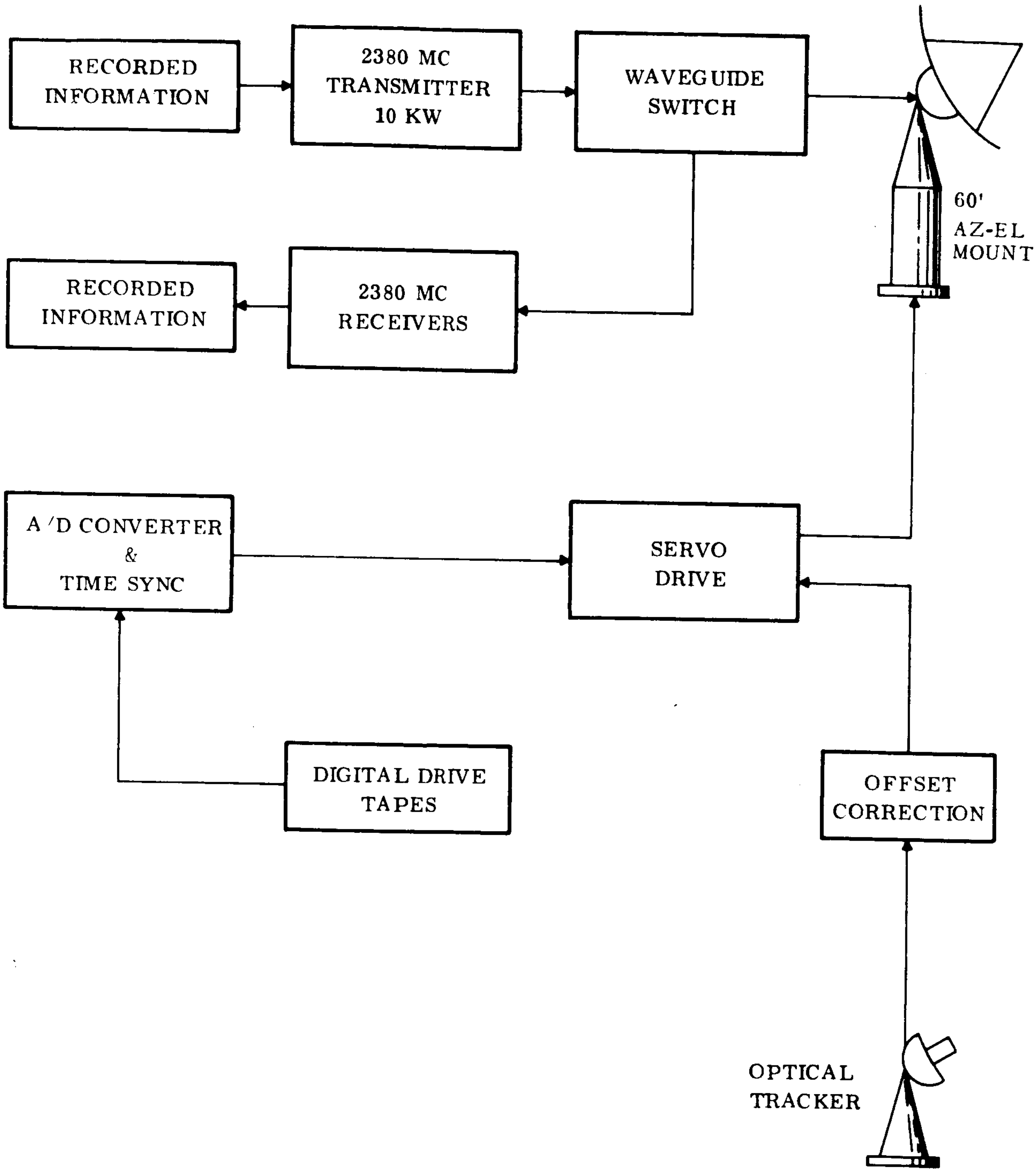

Figure 5 – NRL Space Communication Facility, Stump Neck, Maryland

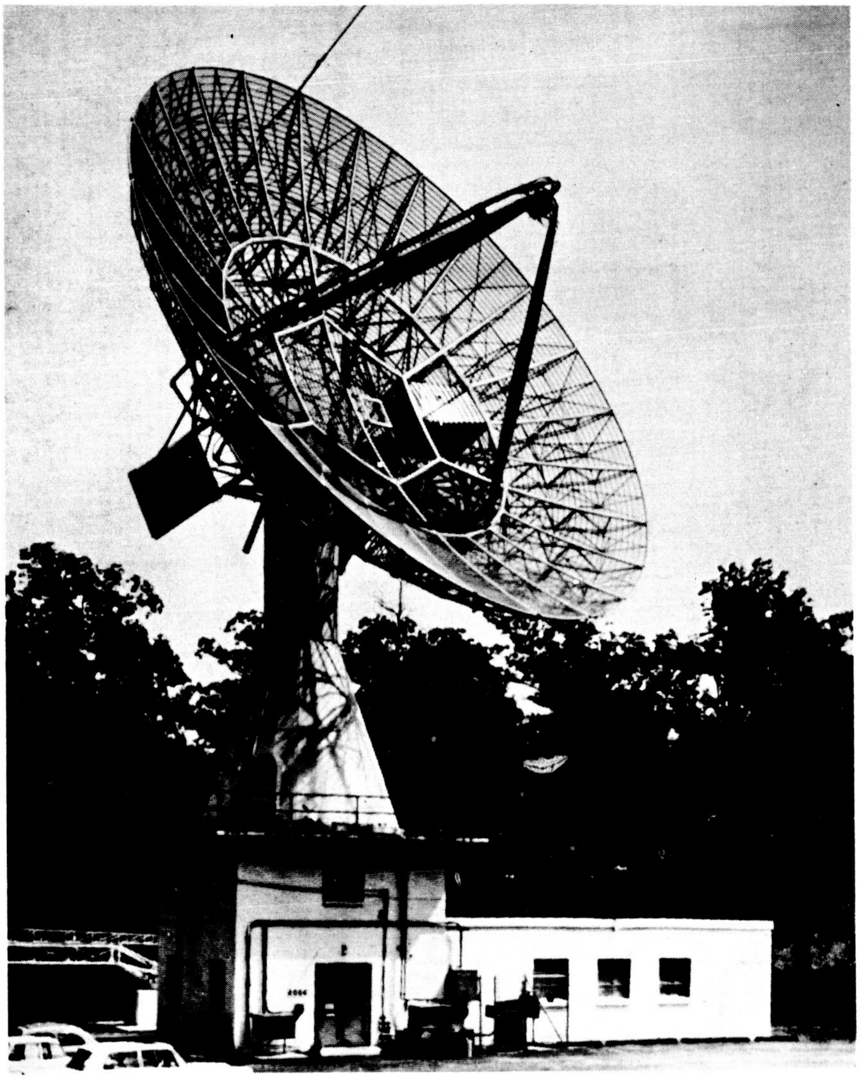

Figure 6 – Photo of NRL Station

2.2 Data Reduction and Analysis

Data reduction and analysis is done at the Collins Cedar Rapids facility, the Collins Dallas facility, or the NRL Washington facility, depending on the particular data. Details concerning the reduction and analyses of data collected during the Echo II communication experiment are set forth in the "Echo II Communications Experiment Data Reduction and Analyses Plan." For completeness a brief summary of the data processing plan follows. In addition, certain details are also included in Section II of this report.

Direct data from experiment #1 (Measurement of Received Signal Level) is reduced at Cedar Rapids to produce effective cross-section vs time, median effective cross-section, variance of effective cross-section, relative power spectrum (out to about 300 cps) of amplitude fading, and distribution of amplitude fading. Indirect data pertaining to this experiment, such as system gains, responses, and pointing accuracy, are reduced at the facility involved.

Data reduction for experiment #2 (Measurement of Instantaneous Received Signal Level) is done at NRL to ascertain whether there are significant frequency components of fading beyond 300 cycles.

Data reduction for experiments #3 and #4 (Signal Amplitude Correlation Measurements) is done at Cedar Rapids to determine the correlation coefficient between the fading on two signals. High correlation for a particular frequency spacing indicates that the satellite will support transmissions of a bandwidth corresponding to that spacing.

Experiment #5 (Signal Phase Correlation Measurement) is the same as experiment #3 from a data standpoint, except that information as to the relative phase variations of the two signals is added to more fully define the bandwidth capability of the satellite. The data is recorded directly as a phase difference at NRL and requires no reduction.

Data from experiment #6 (Audio Frequency Transmission Test) will be reduced at Dallas to determine the ratio between the desired modulation signal to undesired signals (noise and distortion products).

Experiments #7 and #8 (Voice Transmission and Facsimile Tests) yield results that are not reducible as such. Some of the voice transmission results will be placed on records by Dallas, and the facsimile pictures will be reproduced by NRL.

Experiment #9 (Data Experiment) yields recorded demodulated digital signals. These recordings will be reduced at Dallas to determine bit error rate vs time.

II. TEST RESULTS

1.0 GENERAL

Contractual arrangements between GSFC and Collins were not completed in time to permit the Dallas facility to become fully operational by launch time. However, in order to obtain coverage at launch it was decided to employ an interim system until such time as the full system could be completed. This interim system employed the 28-foot antenna and optical tracking only.

Operations on the Echo II communication experiments program with the interim system began on 25 January 1964 with the sixth orbit of Echo II. This was the first pass which entered the mutual visibility zone between Dallas and NRL. NRL's reception at Stump Neck of the 2380-mc CW transmission from Dallas was successful. These operations were continued during the two weeks prior to the time the satellite entered its first eclipse period. Six passes yielded data suitable for reduction.

After the satellite entered the eclipse, experiments with the interim system were discontinued because of the optical tracking requirement. Efforts at Dallas were then concentrated on achieving the full system configuration. This was accomplished by 10 April, and on 13 April operations were resumed between Dallas and NRL on 2380 megacycles on a 5-day-per-week basis. During the week of 30 June the 2380-mc operating frequency was changed at both Dallas and Stump Neck to 2260 mc to permit the Ohio State University (O.S.U.) station in Columbus, Ohio, to participate in the experiments. Following this conversion, the operations were resumed and are presently continuing at that frequency. Due to technical difficulties with their system, the Navy Electronics Laboratory (NEL) has been unable to participate in the experiments. It is anticipated that OSU will begin participation by August 1964.

As of 10 July 1964, a total of 119 passes had been scheduled for experiment with Echo II. Of these 119 scheduled passes, 99 were tracked and data collected. In addition, seven Echo I passes were tracked. Table 1 summarizes the operation through 10 July 1964.

Although only a partial reduction of the data from a few selected Echo II orbits and one Echo I orbit has been accomplished our efforts have been quite successful from a number of viewpoints. The following is a description of the experiment results to date.

Table 1

Operations Summary For The Echo Communication Experiments

Description	Echo II		Echo I
	Time Period		
	1/26/64 to 2/20/64	4/13/64 to 7/10/64	5/11/64 to 5/15/64
Number of Orbits Scheduled	19	100	9
Number Tracked:	12	87	7
Optical Tracking	12	1	0
Radar Tracking	0	86	7
Number Not Acquired:	7	13	2
Cloud Cover	0	0	-
Equipment Malfunction	2	8	-
Satellite Eclipse	1	0	-
Sky Too Bright To Observe	4	0	-
Reason Unknown	0	5	2
Type of Operation:			
Monostatic (Radar Only)	0	16	3
Bistatic (NRL and/or OSU)	12	71	4
Received Signal Strength (Dallas Only):			
-91 to -100 dbm peak	0	1	-
-101 to -110 dbm peak	0	23	-
-111 to -120 dbm peak	0	50	1
-121 to -130 dbm peak	0	9	6
-131 to -140 dbm peak	0	0	-
Not Recorded	0	4	-
Information Radiated (Bistatic):			
CW	12	48	4
Facsimile	0	7	-
Voice and Music	0	5	-
Audio Tones	0	4	-
Wideband AM	0	4	-
Data	0	3	-

2.0 RECEIVED SIGNAL LEVEL (EXPERIMENT NO. 1)

2.1 General

Measurement of the received signal level on an absolute and relative basis provides data for determining, the effective cross-sectional area of the satellite; relative power spectrum of the fading; the distribution of amplitude fading; and basic information regarding the satellite's shape and surface characteristics. From the primary data, further analysis can be performed to estimate circuit reliability (error rates) and periods of useful communication.

To perform this test, the satellite is illuminated with an unmodulated 2380-mc carrier and the received signal strength is recorded simultaneously on one channel of a stripchart recorder and on one channel of a magnetic tape recorder. The stripchart recorder provides quick-look data for preliminary analysis and screening. The magnetic tape recordings are used for detailed analysis.

At the time of this report, partial reduction of bistatic data for a few selected Echo II orbits (numbers 25, 1170, and 1519) and one Echo I orbit (number 16983) has been performed. These orbit numbers were selected to represent typical data orbits during January, April and May 1964. The reduction of the monostatic data for orbit 1170 has been included for comparison with the bistatic data. The Echo I data provides some comparison between the two satellites.

The average of the mean cross-section for the three passes referred to is approximately 30.2 db above a square meter and for the one radar (monostatic) case, 30.03 db. These compare very favorably with the theoretical calculation of 31.2 db.

Preliminary analysis of the Relative Power Spectrum of the fading reflects no periodic variations in the signal level indicating there are no gross satellite deformations.

Reduction and analysis of the data for the Distribution of Amplitude Fading has not yet been accomplished.

2.2 Effective Cross-Section

The effective cross-section, is defined as the area of a flat, correctly oriented, perfect reflector in the same spatial position as the satellite producing the same signal level as that produced by the satellite. Cross-section is determined from the following expression:

$$\frac{64\pi^3 \, w_R \left(d_T\right)^2 \left(d_R\right)^2}{w_T \, g_T \, g_R \, \lambda^2} \text{ square meters}$$

where

w_R is the received signal power, in watts

w_T is the transmitted power, in watts

g_T is the net gain of the transmit antenna including line and other losses

g_R is the net gain of the receive antenna including line and other losses

d_T and d_R are distances to and from the satellite, respectively, in meters

λ is the wavelength, in meters.

If a cross-section of unit size (one square meter) is chosen as the basis of comparison, then for the given system parameters w_T, d_T, d_R, g_T, g_R and λ, the received signal power will vary as a function of the actual cross-section. Thus the actual cross-section can be expressed relative to one square meter cross-section as follows:

$$10 \log \frac{w_{R(\text{actual})}}{w_{R\left(1m^2\right)}} = 10 \log \frac{\text{Area (actual)}}{\text{Area}\left(1m^2\right)}$$

or cross-section in db relative to one square meter.

The effective cross-section is based on one second averages of the received signal power every two seconds. The processing equipment employed is shown in Figure 7. The original or master signal data is linearized in the analog function converter. Nonlinear functions in the terminal equipments are removed at this point. The analog data is then digitized in the A/D converter at a real-time rate of one sample per 2 seconds. A paper tape is perforated in 5-level binary code.

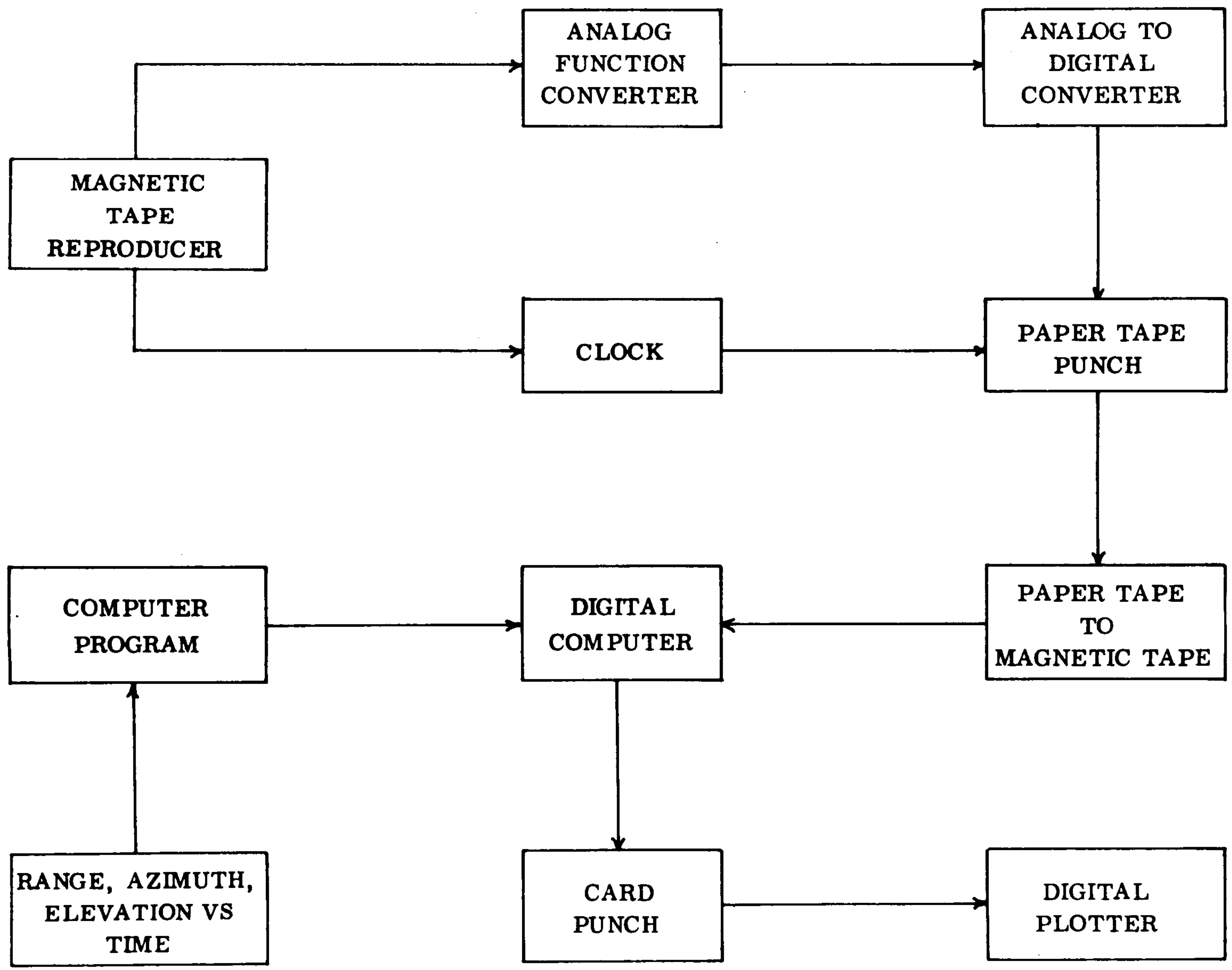

Figure 7 – Computation of Scattering Cross-Section

Conversion is made to high-density storage magnetic tape for input to the digital computer. The GSFC supplied azimuth, elevation, and range versus time data is programmed in the digital computer with the signal data. Output data is available on punched cards which are plotted by a digital plotter.

The received signal strength data on magnetic tape was linearized with respect to signal power (w_R) to be used in the above equation. Linearization errors were $< \pm 0.2$ db. One-second averages of signal power in watts were made every other second and digitized. Corresponding average range data were used for d_T and d_R in the calculation using the above equation. No estimate of tolerance was made for the range data. Sufficient resolution was maintained at the computer so as not to introduce error of a magnitude that might affect the accuracy of cross-section. Resolution at the plotter was also sufficient so as not to introduce appreciable error.

System parameters used in the determination of cross-section for bistatic (Dallas-NRL) operation are:

w_T = +70 dbm	(10 kw)
G_T = +40 db	(28' antenna)
+48 db	(60' antenna)
G_R = +50 db	(60' antenna)

Distances to and from the satellite were taken from GSFC-furnished "post facto" data, and the wavelength, λ, used was 0.126 meter (f = 2380 mc). Data from Echo II, passes 25 (640127:11), 1170 (640423:01), and 1519 (640519:09); and from Echo I, pass 16983 (640511:09); were used to calculate cross-section in 1-second averages every other second. These results are prepared in tabular form as illustrated in the sample from pass number 25 in Figure 8. The cross-sectional areas shown (X SEC AREA) are in +db relative to one square meter. Also computed from the range and angle data is the angle of forward scatter. This angle is formed between the two radius vectors from the satellite to the terminals. Another step in computation results in a tabulation as shown in the sample, also from pass 25, in Figure 9. The mean cross-section per pass is calculated from the running means (1-second averages), and the variances and standard deviations are calculated from the running means less the means for the pass.

Y M D H	M	S	DAL RNG (KM)	X SEC AREA	FD S ANGLE	NRL RNG (KM)
64012711	18	2	2617.874	29.186	82.164	2112.227
64012711	18	4	2607.771	28.689	82.068	2101.483
64012711	18	6	2597.696	32.799	81.972	2090.772
64012711	18	8	2587.643	33.132	81.873	2080.090
64012711	18	10	2577.620	32.161	81.774	2069.444
64012711	18	12	2567.621	28.280	81.674	2058.830
64012711	18	14	2557.650	31.698	81.572	2048.249
64012711	18	16	2547.704	29.584	81.470	2037.702
64012711	18	18	2537.790	30.772	81.366	2027.194
64012711	18	20	2527.900	30.659	81.261	2016.717
64012711	18	22	2518.041	25.157	81.155	2006.280
64012711	18	24	2508.208	31.318	81.048	1995.876
64012711	18	26	2498.405	26.955	80.939	1985.512
64012711	18	28	2488.630	27.649	80.830	1975.184
64012711	18	30	2478.887	29.232	80.719	1964.897
64012711	18	32	2469.176	29.551	80.607	1954.650
64012711	18	34	2459.492	30.819	80.493	1944.440
64012711	18	36	2449.843	31.342	80.379	1934.275
64012711	18	38	2440.220	27.531	80.263	1924.147
64012711	18	40	2430.634	28.632	80.146	1914.064
64012711	18	42	2421.076	27.663	80.028	1904.021
64012711	18	44	2411.554	29.092	79.908	1894.024
64012711	18	46	2402.064	20.253	79.787	1884.069
64012711	18	48	2392.605	23.182	79.665	1874.157
64012711	18	50	2383.185	26.573	79.541	1864.295
64012711	18	52	2373.793	27.509	79.417	1854.473
64012711	18	54	2364.442	28.424	79.291	1844.703
64012711	18	56	2355.121	31.611	79.163	1834.976
64012711	18	58	2345.837	29.845	79.034	1825.298
64012711	19	0	2337.000	26.275	78.913	1816.000
64012711	19	2	2327.826	29.398	78.783	1806.415
64012711	19	4	2318.689	27.719	78.652	1796.881
64012711	19	6	2309.594	26.760	78.519	1787.401
64012711	19	8	2300.537	26.817	78.386	1777.973
64012711	19	10	2291.523	29.919	78.251	1768.602
64012711	19	12	2282.550	25.661	78.115	1759.286
64012711	19	14	2273.618	25.191	77.977	1750.027
64012711	19	16	2264.726	32.063	77.838	1740.823
64012711	19	18	2255.881	28.115	77.698	1731.681
64012711	19	20	2247.074	35.179	77.556	1722.595
64012711	19	22	2238.314	30.381	77.414	1713.572
64012711	19	24	2229.594	27.099	77.269	1704.607
64012711	19	26	2220.920	29.460	77.124	1695.705
64012711	19	28	2212.289	27.551	76.977	1686.865
64012711	19	30	2203.705	32.446	76.829	1678.090
64012711	19	32	2195.168	28.492	76.679	1669.381
64012711	19	34	2186.673	26.616	76.528	1660.734

Figure 8 – Echo II Cross-Section, Ranges, and Forward Scatter Angle (Sample Pass 25)

CROSS SECTION (SQ.M.)	DEVIATION FROM MEAN (SQ.M.)
829.10	-71.69
739.36	-161.43
1904.88	1004.09
2056.96	1156.17
1644.60	743.81
673.01	-227.78
1478.52	577.73
908.70	7.91
1194.53	293.74
1163.74	262.95
327.83	-572.96
1354.59	453.80
496.07	-404.72
581.91	-318.88
837.99	-62.80
901.73	0.94
1207.66	306.87
1361.95	461.16
566.35	-334.44
729.78	-171.01
583.80	-316.99
811.33	-89.46
105.99	-794.80
208.07	-692.72
454.28	-446.51
563.50	-337.29
695.73	-205.06
1449.25	548.46
964.84	64.05
424.14	-476.65
870.60	-30.19
591.47	-309.32
474.27	-426.52
480.53	-420.26
981.58	80.79
368.22	-532.57
330.45	-570.34
1608.18	707.39
647.92	-252.87

Figure 9 – Echo II Cross-Section and Deviation (Sample Pass 25)

Graphs of cross-section versus time are shown in Figure 10. Quantities for the mean, variance, and standard deviation are shown in Table 2. Factors that determine the accuracy of the values in Table 2 are in part determinable at this reporting. The estimates of accuracy in calibration are as follows:

Transmitter Power, w_T	±0.5 kw
Transmit Antenna Gain, G_T	±1 db (60' antenna)
(including Line Losses)	±1 db (28' antenna)
Receive Antenna Gain, G_R	±0.3 db
Receive Antenna Line Losses, L_R	±0.1 db
Receive Antenna Directional Coupler (-15.4 db)	±0.2 db
Signal Generator	±0.3 db @ -20 dbm
w/Atten (Cumulative)	±0.07 db per 10 db
Reading Error	±0.15 db

In all cases, gain stability of the system during any one observation period is assumed to be essentially constant. However, during such an observation antenna pointing errors introduce variations in the received signal power. It is impossible to fully examine tracking records at this writing to determine whether signal degradation may have occurred. Instead, an estimation of error from on-site inspection of boresight camera films or operator reports from optical tracker operators and indicated errors from instrumentation has been made and assembled in Table 3.

With beamwidths at each terminal of approximately 0.5° for the 60-foot antennas (approximately 1.0° for the 28-foot antenna) and assuming mainbeam tapers of typically sin x/x, a peak error of 0.15° would result in a signal strength change of approximately -0.7 db or less (less than -0.35 db for the 28-foot antenna). Until a mean error can be determined from tracking records, it will be assumed for this report that signal degradation due to this cause was negligible.

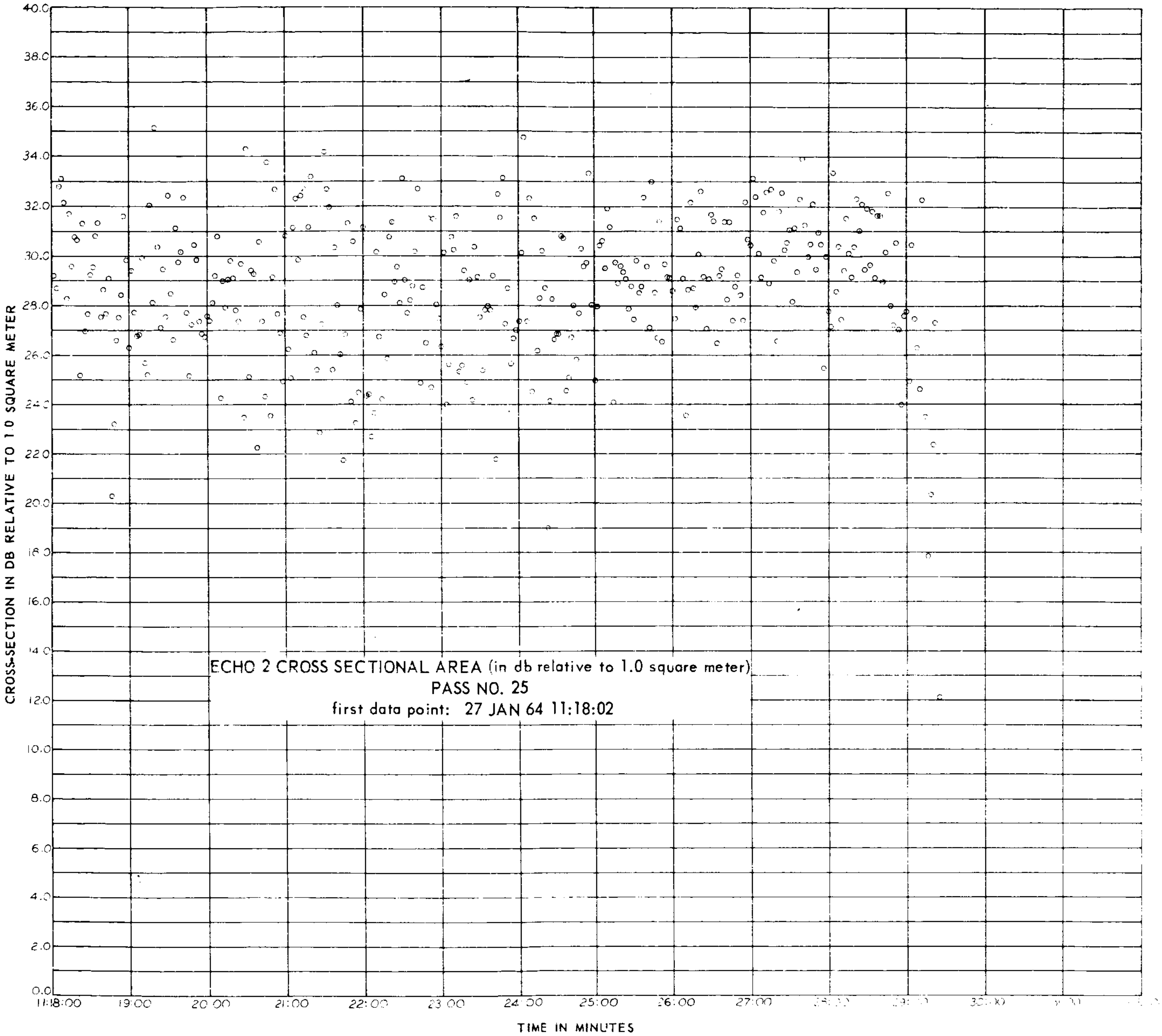

Figure 10 – Echo II Cross-Section vs Time (Pass 25)

Table 2
Mean Cross-Section, Variance and Standard Deviation

Pass Number	Mean Cross-Section	Variance of Cross-Section	Standard Deviation of Cross-Section
Bistatic			
25 (640127:11)	29.55 db or 900.79 $meter^2$	286,549.01 $meter^4$	535.30 $meter^2$
1170 (640423:01)	28.62 db or 727.33 $meter^2$	227,150.00 $meter^4$	150.71 $meter^2$
1519 (640519:09)	32.56 db or 1,801.64 $meter^2$	1,982,510.00 $meter^4$	1,904.44 $meter^2$
16983 (640511:09)	25.43 db or 348.90 $meter^2$	133,463.00 $meter^4$	365.33 $meter^2$
Monostatic			
1170 (640423:01)	30.03 db or 1,012.00 $meter^2$	11,138.69 $meter^4$	105.54 $meter^2$

Table 3
Probable Tracking Errors

Pass Number	Tracking Errors	
	NRL (Peak-Peak)	Dallas
25 (640127:11)	$<0.3°$	$<0.05°$ Az $<0.025°$ El
1170 (640423:01)	$<0.3°$	$<0.05°$ Az $<0.025°$ El
1519 (640519:09)	$<0.3°$	$<0.04°$ Az $<0.02°$ El
16983 (640511:09)	$<0.3°$	$<0.04°$ Az $<0.02°$ El

The probable error from calibration errors is taken to be the rms value of all errors, since some randomness is very likely when so many measurements are made at various times and at various locations. The value for probable error in the calibration of the system is 0.35 db. It is assumed, also, that the error associated with the signal generator attenuator is typically ±0.5 db when delivering -85 dbm of power. This value of probable error in calibration for the system is applicable to results shown in Table 2.

Samples of stripchart records which are used to obtain cross-section data and also to obtain spectra data, are shown in Figures 11 through 14. These records display the received signal linear with respect to voltage on one trace and also the same received signal linear with respect to power on the other trace. Chart speed was 10 mm/second. The stripchart record shown in Figure 14 from Echo I pass 16,983 was recorded at approximately the same recorder settings, to allow ready comparison to the Echo II data. The data is reducible even though the function of power plot is not particularly useful as shown.

2.3 Relative Power Spectrum of Fading

Data from the reduction and analysis of the relative power spectrum of the fading should reveal any periodic variations in the signal level. If there are, communication system responses would need to be adjusted accordingly, and this would influence coding methods for some types of transmitted information. Also, such periodic variations should indicate the presence of gross satellite distortions.

Results of our analysis to date, has shown no periodic variations in the signal level.

The spectrum of the general form of

$$\phi_{(t)} = \sum_{n=1}^{\infty} a_n \cos n\omega t + b_n \sin n\omega t$$

is produced by the analyzer shown in Figure 15. The dc value is not calculated and only the relative power spectrum is obtained. The received signal strength data was linearized with respect to the square of the signal power and transferred to a loop of magnetic tape. The loop was repetitively run while slow frequency scanning was performed by the analyzer. Tape speed-up and re-recording was employed to

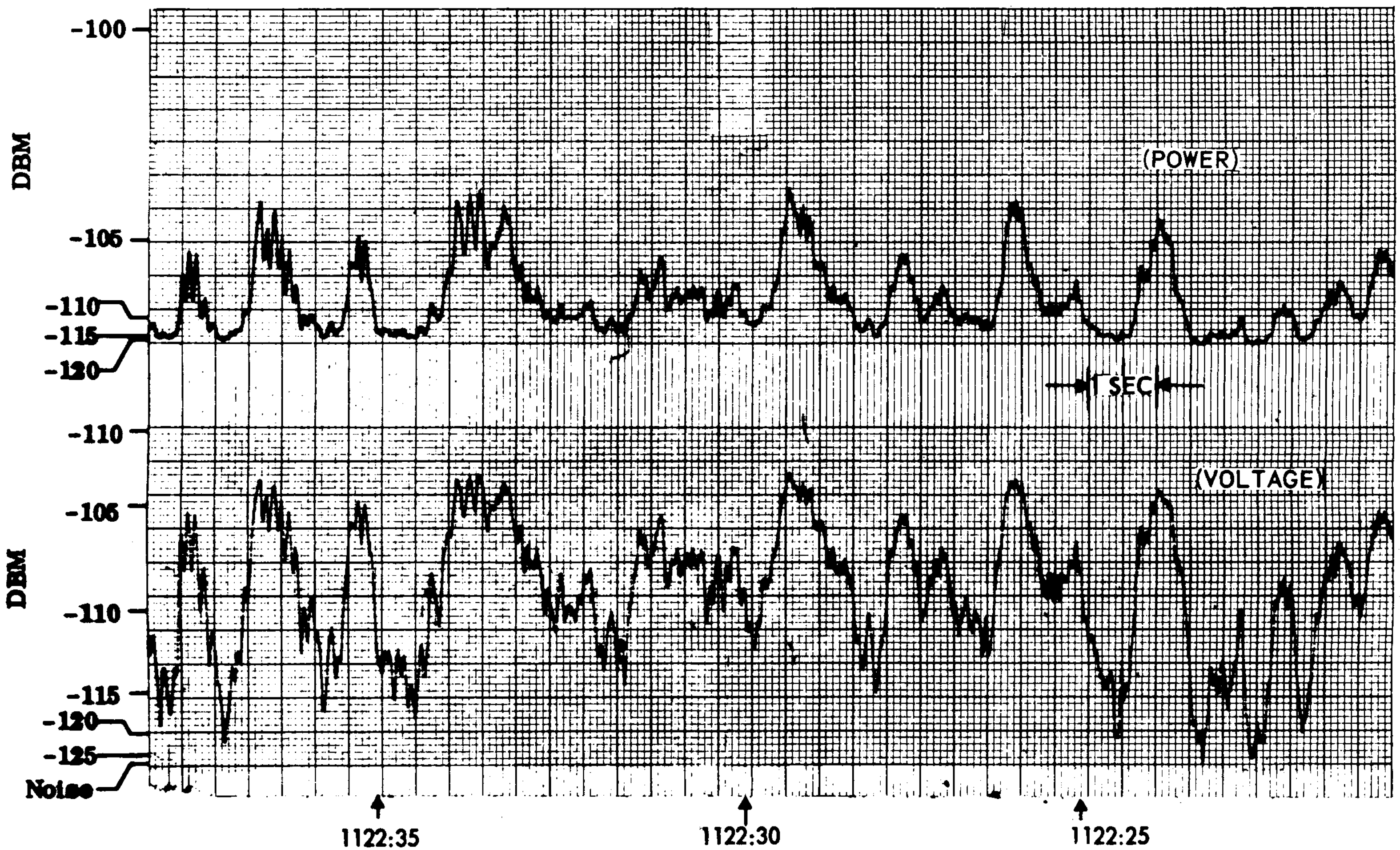

Figure 11 – Received Signal vs Time (Echo II – Pass 25)

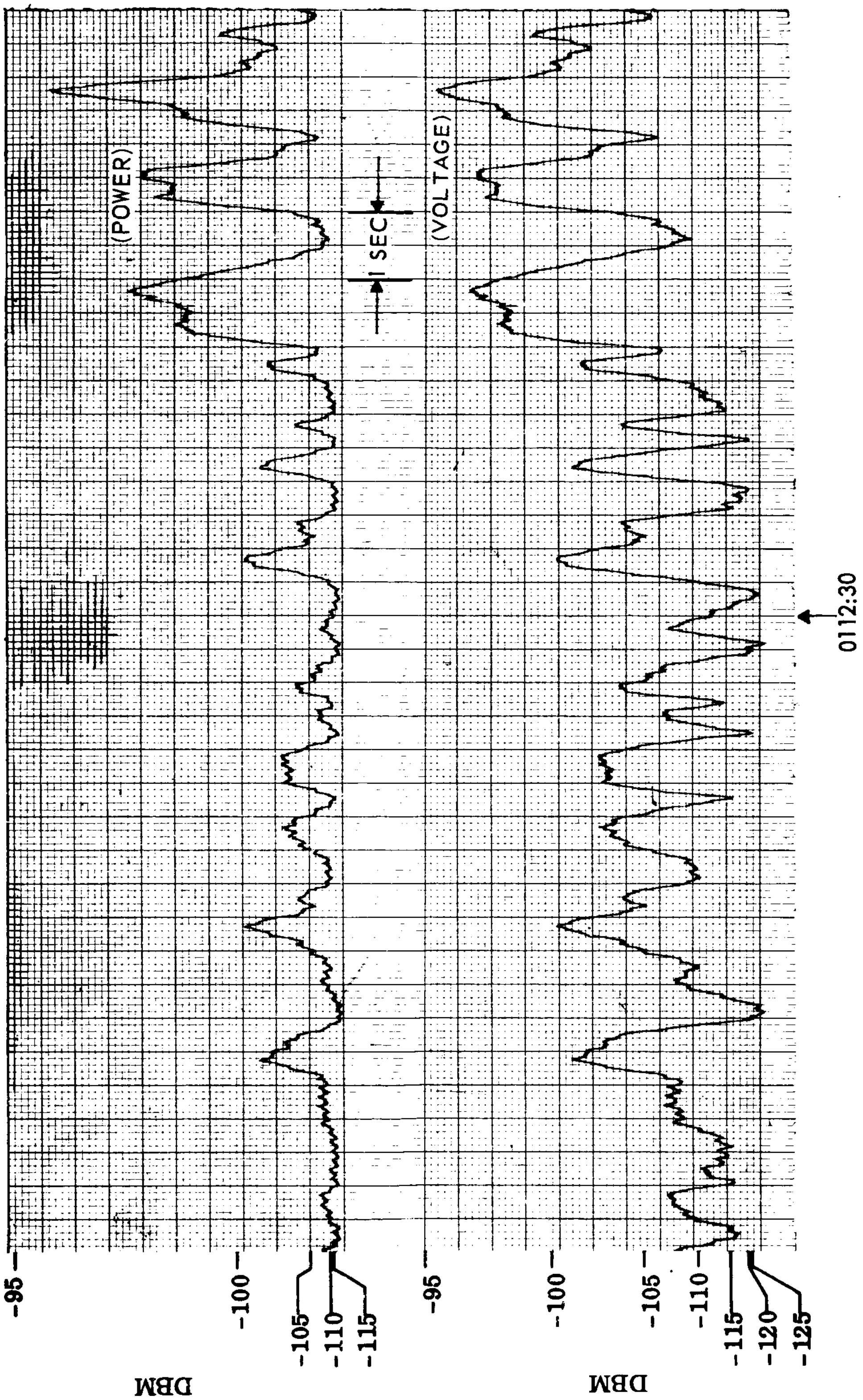

Figure 12 – Received Signal vs Time (Echo II – Pass 1170)

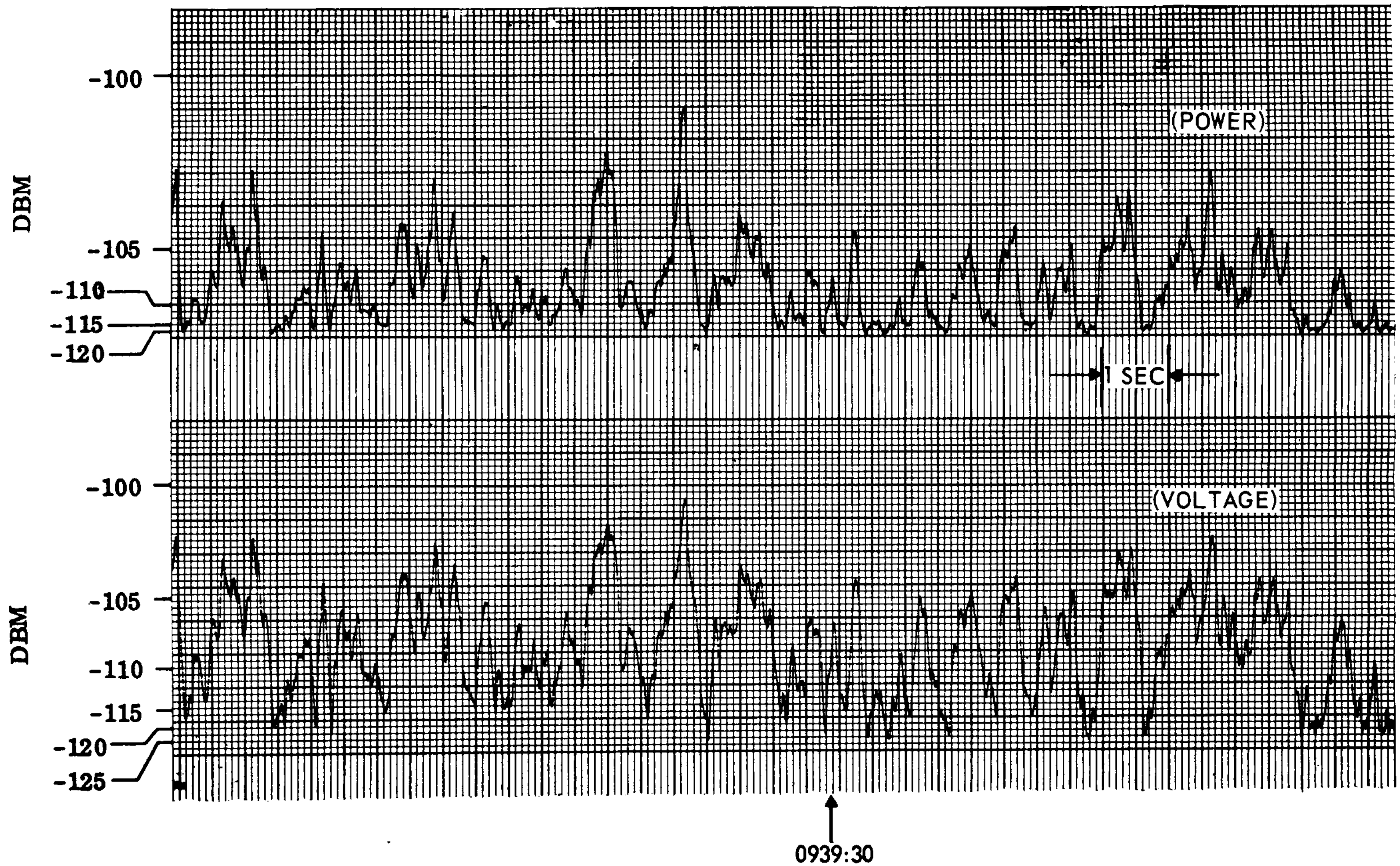

Figure 13 – Received Signal vs Time (Echo II - Pass 1519)

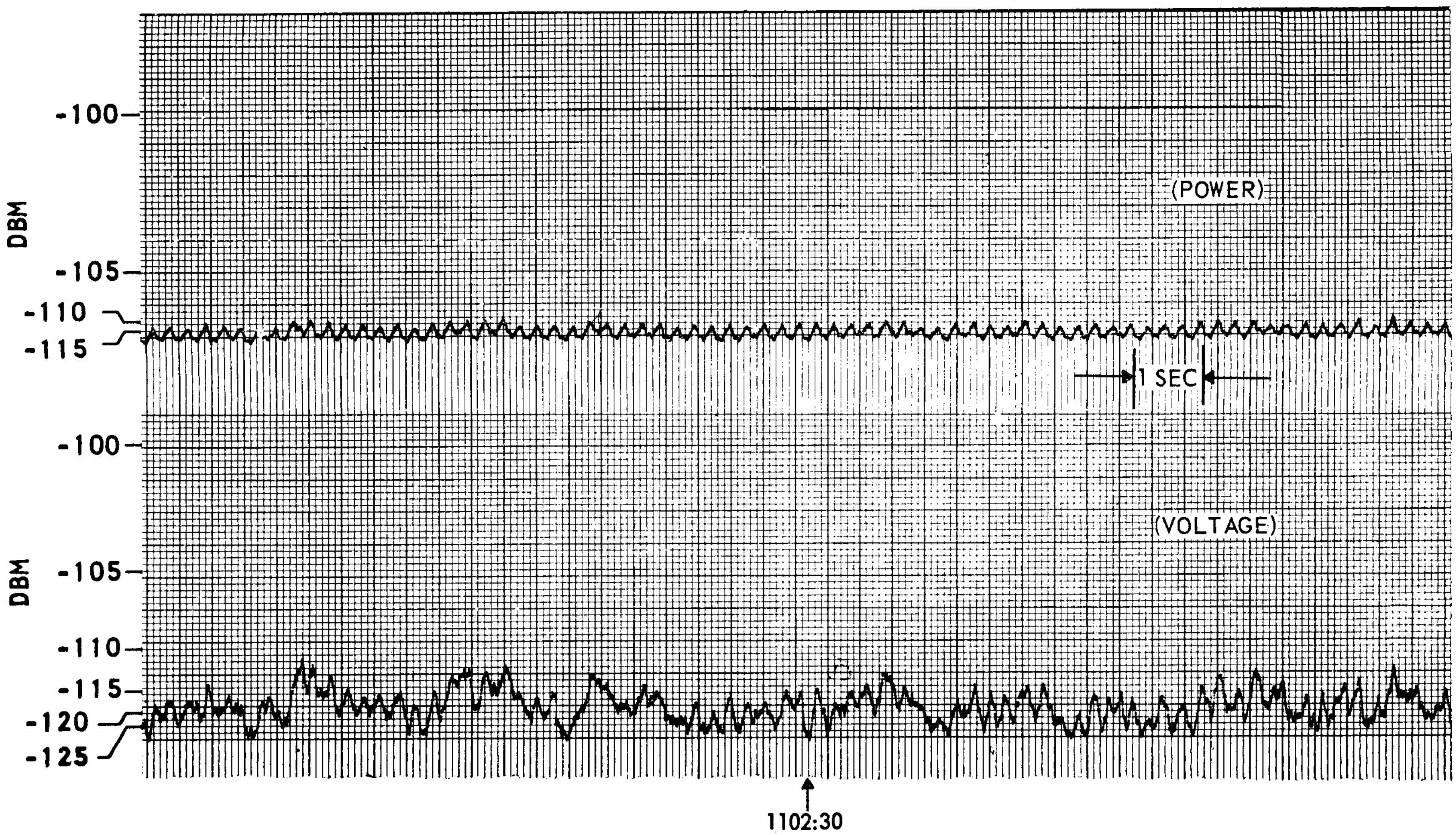

Figure 14 – Received Signal vs Time (Echo I – Pass 16,983)

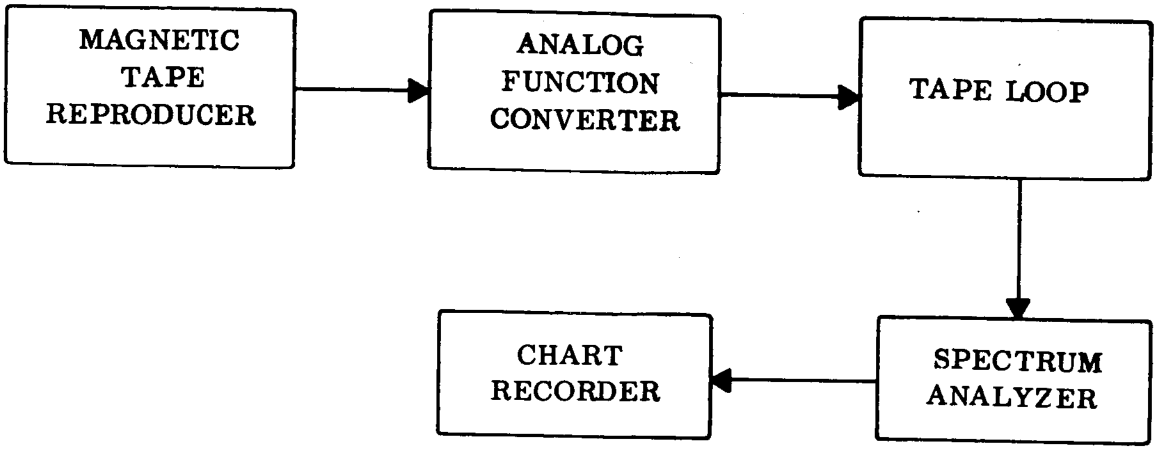

Figure 15 – System for Computation of Relative Power Spectrum of Amplitude Fading (Echo II)

bring very low frequency variations into the range of the analyzer. A frequency multiplication of 8192 was obtained by this process. A filter bandwidth of 23 cps (noise bandwidth) was used, providing a real-time bandwidth for the data of 0.0028 cps.

Since a finite sample of data was used, erroneous contributions to the power spectrum are present. The basic finite period is that of the length of original data (period of one pass). Slant range effects to signal strength were not removed; therefore, considerable spectral power exists at a frequency corresponding to the period of the pass Spectral power also exists at frequencies corresponding to the periods related to the rates at which tape loops were replayed.

Table 4 presents the points in the spectrum where erroneous contributions are anticipated.

The amount of each contribution to the power spectrum cannot be determined directly. Special efforts were made to keep these contributions extremely low in the data handling process. Perhaps the most significant and appreciable contribution present is that of slant range variation.

Comparative spectrum diagrams are shown in Figures 16 through 19. Adjustment of gains in the data preparation yields comparative results even though the dc values are absent. The ordinate scale

Table 4

Frequencies of Contributions to Spectrum From Data Handling

Pass Number	First Loop (CPS)	Second Loop (CPS)	Slant Range (CPS)
25	0.0016	0.00006	0.002
1170	0.0021	0.00006	0.002
1519	0.0023	0.00006	0.002
16983	0.00133	0.00006	0.002

is only relative because of the absence of the dc term. Peaking of the energy in the region of 0.001 to 0.002 that appears in Figures 16 and 17 are possibly the result of the slant range contribution. Since the filter (equivalent) bandwidth was maintained at 0.0028 cps, uneven weighting results across the spectrum. The spread or degree of slope in the decades 0.0001 to 0.01 may not be accurate. Some of the fine detail not apparent in the figures was omitted for the reason of unequal weighting.

The general roll-off of from 5 to 10 db per decade is felt to be valid. There was no opportunity prior to the time of writing this report to cross check by means of a Fourier transform of the autocorrelation function where the dc term is preserved. There were no regions of predominantly strong spectral energy. The trend above 1.0 cps in each case was for a gradual decrease with lesser slope probably due to the gradual decrease in signal to noise.

Sine wave calibration of the instrument was used. The filter bandwidth was accurately determined and converted to noise bandwidth. Calibration error was less than 0.1 db in amplitude and less than 10 percent in bandwidth. It has been assumed that the receiver system responses are flat over this range of interest and do not modify the spectral energy content of the signals.

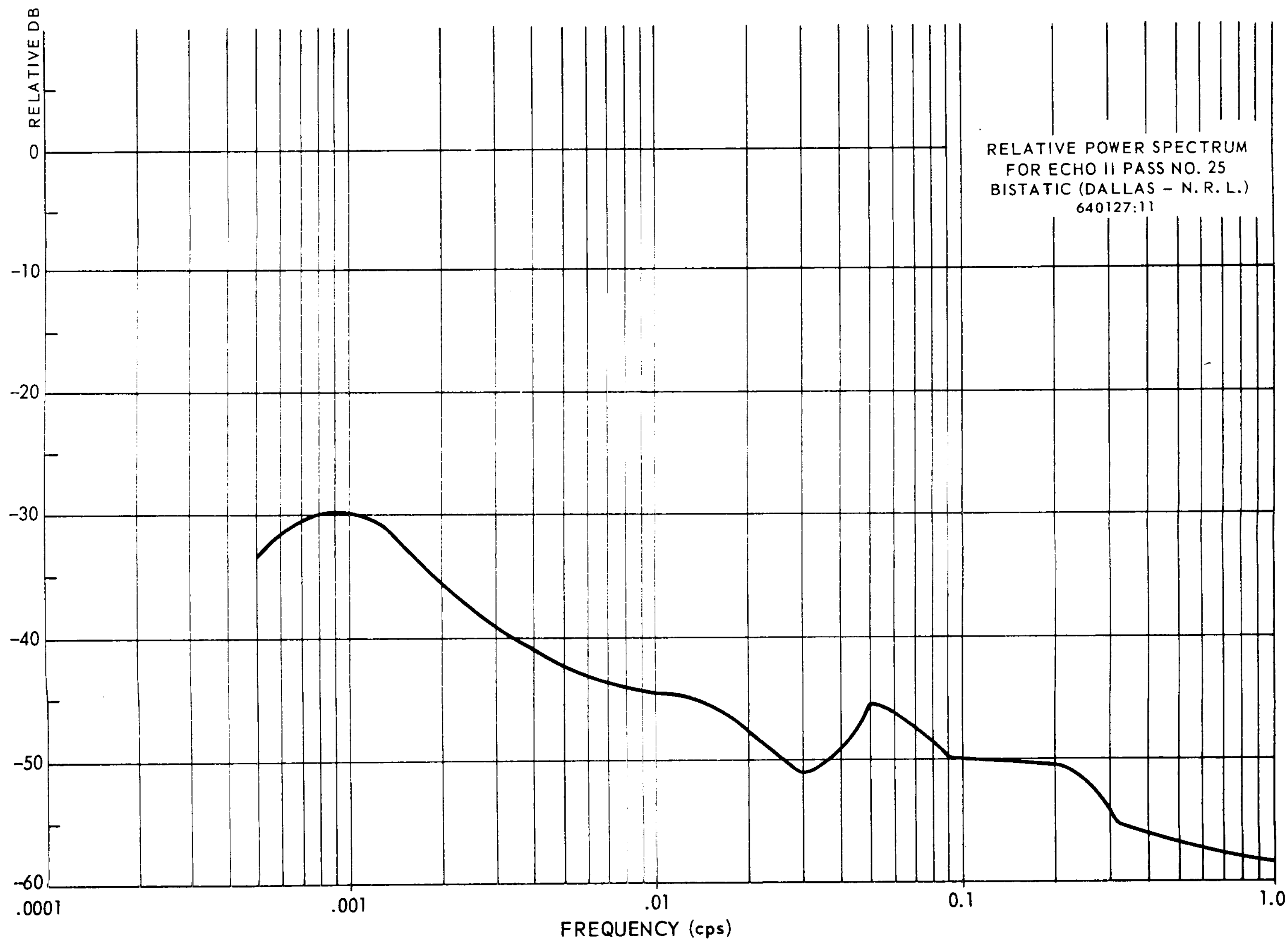

Figure 16 – Relative Power Spectrum (Echo II – Pass 25)

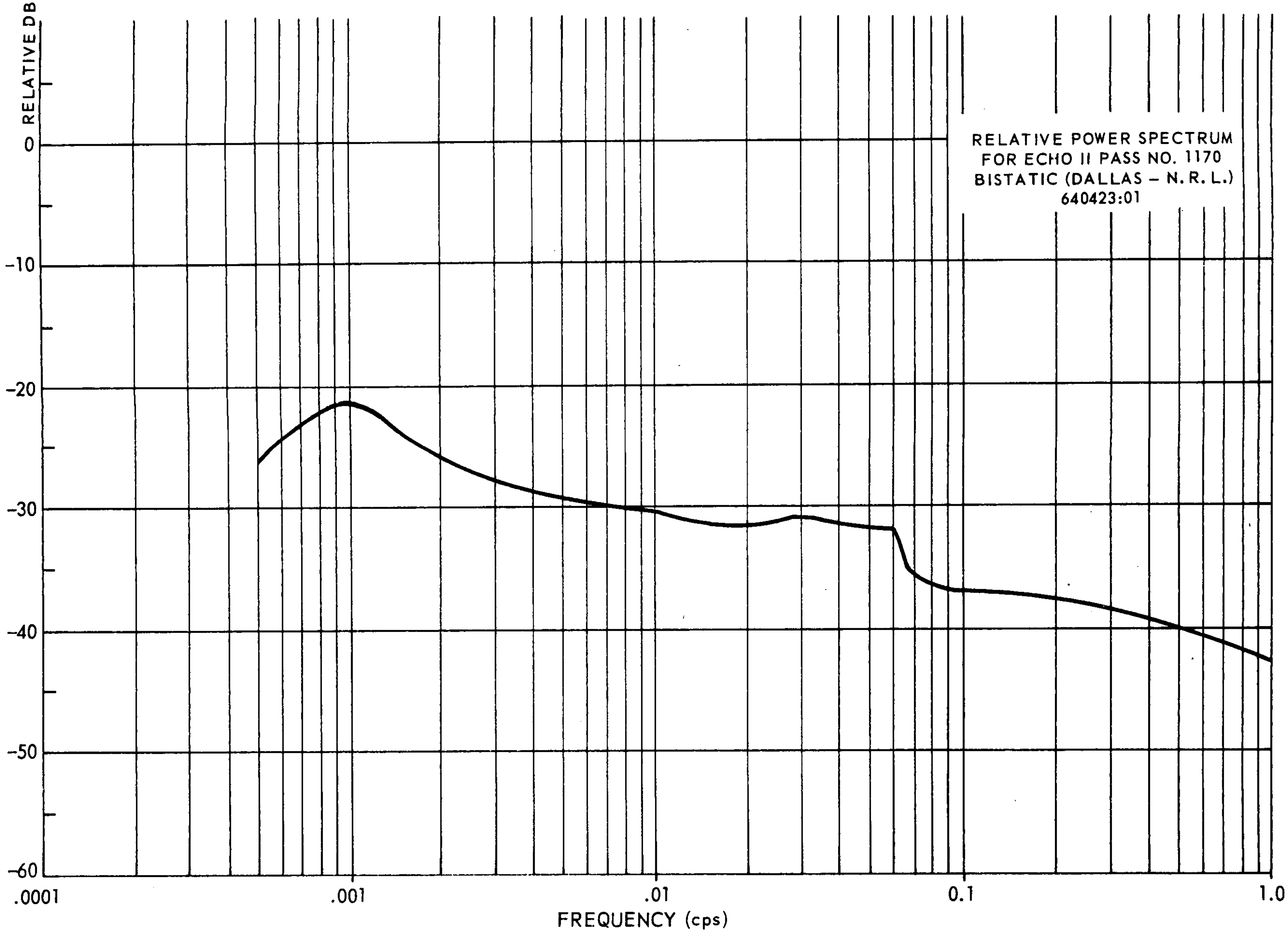

Figure 17 – Relative Power Spectrum (Echo II – Pass 1170)

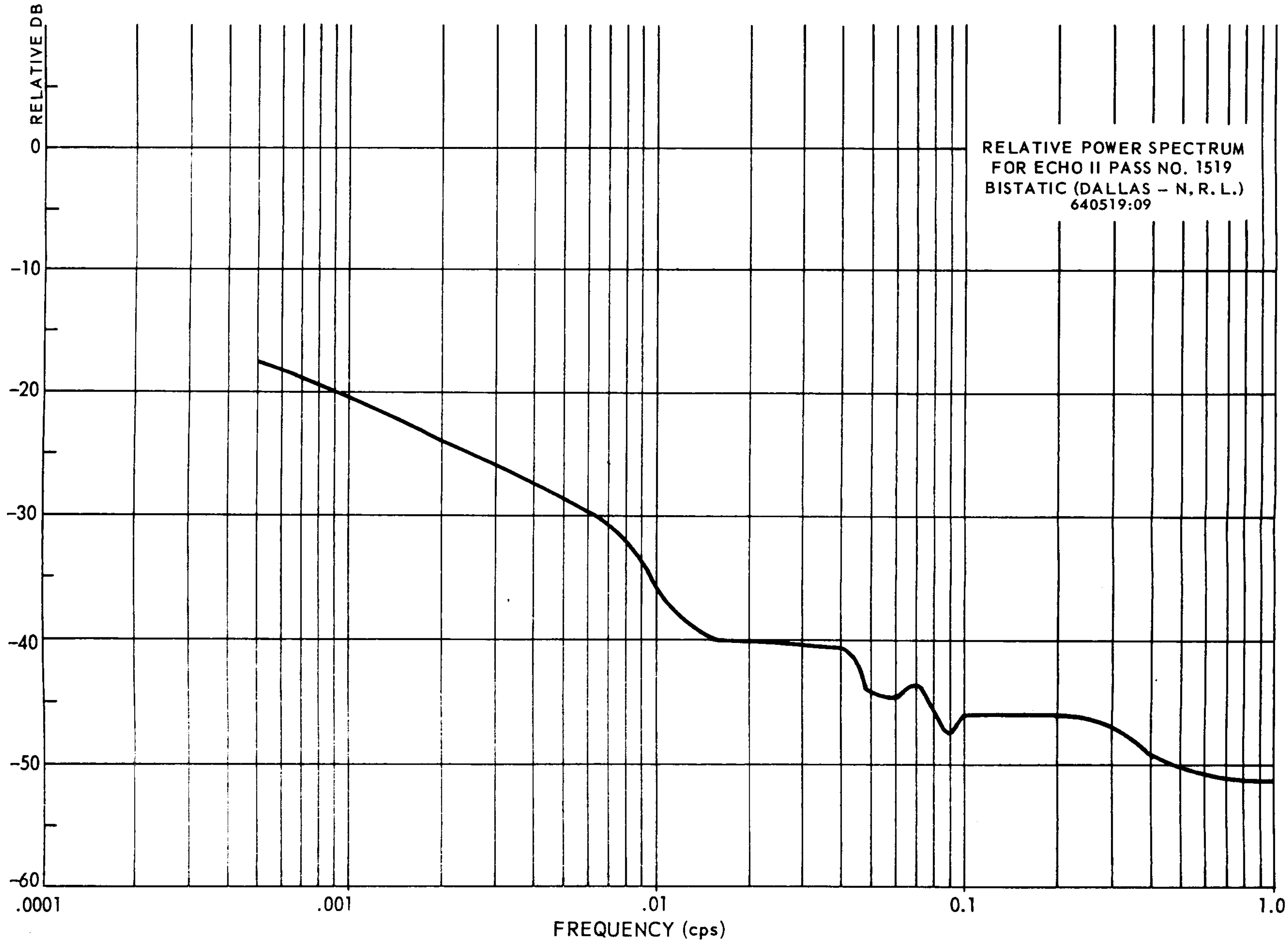

Figure 18 – Relative Power Spectrum (Echo II – Pass 1519)

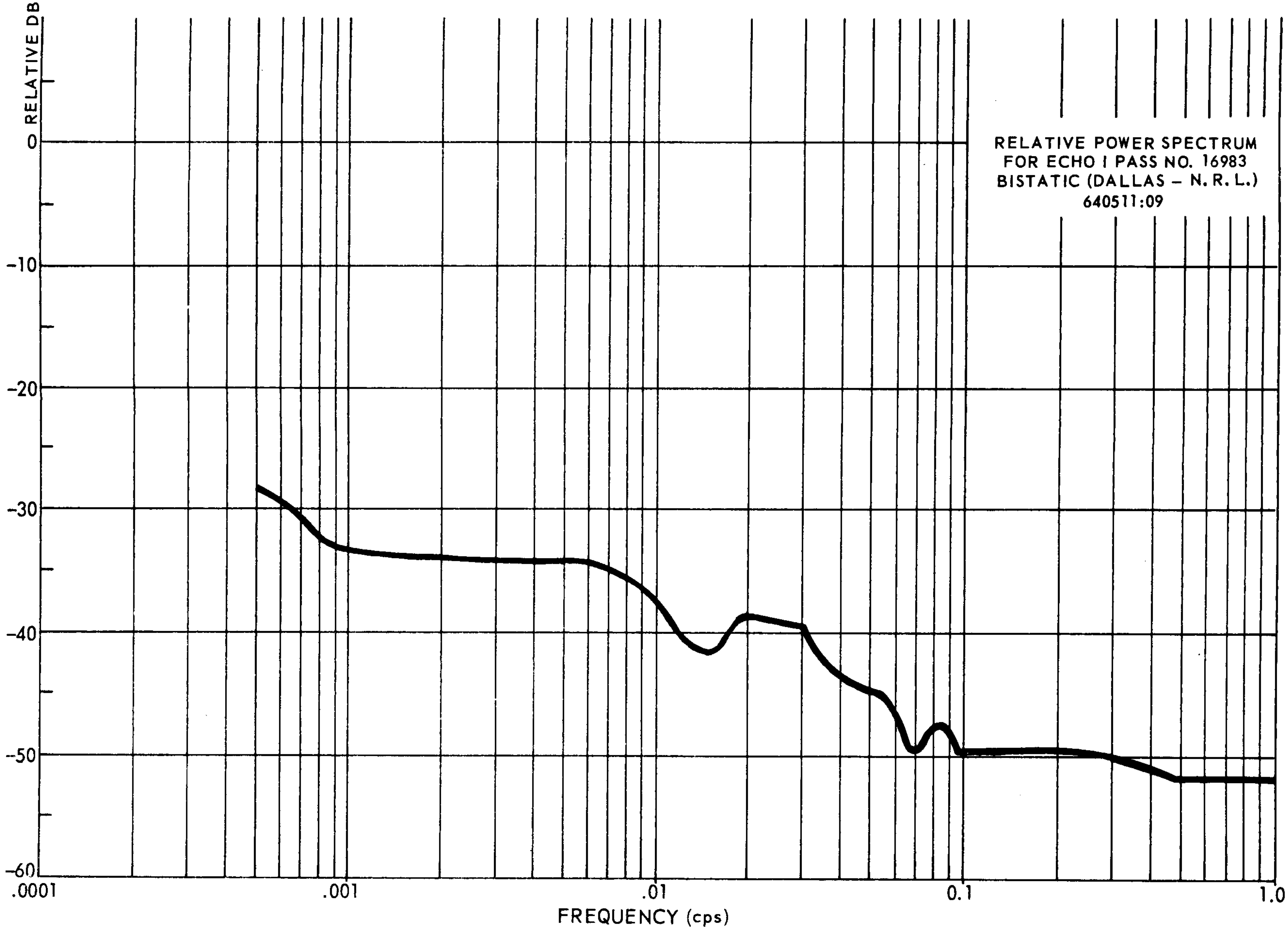

Figure 19 – Relative Power Spectrum (Echo I – Pass 16,983)

2.4 Distribution of Amplitude Fading

The distribution of amplitude fading indicates the percentage of time the signal level will be above or below a given level relative to the median level. This allows determination of the amount of margin relative to the median signal that would be required to produce a given signal-to-noise ratio a given percentage of time. Thus, the necessary circuit gains can be determined to allow satisfactory operation with given types of information and modulation.

The method by which the amplitude distribution is reduced is illustrated in Figure 20. The signal is reproduced and linearized in the analog function converter. The analog output is reproduced on a loop of magnetic tape. The specimen on the tape loop is played repetitively into an amplitude distribution analyzer. Simultaneously, five levels of distribution are measured. At the conclusion of the measurement period, five different levels of amplitude distribution may be measured. A sufficient number of levels are measured in order to accurately display the shape of the distribution curve. These db levels are then plotted as a function of probability. A separate plot will be made for each observation that is analyzed.

Results of these analyses will be included in the Echo II Final Report.

3.0 MEASUREMENT OF INSTANTANEOUS RECEIVED SIGNAL LEVEL (EXPERIMENT NO. 2)

A variation of the received signal level measurement (Experiment No. 1) will be performed periodically by NRL in an attempt to determine if there is any indication of fast, deep fades. In this experiment, the signal is detected after it has been amplified in an IF amplifier with a bandwidth of 800 kc. The video signal is then applied to an oscilloscope and recorded photographically to determine if there is any indication of fast, deep fades.

To date, no usable data has been obtained because of the low signal-to-noise ratio inherent in a 800-kc bandwidth. However, further attempts will be made to secure usable data for this experiment by scheduling for an optimum pass in order to obtain the maximum signal-to-noise ratio.

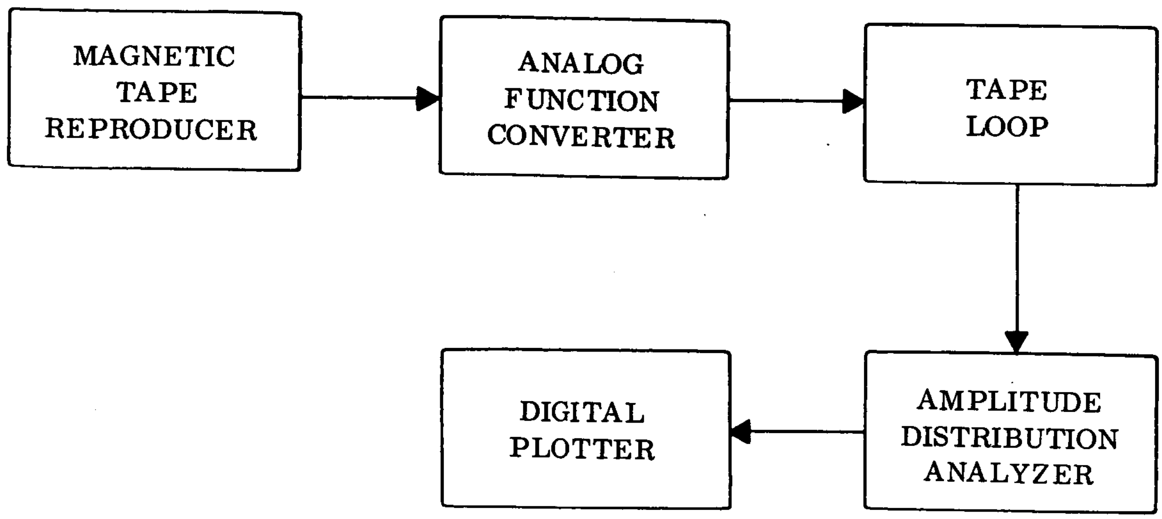

Figure 20 – System for Computation of the Distribution of Amplitude Fading (Echo II)

4.0 SIGNAL AMPLITUDE CORRELATION MEASUREMENTS (EXPERIMENT NO. 3)

The purpose of this experiment is to measure the degree of correlation of signal level variations between two carriers separated in frequency. This in turn can be related to the bandwidth capability of the satellite. The frequency separation at which the percentage of correlation decreases significantly establishes limitations on bandwidths of signals to be utilized. Bandwidth capability is expected to degenerate when the balloon surface becomes irregular.

To perform the signal amplitude correlation measurements, the satellite is illuminated with two signals that are separated in frequency by a specified amount. The two received signal strengths are recorded simultaneously on separate channels of a stripchart recorder and on separate channels of a magnetic tape recorder.

Data for this experiment was collected during 4 Echo II orbits. Partial reduction of the data indicates an amplitude correlation (between two signals spaced 12 megacycles apart) of 99.9 percent (see Table 5). This indicates that the Echo II satellite will reflect a communication signal having a 12-megacycle bandwidth without degradation due to selective fading within the 12-megacycle band. (Selective fading occurs if all frequencies within a given bandwidth fail to propagate uniformly. This results in distortion or garbling of the message.)

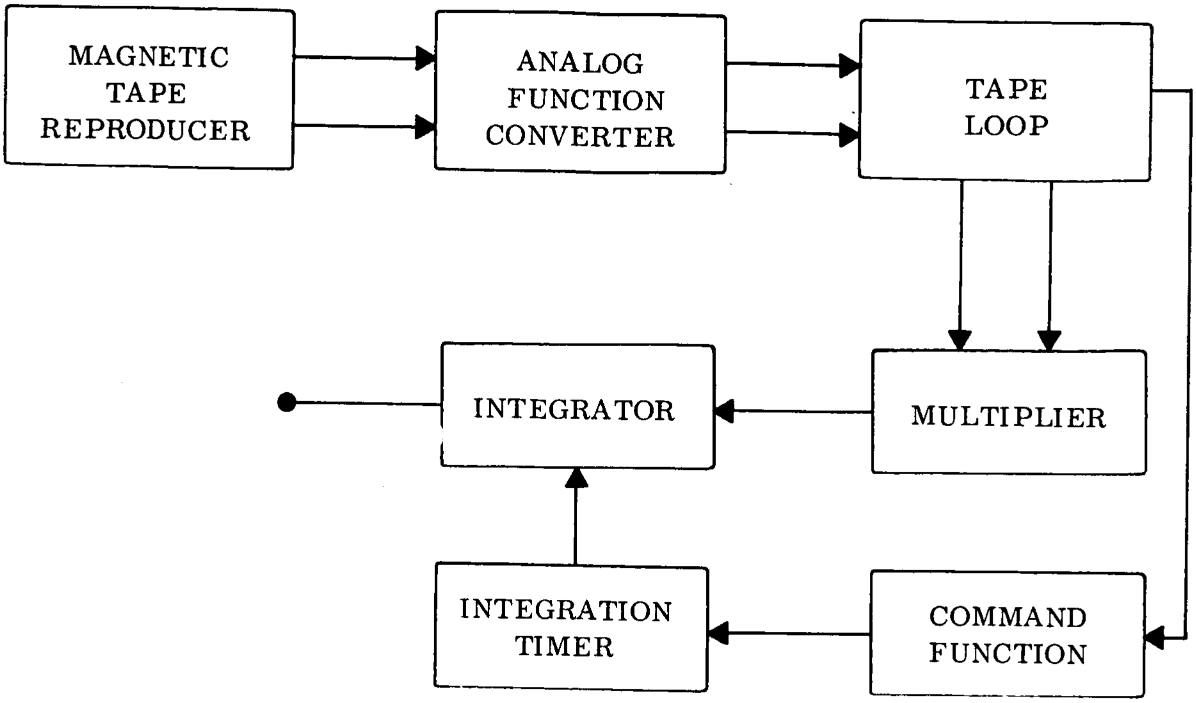

Figure 21 – System for Computation of the Cross-Correlation Coefficient for Spaced Frequencies (Echo II)

Table 5

Cross-Correlation Coefficient of Amplitudes of Signals With 12-mc Spacing

Pass	$R_{(r=0)}$
1533 (640520:10)	0.99 ± .005

The method by which the correlation coefficients are computed is illustrated in Figure 21. The amplitudes are simultaneously reproduced and are linearized in the analog function converter. The data is reproduced on a tape loop for handling convenience when the sideband amplitudes are taken separately from master tapes. The signals are multiplied and integrated, normalized. These values are plotted in terms of coefficients ranging from -1 to +1.

The analytic form for the coefficient is:

$$R_{(\tau=0)} = \frac{\frac{1}{T}\int_0^t F_{(t)}\, G_{(t)}\, dt - \overline{F}\overline{G}}{\left\{\left[\frac{1}{T}\int_0^t F_{(t)}^2\, dt - \overline{F}^2\right]\left[\frac{1}{T}\int_0^t G_{(t)}^2\, dt - \overline{G}^2\right]\right\}^{1/2}}$$

The equipment in the block diagram of Figure 21 was utilized in various configurations to produce both numerator and denominator in the above equation.

Cross-correlation of the amplitudes from the main channel (one sideband) and the offset channel (other sideband) for pass 1533 (640520: 10) was performed. The result is shown in Table 5.

The amplitude modulating signal was 6 mc and resulted in a first-order side-band spacing of 12 mc. The sidebands were transmitted at approximately -6 db relative to carrier. A stripchart of the received signals is shown in Figure 22. Computational accuracy was determined by the use of known test functions. Those results are illustrated in Table 6.

Table 6

Cross-Correlation Coefficient With Test Function

Test Function	$R_{(\tau=0)}$	Comment
Sine Wave	0.994 ± 0.005	In Phase Wave
	-0.999 ± 0.005	180° Out of Phase Wave

5.0 WIDEBAND SIGNAL AMPLITUDE CORRELATION MEASUREMENTS (EXPERIMENT NO. 4)

This experiment is similar to experiment #3 except that the frequency spacing between signals is much greater (70 mc and 190 mc). Transmissions at 2260 mc and 2190 mc will be employed for the 70-mc spacing with 2380 mc and 2190 mc being used for the 190-mc separation. The results of this experiment will also determine the degree to which

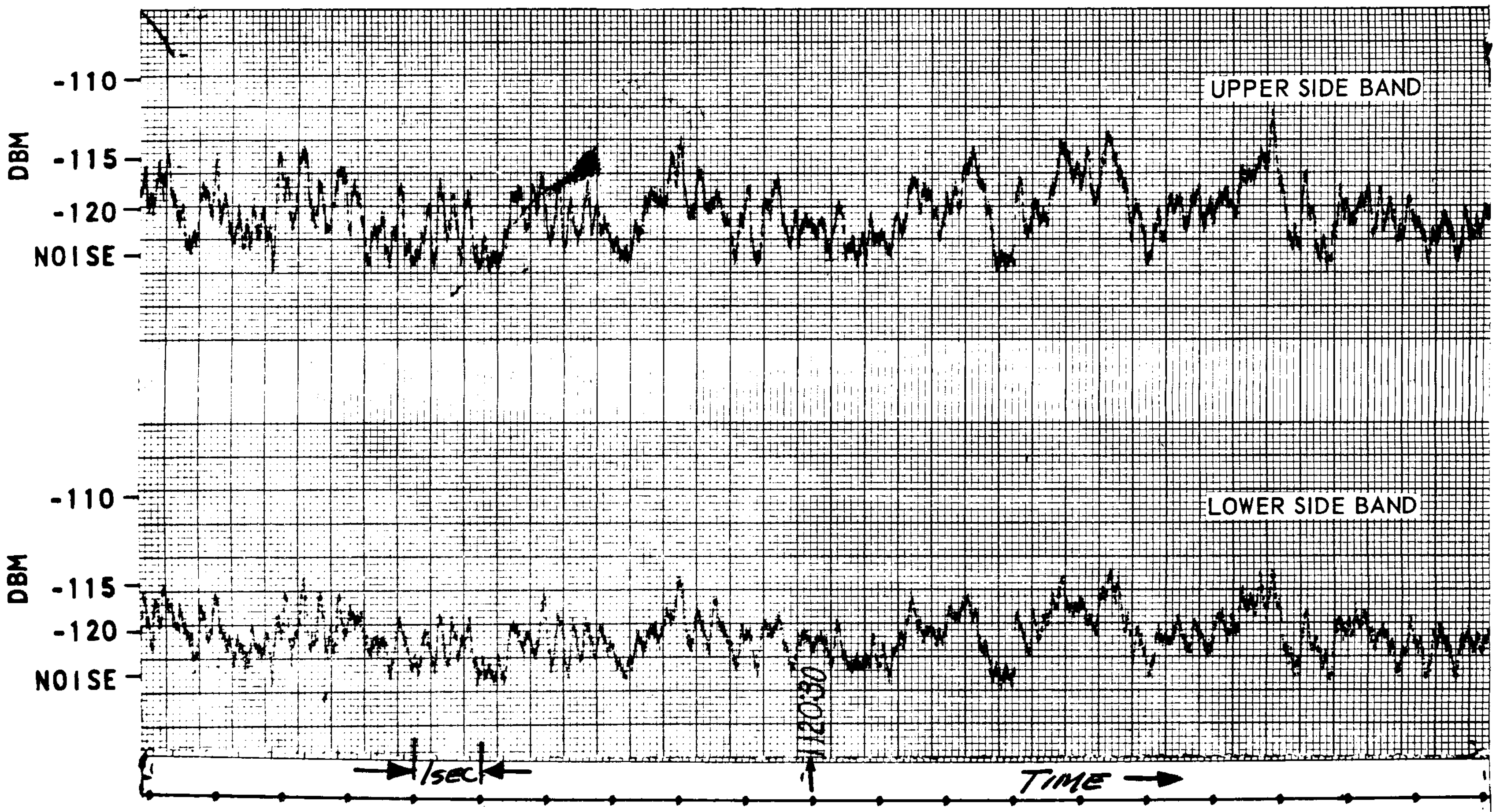

Figure 22 – Amplitude Correlation Measurements (Echo II - Pass 1533)

the use of frequency-diversity techniques will improve communications via the satellite. The data reduction is performed in the same manner and by the same equipment as experiment No. 3.

Although data reduction and analysis is not complete, preliminary results indicate a good degree of correlation on 70 mc separation and somewhat less correlation at 190 mc separation. This would imply that frequency diversity techniques could be used to some advantage with Echo II. If certain receiving equipment can be made available at NRL, Frequency Diversity Experiments will be conducted later this year to determine just how effective such techniques are. Results of these experiments will be included in the Project Final Report.

6.0 SIGNAL PHASE CORRELATION MEASUREMENTS (EXPERIMENT NO. 5)

The purpose of this experiment is to measure the degree of phase correlation between the sidebands of a modulated signal. Again, as in signal amplitude correlation measurements, the frequency separation at which the degree of phase correlation significantly decreases establishes limitations on bandwidths of signals to be utilized.

To perform this experiment, the satellite is illuminated with a signal that is modulated in such a way as to provide two sidebands of significant power separated by the specified amount along with the carrier. Three phase-lock receivers are required at the receiving station to perform the measurements. The three phase-locked receivers will be tuned, one each, to the two sidebands and the carrier. The vco of the receiver locked to the carrier is mixed with the vco of the two receivers locked to the two sidebands. Phase measurements are then made between the two resulting signals with a phase detector, and will be recorded on a Sanborn channel and a channel of the tape recorder.

NRL now has two of the required receivers but construction of the third receiver has not been completed. It is anticipated that this receiver will be completed and the test conducted in late November or early December.

7.0 AUDIO FREQUENCY TRANSMISSION TEST (EXPERIMENT NO. 6)

The purpose of this experiment is to determine the quality of audio transmission over a passive satellite communication channel. This experiment determines the degree of distortion introduced during the transmission of a signal frequency-modulated by one of several audio tones ranging from 30 cps to 15,000 cps. Data collected consists of magnetic tape recordings of each audio tone as it was demodulated at the receiver. Comparison of the received and transmitted tones from these two recordings with a standard distortion analyzer determines the amount of distortion introduced by the communication system.

To perform these tests, audio frequency tones of 30 to 15,000 cps are transmitted using frequency modulation. This audio signal is derived from an audio signal generator and fed into the transmitter modulator. The received signal is recorded on magnetic tape and signal levels are recorded throughout the test.

Data for this experiment was collected during 4 Echo II orbits. Although this data has not yet been reduced, the results of experiment No. 7 (voice and music transmission tests) indicate that Echo II will support an FM signal without distorting modulating frequencies over the range indicated above.

8.0 VOICE TRANSMISSION TESTS (EXPERIMENT NO. 7)

A variation of the audio transmission tests will be the transmission of voice and high-fidelity music via the Echo II satellite. These transmissions will be performed using pre-recorded magnetic tapes. This experiment provides the data to audibly evaluate the capability of the Echo II satellite to reflect a signal, frequency-modulated by voice and music.

A high-fidelity tape recording of music with voice commentary was made by the Goddard Space Flight Center and has been transmitted by Collins Radio Company to the NRL station with excellent results. The peak deviation used was ±15 kc. The receiver used had a 50-kc predetection bandwidth and a standard Foster-Seeley discriminator with a 16-kc information bandwidth. This system has a noise temperature of 550°K, therefore the conventional threshold, at 10-db predetection signal-to-noise ratio, is reached at -114 dbm. This compares to a predicted signal level varying from about -114 dbm to a maximum of -100 dbm, assuming a perfect 135-foot balloon on the best possible pass. The pass used in this case was not as favorable as in the facsimile case discussed below, since the elevation angle at NRL was high enough to cause the azimuth rate capability to be exceeded and thus the center portion was unusable. As a result the maximum usable calculated signal level was limited to about -104 dbm for a perfect balloon as compared to the -114-dbm threshold of the receiver. This resulted in the signal level dropping, on occasion, into the receiver threshold level during signal variations of the type discussed in paragraph 2.0 above. This shows up as rapid noise bursts in the received signal. A sample of this tape as received at NRL has been transcribed on phonograph records and can be made available if required.

It must be emphasized that no special demodulation scheme or compensation filtering has been done in producing this recording. If appropriate preemphasis and postemphasis had been used, or if more advanced low noise receivers had been employed the noise bursts would have been considerably less noticeable for the type of signal characteristics present.

9.0 FACSIMILE TEST (EXPERIMENT NO. 8)

This experiment determines the quality of facsimile transmission over the satellite. The facsimile test was made using a standard military facsimile machine that normally uses a 3-kc voice channel. A magnetic tape recording was made at NRL of the facsimile signal. Also, a low-level, 1000-cycle tone was simultaneously recorded for tape recorder speed control and doppler correction. This tape was then used at Dallas at four times the recording speed to provide a 12-kc baseband signal for FM of the Dallas transmitter. This was received and demodulated at NRL with a 50-kc predetection bandwidth and a standard discriminator with a 16-kc information bandwidth. The peak deviation used was ±15 kc. The demodulated signal was recorded again on magnetic tape and then subsequently played back at one-fourth the recording speed into the facsimile machine. The same parameters (deviations, bandwidth, etc.) were used as in the voice and music experiment.

Data for this experiment has been collected during 7 Echo II orbits. Results from this experiment are quite good, considering that a standard military facsimile machine and conventional modulator and demodulator circuitry was used.

The pass used (12 June 1964) was one of the better passes. Facsimile reproductions made directly from the original magnetic tape are shown in Figures 23 and 25. Facsimile reproductions made from the magnetic tape recording of the received signal are shown in Figures 24 and 26. Both pictures were sent during the same pass in a total of less than three and one-half minutes.

It will be noted that the fine detail in the pictures is largely retained but that some streaks and some distortion was introduced. It appears that both can be traced to fluctuations in the signal level, which caused the signal to drop momentarily into or below the threshold region of the receiver. This, of course, allowed the noise output of the receiver to increase appreciably and allowed the recorder to lose speed control. The loss of speed control appears responsible for the distortion in the horizontal lines.

As in the case of the Voice and Music Experiment (Paragraph 9.0 above), with more advanced, state-of-the-art receiving system, the effect of the noise bursts would be essentially unnoticable.

10.0 DIGITAL DATA EXPERIMENT (EXPERIMENT NO. 9)

The purpose of this experiment is to determine the quality of digital data transmission over the Echo II satellite circuit.

As originally planned, prerecorded test tape containing approximately 2400 bits/second would be used in place of the kineplex terminal equipment at the transmitter. During transmission, this tape would be played at four times its normal pre-recorded speed. At the receiving end, the signal is recorded at the same accelerated speed used at the transmitter. Again, a tape recorded at the receiver site would take the place of kineplex terminal equipment.

The data experiments that have been performed to date have been modified from those of the original experiments plan because the kineplex waveforms are not suitable for transcribing onto magnetic tape without incurring a bit error rate on the order of 10^{-3}. Due to this lack of appropriate equipment for encoding, decoding, and error checking more complex data transmission, a data stream of alternate ones and zeros square wave at a 1.2 kc rate was transmitted and the demodulated signal recorded at NRL. Although reduction of this data has not been completed, the method to be used is illustrated in Figure 27.

Figure 23 – Copy of Photograph Transmitted by Facsimile

Figure 24 – Copy of Photograph Received by Facsimile, Via Echo II

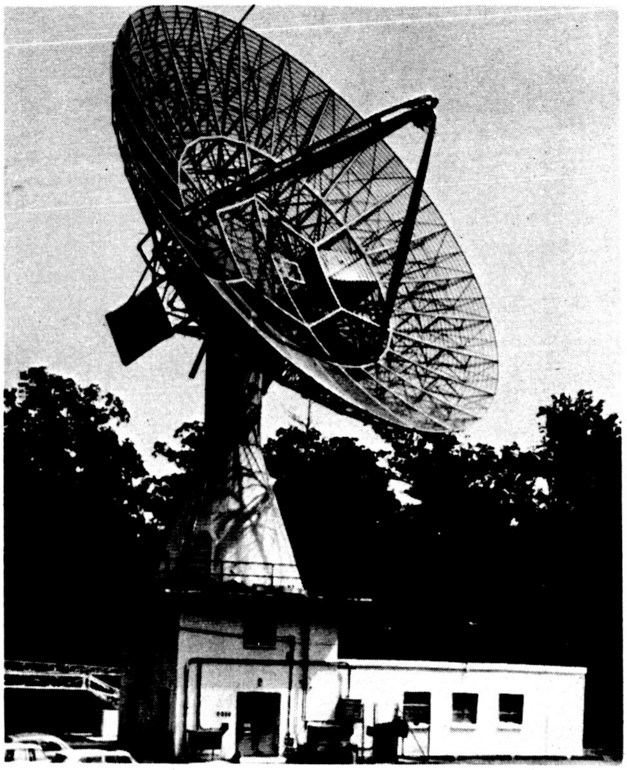

Figure 25 – Copy of Photograph Transmitted by Facsimile

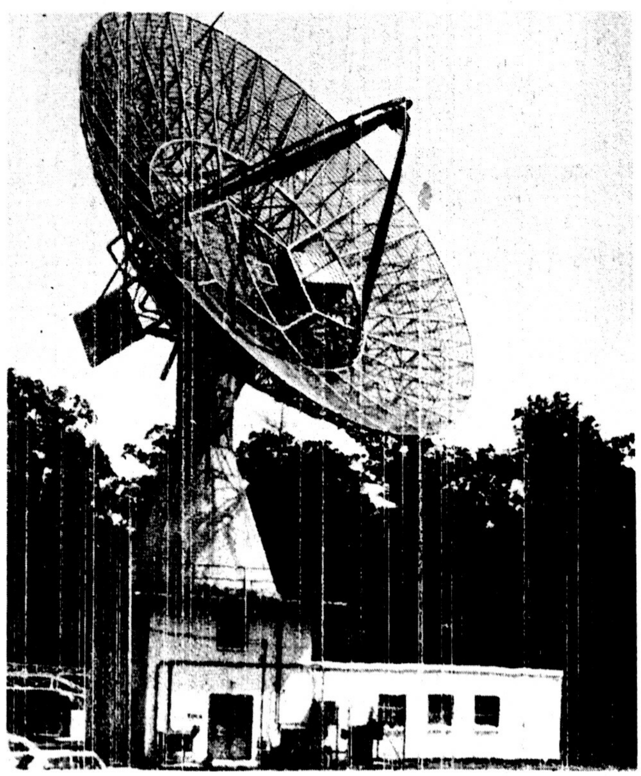

Figure 26 – Copy of Photograph Received by Facsimile, Via Echo II

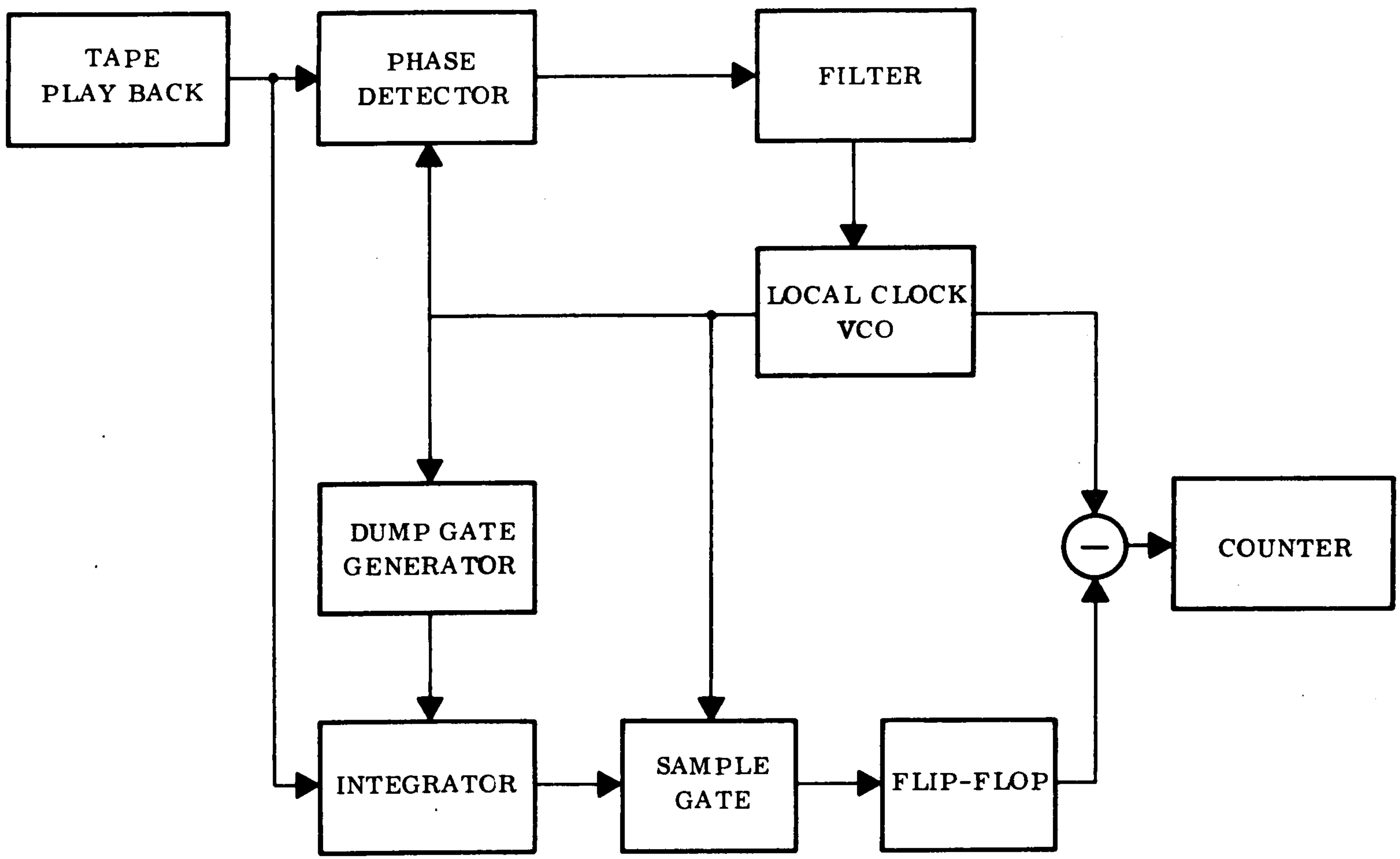

Figure 27 – Data Error Detector System (Echo II)

The upper portion of the diagram depicts a phase loop which synchronizes a local clock to the received signal. In this case, the local clock also provides the local code for automatic error detection. If a more complex code had been employed, the clock would have driven a local code generator and a second loop employed to lock the local code to the received code.

The received code is decoded in a matched filter (integrate and dump) which makes an independent one or zero decision for each bit space. These decisions are sampled at the end of each bit space and read out as the received bit stream. This received bit stream is compared to the local code and a pulse read out for each incorrect bit. Tabulation of these output pulses for known time period yields the bit error rates.

Results of this test will be included in the Echo II Final Report.

III. SUMMARY

Operations on the Echo II communication experiments program began on 25 January 1964, with the sixth orbit of Echo II. This was the first pass which entered the mutual visibility zone of Collins and NRL.

From January 25 until February 20 experiments were conducted with an interim system employing optical tracking at the Collins (Dallas) site. After the satellite entered the eclipse, experiments with the interim system were discontinued and the efforts at Collins were concentrated on achieving the full system configuration. Operations with the full system configuration began on April 13th.

Due to technical difficulties with their antenna systems, the Navy Electronics Lab (NEL) at San Diego, has been unable to participate in the experiments. It is anticipated that they will begin participation in early November.

To date, technical problems encountered in conducting these experiments have been of the type normally expected in an operation of this kind. The lack of an auto-track system at NRL required operations at night or when the satellite was optically visible at NRL. However, this constituted an inconvenience more than a technical limitation and has had no discernible effect on the technical quality of the experiments.

Comparison of the look angle predictions for both Echo I and Echo II with actual acquired tracking data indicates that the predictions are normally very accurate, i.e., within a few tenths of a degree at a specified time. On the other hand, there are times when they are grossly in error. It is noticed that the errors change smoothly during the week, which indicates that the errors are not grossly affected by unpredictable orbit perturbations. Even though it has been necessary to correct the NRL program tracking by optical observation, the look angle predictions have been entirely adequate for reliable acquisition (without optical aid), by the Dallas acquisition system. This points out that operational ground stations equipped with a moderate acquisition and tracking capability is preferred to the program type of tracking.

The operational experience also indicates that with a well operating radar acquisition and auto-track system, acquisition, tracking, and communication quickly becomes routine. The occasional unsuccessful acquisitions were largely, if not entirely, due to equipment malfunctions, which are primarily due to the experimental nature of the system design.

After the initial problems were solved, operations became quite routine. For example, as of July 10, 119 passes had been scheduled for experiment with the satellite. Of these 119 scheduled passes, 99 were tracked and data collected, indicating an overall operation efficiency of approximately 85%.

Due to late availability of certain equipment at Collins and the relatively long delay in the data flow, only a limited amount of data has been reduced and analyzed at Collins, Cedar Rapids. However, partial reduction of the data from a few selected Echo I and Echo II orbits has been accomplished. Based on this data it appears that Echo II is performing quite well as a passive communication satellite. It appears that the satellite is essentially spherical in shape with no major signal dropouts or discernible change in average cross-section being observed.

The Received Signal Level Experiment has yielded the most data. Information regarding satellite cross-section; power spectrum of fading; and the distribution of amplitude fading has been obtained.

An overall average satellite cross-section of approximately 30.2 db above a square meter has been observed. This is compared to the theoretical value of 31.2 db - a difference of approximately 1 db which is well within the calibration tolerance of the system.

No periodic variation in the relative power spectrum of the fading has been observed, which is a further indication of no gross distortion in the satellite.

There are no results available at this time from the Signal Level data collected for evaluation of the distribution of amplitude fading.

Results from our Signal Amplitude Correlation Measurements indicate the satellite has a bandwidth of at least 12 mc. This is based on test results yielding on an amplitude correlation of 99.0% ± .5% for two signals spaced 12 megacycles apart.

Additional signal amplitude correlation measurements have been conducted at 70 and 190 mcs. Although data reduction and analysis is not complete, preliminary results indicate a good degree of correlation at 70 mcs separation and somewhat less correlation at 190 mcs separation. This would imply that frequency diversity techniques could be used to some advantage with Echo II. If certain receiving equipment can be made available at NRL, Frequency Diversity Experiments will be conducted later this year to determine just how effective such techniques are.

Phase correlation experiments designed to verify the amplitude correlation (bandwidth) measurements will be conducted during the latter part of this year. This schedule is dictated by the availability of special receiving equipment at NRL.

Several Voice-Music experiments have been performed between Collins and NRL from recordings made here at GSFC. Excellent results have been obtained. However, inherent limitation of the ground system limits the results. A disc recording of one of the experiments is available for demonstration if required. Although the quality of the reproduction is excellent, occasional noise bursts can be heard, due to variations in the received signal. However, reasonable improvements in the ground system capabilities should greatly improve these results.

Very good results have been obtained with our facsimile experiments. This is particularly true in view of the limitation of our ground equipment. These tests will continue, with OSU as the receiving site and NRL providing the data reduction.

While Echo I data from this program is very limited, the indication is that the Echo I satellite is less spherical and more wrinkled than is Echo II. A more detailed comparison between Echo I and Echo II cannot be made at this time due to the limited amount of data collected and analyzed. It is possible to conclude, however, that Echo I still offers a very usable communication medium. Inasmuch as several additional experiments are planned on Echo I during the remainder of the program, it is expected that the more detailed and complete comparison between the two satellites can be made after these tests are completed.

IV. CONCLUSIONS

Based on the data reduced and analyzed as of the date of this report, the following preliminary conclusions can be made:

(1) Operations with the satellite between NRL and Collins have become routine with no significant technical problems being encountered.

(2) Optical tracking requirements at NRL which require operations when the satellite is optically visible, while being an operational inconvenience, presents no technical problem nor does it affect the technical quality of the test results. However, because of the visibility requirements, it is inclined to restrict the amount of data one can collect over a given period of time and points out the need for an auto-track system such as that employed by Collins.

(3) A moderate radar acquisition and auto-track system (similar to that used by Collins in these experiments) is entirely adequate and most desirable for this type of operation with no special orbital information being required in advance.

(4) The orbital data supplied by GSFC on a routine basis is entirely adequate for operations with a passive satellite of this nature. However, because of inescapable acquisition and tracking errors inherent in a program tracking system when used with the Echo type satellite, an auto-track capability is highly desirable for flexible operations.

(5) There has been no apparent change in the effective cross-section of the satellite during the course of these experiments. Data collected and analyzed over an extended period of time since launch indicate an overall average cross-section of approximately 30.2 db. (This is compared to a theoretical cross-section of 31.2 db.)

(6) Data from the signal level measurements reveal no periodic variations in the relative power spectrum of the signal fades. This indicates there are no gross satellite distortions.

(7) There have been no signal dropouts observed (of the type reported by certain of the radar stations) in any of the

radar data at Collins, nor from the bistatic data received by NRL or OSU.

(8) Average scintillations on the order of ±5 db with frequent rapid fades have been observed during these experiments. There has been no discernible change in the character or level of these received signals.

(9) Based on the above, it is concluded that the satellite has met its design requirement for rigidity in spite of the fact that since launch it has been eclipsed by the earth shadow more than 1800 times, experiencing changes in temperature from -115°C to a +90°C.

(10) Signal amplitude correlation measurements indicate a satellite bandwidth of at least 12 mcs.

(11) Preliminary results from additional signal amplitude correlation measurements over, more widely separated frequencies (70 and 190 mcs), indicate frequency diversity techniques may be effective at a frequency separation of approximately 190 mcs.

(12) Excellent results have been obtained from the Voice-Music experiments. Transcriptions demonstrating this experiment are available.

(13) Very good results have been obtained from the facsimile experiments conducted via the satellite. A sample of the results are included in this report.

(14) Limited tests also performed with Echo I indicate that Echo II is considerably superior to Echo I as a communication satellite. However, the results obtained with Echo I are remarkably good in view of its original configuration and its lifetime in orbit. Echo I still offers a very usable communications medium.

(15) There still remains much to be done to complete the Echo II Communication Experiments as scheduled by the end of 1964.

APPENDIX D

MEMO-REVIEW OF USSR REPORTS, 4 June 1964

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

REF: 625-413:AK:cs
DATE: 8 September 1964

TO : Echo II Project Manager
H. L. Eaker

FROM : Communications Satellite Research Branch
A. Kampinsky

SUBJECT: Comments on Experiments with Echo II - Jodrell Bank and Zimenki

Ref : Memo-Review of USSR Reports, 4 June 1964

During August 1963, the undersigned performed calculations for the Jodrell Bank to Zimenki path via Echo II backscatter techniques. The original calculations were based upon assumed values of USSR receiving equipment noise figures, system temperatures, and transmission from Zimenki to Jodrell Bank. These calculations (Appendix I) revealed a 10 db C/N level (maximum) value. When actual USSR equipment data was made available in March 1964, these calculations were repeated for the reverse path from Jodrell Bank to Zimenki, and indicate that a maximum C/N level of 12 db was to be expected in a 1 Kc bandwidth (Appendix II). Both calculations may be interpreted to indicate that the experiment was a marginal one even at the best available C/N levels expected, since no fading margin is permissible.

Examination of the Russian recordings reveals that for most passes the average value of $\left(\frac{P_s + P_n}{P_n}\right)$, as recorded, is no better than 4:1 with maximum values of 12 db for few passes. Where the signals were maximum, scintillation levels were also varying between peak levels down to 0 level (noise level of the system). When compared with monostatic radar records, the Russian data fluctuations exhibit scintillation peaks at least 10 db greater than the lowest frequency radar observation (400 Mc) and those expected at 162 Mc. It should be noted that all radar experiments were conducted on a monostatic look-angle basis, hence no comparable radar records exist for comparison with the communications experiment wherein the best data could be expected for bistatic intercept and look angles of 60° at the balloon. Particularly for rough surface balloon reflections, extrapolation from monostatic to wide angle bistatic observations are meaningless.

The major factors which appear to have degraded the Russian experimental data are as follows:

1. Inaccuracies in pointing Jodrell Bank antenna;
2. Refraction errors;
3. Multipath propagation;
4. Faraday rotation;
5. Extraneous noise.

Inaccuracies in pointing may be judged from Figure 1 - For Jodrell Bank (1.7° beamwidth -3 db points), pointing errors in azimuth or elevation of 1° and 1.5° result in 4.2 and 9.5 db degradation of signal incident on the Echo balloon.

(Pass 6 - 23.02.64, t = T - 20.5, is typical). In addition, if the elevation angle at Jodrell Bank is less than 10^o, refraction errors, shown in Figure 2, must be added to the angular pointing error. For reception at Zimenki, elevation angles average 15^o or less over most passes. For these conditions and since the balloon reradiates omnidirectionally, the Zimenki receiving system can experience extreme scintillations due to multipath reception. (Pass 10 - 25-02-64, t = T-24) Scintillations will provide excursions of +6 db above free space values to complete signal cancellations, as are evident in most passes where the carrier to noise level reaches at least 10 db.

Some passes reporting no change in signal level for deliberate reversal of polarization sense at Zimenki, leads to confusing conclusions; i.e., that Jodrell Bank transmissions behaved as linearly polarized as seen at Zimenki. If the Zimenki antenna were elliptically polarized or circular polarization degraded by ground reflections or poor circuit phasing, decoupling between transmission signals and reception over the entire path may be estimated from Figure 3. Faraday rotation at 162 Mc for the two way path is given approximately:

$$\theta \text{ max} \approx 1600^o \text{ rotation, } 0^o \text{ elevation}$$
$$\theta \text{ min} \approx 80^o \text{ rotation, } 90^o \text{ elevation}$$

When applied to Figure 3, these decoupling losses must be added to the tracking error losses, refraction losses and multipath scintillations.

It may be noted in the Russian calculations, that the cosmic noise temperature T_k was cited as 200^oK. Their text however indicates that considerable variation in external noise was evident as the Zimenki antenna system swept through the areas where the galactic "hot spots" exist. From existing sources T_k can be expected to range from 400^oK to perhaps 1000^oK at the galactic center at 162 Mc.

In the calculations, Appendix II, a galaxy noise temperature of 450^oK was employed. The total effect in received carrier to noise levels, when compared to Russian calculations, will differ by approximately 3 db.

In summary, the recorded data for the Zimenki-Jodrell Bank tests are not directly comparable to the results of monostatic, multi-frequency radar observations. Whereas most radar systems permit dynamic recordings of 60 db, the Russian data rarely exceeds 15 db; hence peak scintillation levels are lost in signal saturation. In addition, the minimum detector noise levels are also variable. This Echo II experiment is characterized by cumulative degradations which appear as combination of degradations in most of the data, whereas, under controlled conditions, such effects may be deduced if allowed to occur singly. The data, overall, is characterized by scintillation levels at least 10 db greater than can be extrapolated from radar signature data at higher frequencies.

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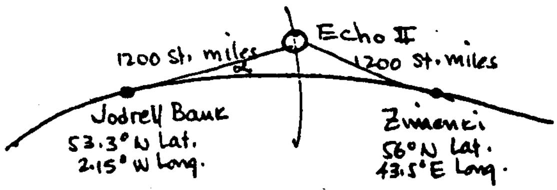
Enclosures:
Figures 1-3
Appendix I and II

Appendix I   Jodrell Bank – Zimenki

Aug. 63



Echo II   135 ft. DIA
$\sigma = 31.2$ db / M^2
$\alpha = 60°$ max.

Assumptions: Zimenki Transmits 3kw, 162 Mc., ANT. (50 ft. dia) Gain 25.7db
Jodrell Bank Receives, Estimated Circuitry   Beam 8.6°

0.3db loss – Antenna System Temp. TR = 673°K
5.7db loss – Preamplifier   NF = 3.5db (360°K)
G = 20db
Receiver   NF = 9db (2010°K)

ANT. (250 ft. dia.) Gain 39.5db, Beamwidth 1.7°

SYSTEM PERFORMANCE

Space Loss	–247db
Pt (3KW)	34.8dbW
Gt (50')	25.7db
GR (250')	39.5 db
Carrier Level	– 147 dbW

TR = 673°K
TG = Galactic Noise 450°K
Ts = Total System Noise (1123°K)   30.5 db
Noise Power Density   –228.6 dbW/Mc.
– 198.1 dbW / Mc.

Bandwidth:
for 100KC   50.0db,   Noise Level = – 148.1 dbW
10KC   40.0db,   Noise level = – 158.1 dbW

Carrier/NOISE
100 KC   –148.1 + 147 = 1db
10 KC   –158.1 + 147 = 10db.

10 KC BW is marginal for straight FM RECEIVER.

10 March 1964

Appendix II Jodrell Bank – Zimenki

Assumptions: Jodrell Bank Transmits 1KW, 162.4 Mc.
Zimenki Receives, Circuit Data (RUSSIAN DATA)

$T_R = 423°K$ ANTENNA SYSTEM TEMP.
$L_1 = 0.3db$
Paramplifier NF = 3.5db.
G = 20db.
$L_3 = 3.0db$
Receiver NF = 5.3db (700°K)

Total System Temperature $T_S = T_R + T_G$ = 423°K + 450°K
T_S = 873°K

SYSTEM PERFORMANCE

Space loss (2400 mi)	−245.3 db.
P_t (1KW)	30.0 dbw
G_t (250')	39.5 db.
G_R (45')	24.8 db.
Carrier Level	−151. dbw

Total System Noise T_S (873°K)	29.42 db.
Noise Power Density	−228.6 dbW/Mc.
Noise Power	−199.18 dbw/Mc.
Bandwidth (1KC)	30.0
Noise Level	−169.18 dbw in 1KC Bandwidth

Carrier/NOISE (1KC) −169.18 − 151 = 18.18 db
Receiver Threshold 6db 6.00 db
Carrier/NOISE (1KC) 12.18 db margin

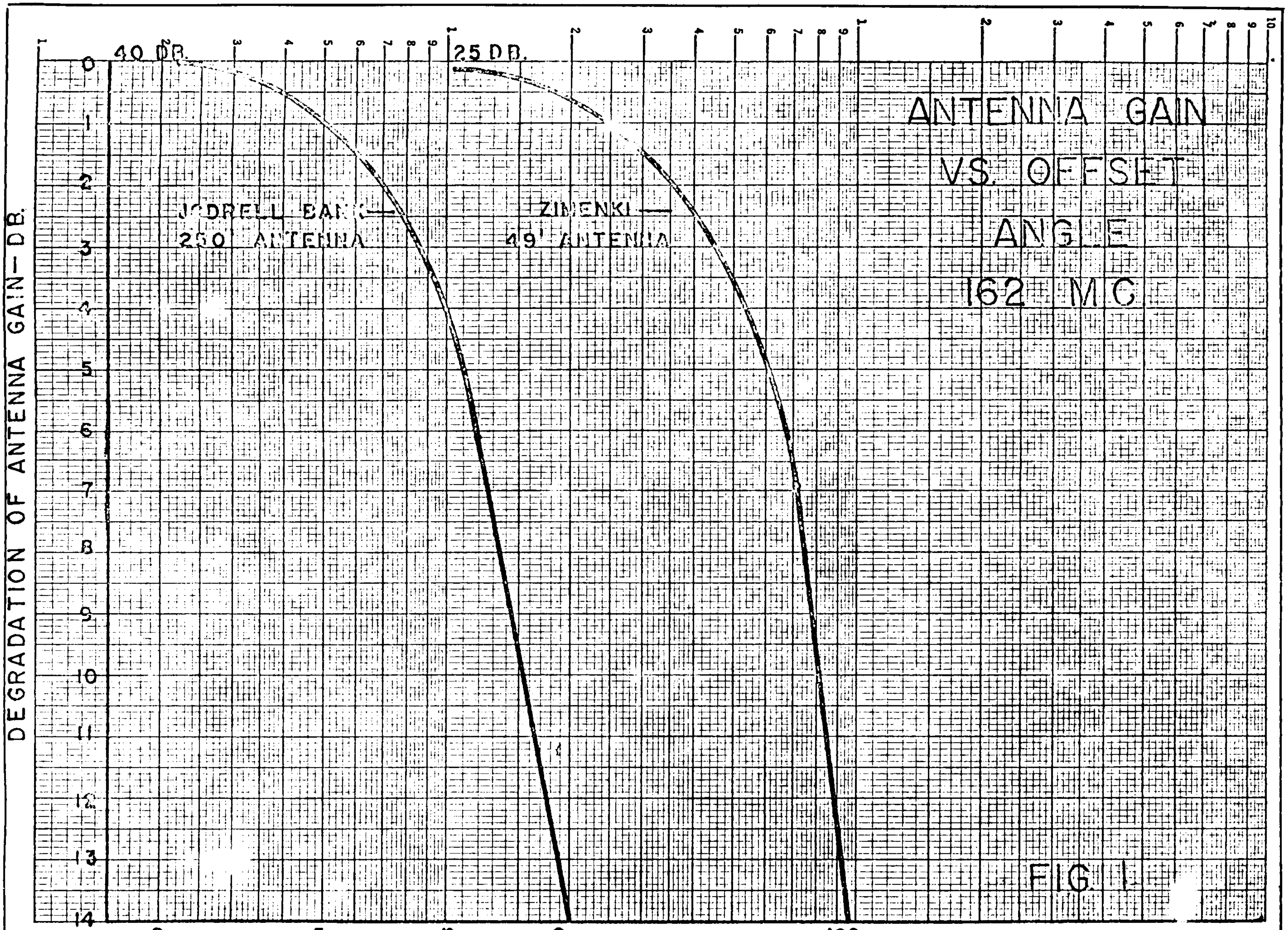
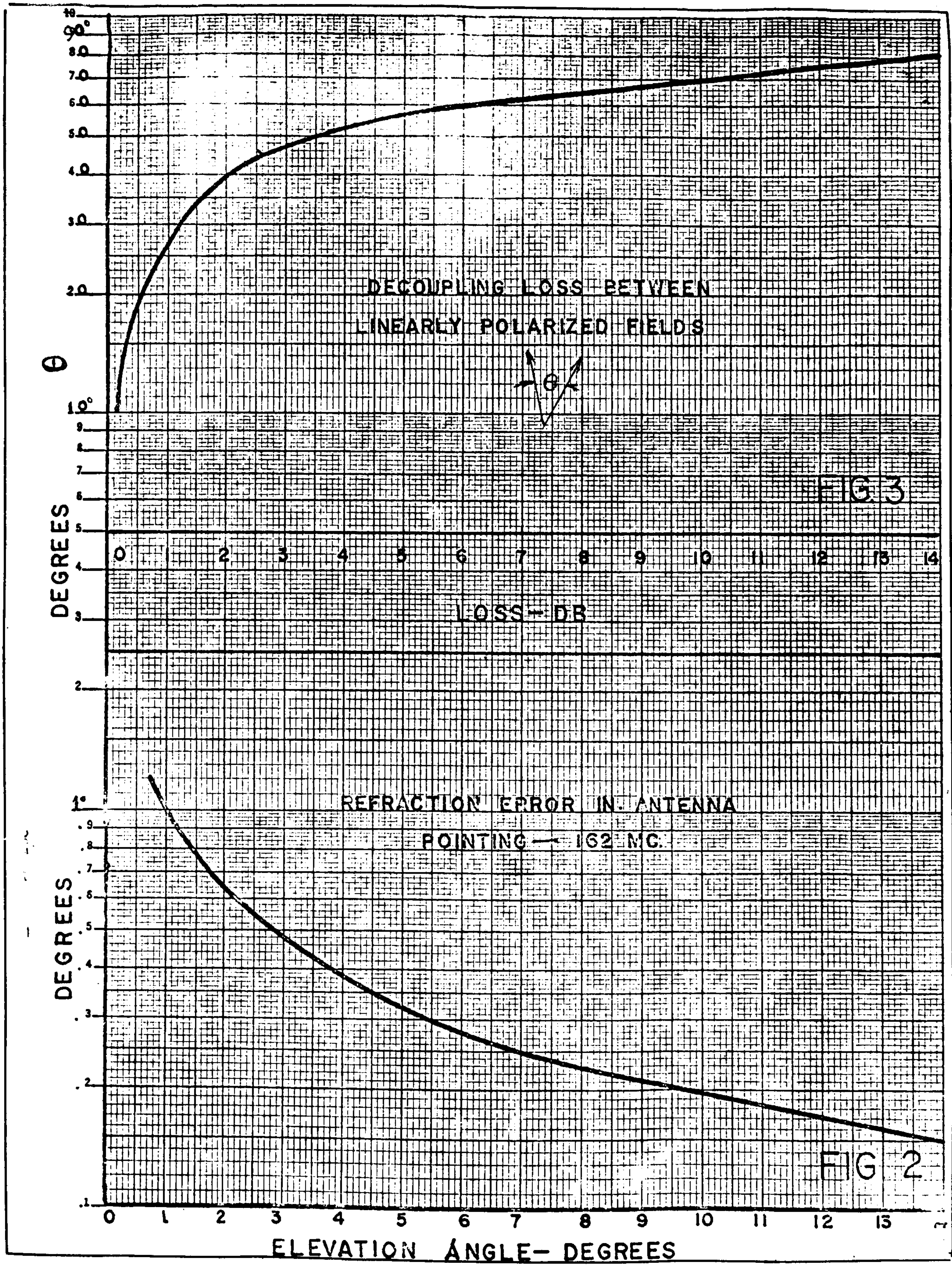

ANTENNA GAIN
VS. OFFSET
ANGLE
162 MC
40 DB.
25 DB.
JODRELL BANK
250' ANTENNA
ZIMENKI
49' ANTENNA
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
.2
.5
1°
2
10°
DEGRADATION OF ANTENNA GAIN-DB.
ANTENNA POINTING ERROR-DEGREES

FIG. 1

A&P SECT.


DECOUPLING LOSS BETWEEN
LINEARLY POLARIZED FIELDS
θ
DEGREES
LOSS — DB
FIG 3
REFRACTION ERROR IN ANTENNA
POINTING — 162 MC.
DEGREES
FIG 2
ELEVATION ANGLE — DEGREES