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UNDERWATER SOUND PROPAGATION IN THE STRAITS OF FLORIDA: THE MIMI CONTINUOUS AND SAMPLED RECEPTIONS OF 11, 12, AND 13 AUGUST 1966

by

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ABSTRACT

As a part of a study of underwater sound propagation in the Straits of Florida, called Project MIMI, 24-hour continuous and sampled receptions were taken on 11, 12, and 13 August 1966. The amplitude modulation of the 420-Hz carrier wave by a maximal pseudo-random sequence (AMSEQ), simultaneously yields information about the oceanic modulation of the carrier (continuous wave analysis), and the multipath sound propagation (sequence analysis). This report describes the experiment and the data processing and presents the results in photographic form as amplitude and phase versus time displays.

FOREWORD

The MIMI mid-August 1966 test is one of a series of propagation experiments at 420 Hz. It was designed with two specific objectives, both aimed at improving future long duration experiments. The first objective was to determine if AMSEQ is a useful signal. AMSEQ divides the power between the carrier, which can be analyzed in the same manner as the CW used in present MIMI long duration experiments, and the sidebands which are used to determine the multipath structure. The second objective was to determine if a 5% sampling, of six minutes every two hours, would yield a reasonably complete description of the multipath structure and its changes. Other subsidiary objectives were to develop and test the automatic scheduling equipment at transmitting and receiving sites used for running "sampled" tests, and to refine the computer processing techniques. In addition a considerable collection of processed multipath results would be available for future detailed analysis, if desired.

The test was certainly successful in meeting all objectives. The following are the conclusions related to future MIMI experiments.

(1) The AMSEQ transmission is useful. However, in addition to the carrier and multipath analysis presently used, it would be valuable to include a spectral analysis of the multipath results. Spectral analysis will require a higher signal-to-noise ratio than multipath analysis, and hence will demand the use of more processing gain.

(2) The six minute every two hours sampling is inadequate to follow the detail of the multipath changes. One minute every ten would be better. However, if it can be developed, continuous AMSEQ transmission and selective analysis at intervals depending upon the actual rate of path structure change would be best.

(3) The automatic transmission and recording worked satisfactorily, with one minor problem in the transmitter.

ACKNOWLEDGEMENTS

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The stimulating support by the Sponsor, Acoustics Programs, Code 468 of the Office of Naval Research, made possible the present development in the MIMI Project.

The enthusiastic and skillful work by members of the Acoustics Group of the Institute of Marine Sciences (IMS), The University of Miami, and in particular by J. Loewenstein and T. Crabtree, on transmission and reception, implemented the success of the experiment.

In the organization of the Stochastic Signal Processing Program, Cooley Electronics Laboratory (CEL), The University of Michigan, the outline for the experiment and data processing were given by the project director, Dr. T. G. Birdsall, R. Veenkant and Paula Kanarek designed the computer program, N. Hatter built the circuitry for photographic recording. R. Unger, together with the IMS members mentioned above, performed the actual experiment and supervised the overall data-processing.

The authors would like to express their special gratitude to B. Lastinger and the personnel in the CEL Reports Office for the careful processing and assemblage of the large amount of photographic results and for the drawing of the illustrations.

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1. INTRODUCTION

A study of underwater sound propagation in the Straits of Florida and its relation to environmental circumstances, the project nicknamed "MIMI," is a joint effort by the Acoustics Group, Institute of Marine Sciences (IMS), The University of Miami, and the Stochastic Signal Processing Program, Cooley Electronics Laboratory (CEL), The University of Michigan. A series of experiments were made and the results reported in publications of IMS and CEL, and in articles in the Journal of the Acoustical Society of America (Ref. 1), and in Symposia on Underwater Acoustics (Ref. 2).

Most of the experiments consist of a 420-Hz continuous wave transmission (CW) from a sound source off Miami (MIMI-A), and the phase-coherent on-line demodulation (PCD) of the signals received by deep and shallow hydrophones off Bimini, Bahamas (MIMI-B). Environmental measurements are correlated with the amplitude and phase of the demodulated signal. The CW transmission power with an applied transducer voltage of 1000 V is at a level of approximately 95 dbμb referenced to one meter. The expanse of the Straits is 43 nautical miles; the maximum depth is 800 meters.

The long term CW experiments are occasionally combined with transmission of a maximal pseudo-random sequence (SEQ) modulated onto the 420-Hz carrier to probe multi-path sound propagation. While the instrumentation of all tests and the processing of the long term CW experiments are done by the IMS Acoustics Group, the signal design and data processing of combined CW/SEQ tests are done by CEL (MIMI-C), using correlation techniques with The University of Michigan's IBM 7090 computer. A prior report (Ref. 3) describes the MIMI experiment of 3 and 4 February 1965 using CW on/off (CW 25/5) and bi-phase modulating sequence (BMSEQ) transmission.

Another CW/SEQ experiment was conducted on 11, 12, and 13 August 1966, using amplitude modulating sequence (AMSEQ) transmission. The AMSEQ signal enables the simultaneous processing of CW and SEQ signals. The experiment consists of a 24-hour continuous transmission and reception, and a 24-hour "sampling" test in which periods of

6 minutes of reception were recorded every 2 hours. The basic processing system as described in Ref. 3 was improved in efficiency by buffering the computer program and by 5-bit analog to digital recording. A method was developed for coherent processing of all data.

This report describes the 24-hour AMSEQ experiments and the improvements in data processing and presents the CW and SEQ analysis results in photographic form.

2. THE 24-HOUR AMSEQ EXPERIMENTS: TRANSMISSION AND RECEPTION

2.1 Transmission at MIMI-A: AMSEQ

The amplitude modulated pseudo-random sequence transmission is described by the signal

$$s_a(t) = \frac{1}{2}[1 + m(t)] \cos \omega_0 t \qquad (2.1)$$

where

$s_a(t)$ = transmitted signal in AMSEQ transmission

$m(t)$ = biphase pseudo-random sequence (BMSEQ)

ω_0 = $2\pi f_0$

f_0 = 420-Hz carrier frequency

$\frac{1}{2}[1 + m(t)]$ = amplitude modulation of the carrier (AMSEQ)

The biphase pseudo-random sequence (Refs. 3 and 4) is a periodic pulse pattern, each period consisting of 63 digits, 32 "plus ones" and 31 "minus ones." One period of sequence is 1.2 sec; each digit has a duration of eight carrier cycles, i.e., $\frac{1}{52.5}$ sec = $19\frac{1}{21}$ msec. The 420-Hz sine wave and the 52.5-Hz clock frequency are coherently derived from the MIMI-A 1680-Hz precision oscillator.

From Eq. 2.1 it follows that AMSEQ, $\frac{1}{2}[1 + m(t)]$, consists of 63 digits, 32 ones and 31 zeros. Where BMSEQ transmission

$$s_b(t) = m(t) \cos \omega_0 t, \qquad m(t) = \pm 1 \qquad (2.2)$$

contains approximately the same power as CW transmission,

$$s_c(t) = \cos \omega_0 t \qquad (2.3)$$

the AMSEQ modulation causes a loss of approximately 3 db transmission power, since 31 out of the 63 sequence digits turn the carrier signal off.

Writing Eq. 2.1 as

$$s_a(t) = \underbrace{\frac{1}{2} \cos \omega_0 t}_{CW} + \underbrace{\frac{1}{2} m(t) \cos \omega_0 t}_{BMSEQ} \qquad (2.4)$$

it may be seen that the AMSEQ transmission power is equally distributed over the signals CW and BMSEQ. Thus, by applying CW analysis and SEQ analysis as described in Ref. 3, it is possible to obtain simultaneously information about the low frequency modulation of the carrier by the ocean and about the multipath sound propagation. Since in AMSEQ both signals, CW and BMSEQ, appear with one-half the amplitude, the processing results are 6 db less compared with processing either CW, or BMSEQ signals as in the February 1965 experiment. Furthermore, the sound source has deteriorated, now transmitting at a level of only 95 dbμb instead of the original 103 dbμb. Thus, in comparing the signal strength of processed data in the August 1966 with that of the February 1965 experiment, a total loss of 14 db has to be taken into account.

2.2 Reception at MIMI-B

The reception techniques used in this experiment are essentially the same as described in Ref. 3. Summarizing, the received signal is amplified, filtered in a fixed filter with a passband of 370 Hz to 470 Hz, and recorded onto analog tape by means of an SP 300 4-track analog tape recorder, in this experiment, at a speed of $1 \frac{7}{8}$ ips. The signals were received by two shallow hydrophones only. The reference signal from the 1680-Hz precision oscillator at MIMI-B was recorded on channels 1 and 4, the signal from the A-3 hydrophone on channel 3, and the signal from the D-2 hydrophone on channel 2 (Fig. 1). Also, the signal from the A-3 hydrophone was phase coherently demodulated and the resulting amplitude R(t) and phase angle θ (t), together with the filtered, non-demodulated A-3 signal, were recorded on a Sanborn graphic recorder. In this recorder the "raw" signal is rectified, low-pass filtered, and scaled logarithmically, the recording giving an impression of the power level of the received noise in the 370- Hz to 470-Hz band. The signal R(t) is also scaled logarithmically. Both the phase coherent demodulator (PCD) at MIMI-B,

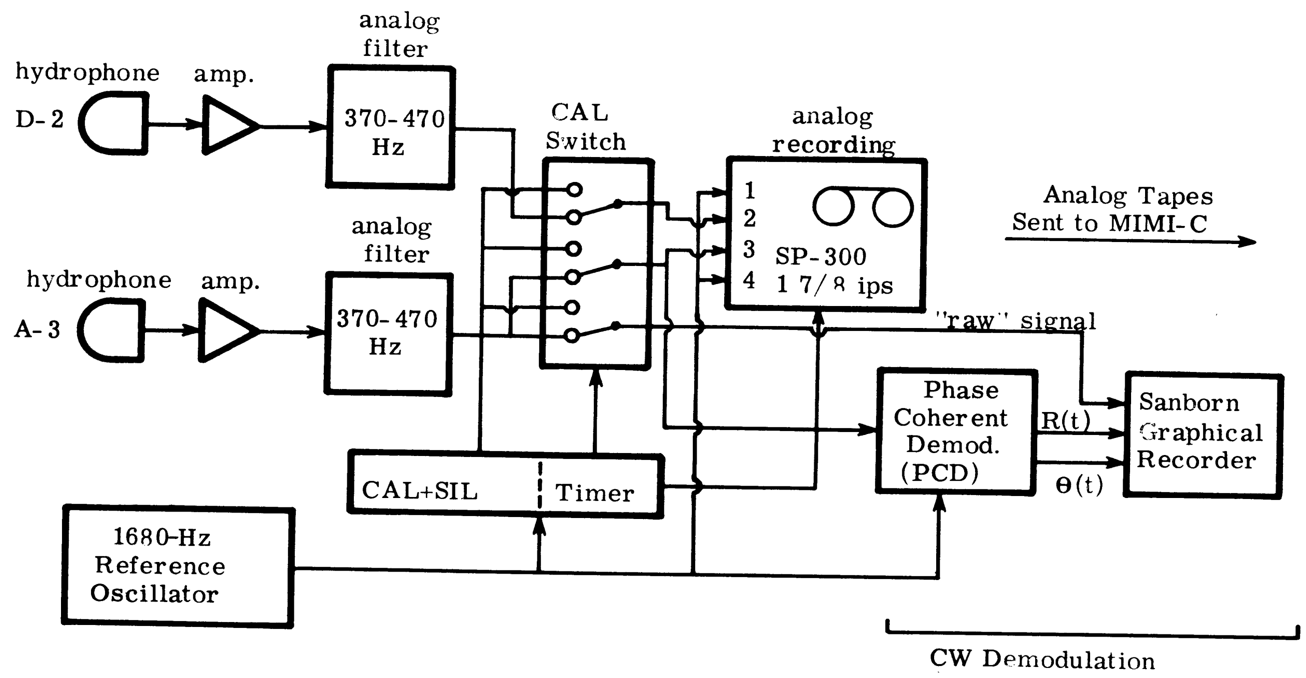


Fig. 1. Reception at MIMI-B

and the processing at MIMI-C use the 1680-Hz reference signal from the MIMI-B precision oscillator. Phases and delays thus find their reference at reception rather than at transmission. The reference oscillators at transmission and at reception have a stability of about one part in 10^{10}.

To provide for coherent processing at MIMI-C, calibration tones (CAL) were inserted periodically in the analog recordings. CAL is a 420-Hz noise free sine wave, the amplitude for the present experiment corresponding to a -25 dbμb hydrophone reception, and has a duration of $39 \frac{1}{105}$ sec. CAL is followed by a period of zero signal or "silence" (SIL) of $19 \frac{1}{21}$ msec, the duration of one sequence digit.

In the 24-hour continuous reception the format CAL + SIL was recorded every 12 minutes, starting at the beginning of each analog tape. The tapes were stopped after 4 hours and 24 minutes of on-line recording, each tape reel containing 21 complete 12-minute files plus an extra 6 minutes of recording including CAL + SIL. Tape reels were changed in the remaining 6 minutes of the 22nd file.

In the 24-hour sampled test, the analog recording was started every two hours, beginning with the CAL + SIL format, and stopped after 6 minutes. The recording of this test thus contains twelve 6-minute samples or files, each starting with the CAL + SIL format.

The derivation of the 420-Hz CAL tone, the durations of CAL and of SIL, and all timing involved in programming the SP 300 recorder were coherently derived from the 1680-Hz reference oscillator by means of logic countdown circuitry.

3. THE DATA PROCESSING SYSTEM AT MIMI-C

As mentioned in Sec. 1, the system used to process the large amount of data acquired in this experiment is an improved version of the data processing system described in Ref. 3. Computer time was reduced to a minimum by using a 5-bit input and by buffering the program so that several functions could be performed simultaneously. Coherent processing of the entire data was made possible by using the specific calibration tone format recorded on the analog tape. Execution time of the program equals the reading time of the 5-bit input tapes recorded at a speed of 8 times the analog recording speed. Thus, 24 hours of analog data requires essentially three hours of continuous processing in the IBM 7090 computer. However, additional time is required, mainly for tape-hanging.

The changes in the computer program implied changes in some of the logic circuitry for analog to digital (A-D) recording, and improvements were made in the circuitry for photographing the CW and SEQ analysis results. Referring to Chapter III of Ref. 3 as the basic description for the present data processing system, these changes and improvements are explained in the following sections. Figure 2 gives a block diagram of the data processing system.

The data of the 24-hour sampled test, 12 August 1403 hours to 13 August 1209 hours, and the "continuous" data received from 11 August 1345 hours to 12 August 0139 hours were processed 10-bit; 5-bit processing was applied to the data of 12 August 0139 hours to 1239 hours. Due to a processing error, the remaining data, 12 August 1239 hours to 1345 hours, was deleted. The change from 10-bit to 5-bit computer input does not affect the essence of the processing method applied. The system, therefore, is described in its most recent form, i. e., with 5-bit input.

3.1 5-Bit Computer Input

In a test run of 3 February 1965 data in which the low order 5-bit of the regular 10-bit input were ANDed off to simulate a 5-bit input, it was found that the results of processing this 5-bit input were within 3 percent of being equal to the results of processing the 10-bit

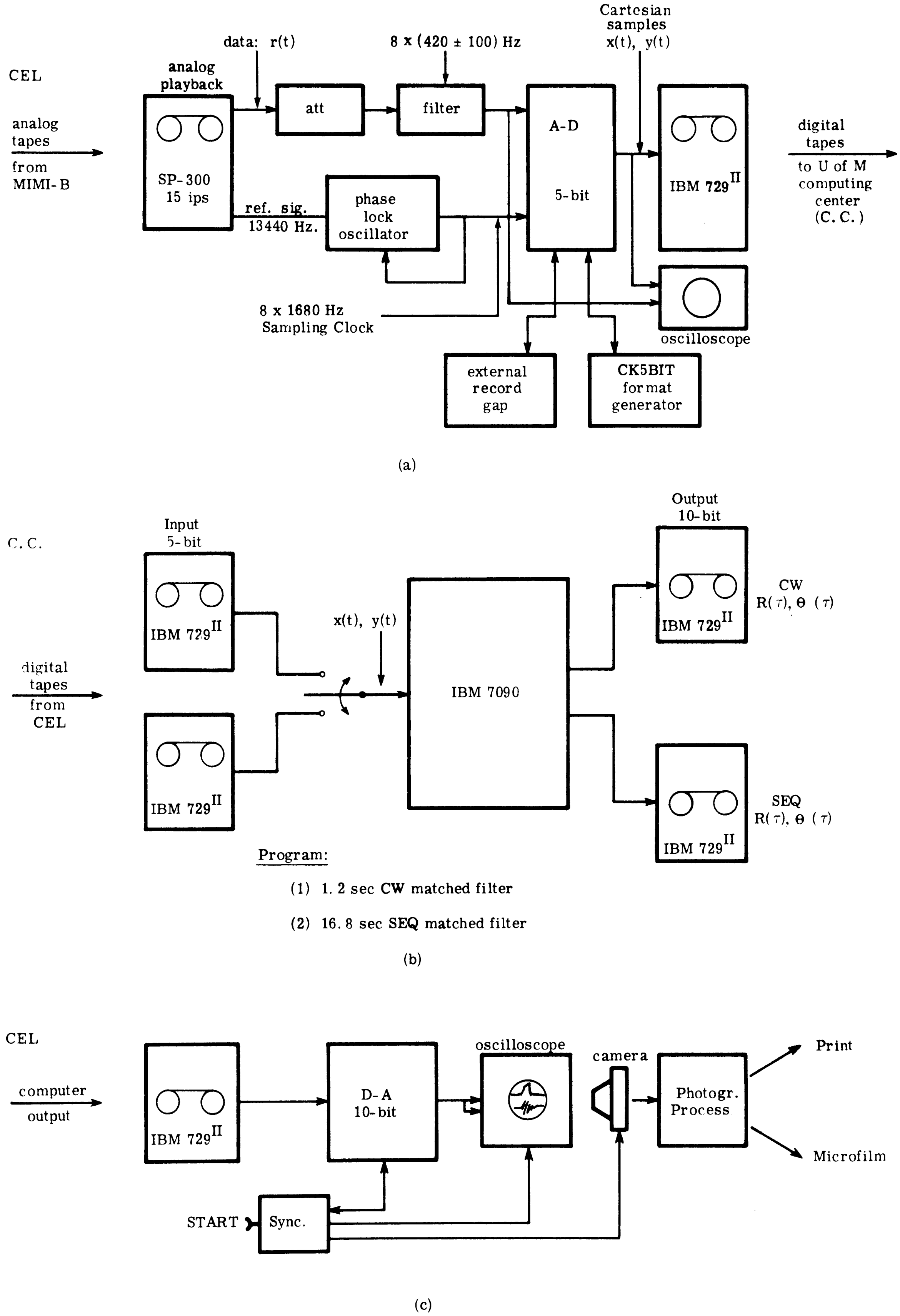


Fig. 2. Block diagram of the data processing system

input. Both cases are shown in photographic form in Fig. 3; there is no visual difference. Since a 5-bit tape contains twice as much data as a 10-bit tape, the reading time for a certain amount of input data can be halved. Together with the possibility of buffering the computer program, this means a reduction of the total program execution time by a factor of two. In order to detect byte errors caused by the difference between the MIMI writing frequency and the standard IBM LD (low density) writing frequency, the sixth data track of the digital tape was used to record a special checking format. (Secs. 3.2.2 and 3.3.4.)

3.2 Analog Recording to Digital Recording

3.2.1 General Block Diagram. Figure 2(a) gives the block diagram for the analog to digital (A-D) recording system. The analog tapes are played back at a speed of $8 \times 1\frac{7}{8}$ ips = 15 ips. The output of channel 3 of the SP 300 is filtered in a Kronhite filter with a passband set at 8 x (420 ± 100) Hz to minimize instrumentation noise, and is attenuated in a calibrated attenuator so that only occasional clipping of the analog signal occurs in the A-D conversion. The attenuation applied was usually 8db; in some high level noise records it was increased to 14 db. The 1680-Hz reference frequency recorded simultaneously with the data, now played back as 13,440 Hz, is used to clock the sampling in the A-D converter. Together with the use of the phase-lock oscillator, a sampling rate of exactly 4 times carrier frequency is obtained.

3.2.2 5-Bit Digital Recording, CK5BIT Format. In 5-bit A-D conversion the originally bipolar analog signal is described unipolarly by 32 voltage levels recorded as binary codes representing the decimal numbers 0, 32, 64, ..., 1023. The sixth available bit (the lowest order bit) of the A-D converter output is disconnected from the tape unit format generator and is replaced by the output of the CK5BIT format generator, a periodic 1 1 1 0 0 0 format fitting the 36-bit IBM word. (Sec. 3.3.4.)

The CK5BIT format is generated in a 6-stage shift register pulsed by the A-D converter "output data clock" (Fig. 4). Each moment a "write command" occurs, pulses from these clock pulses shift around the initially set contents 1 1 1 0 0 0 of the shift registers. The output of the fourth stage is written directly onto the sixth track of the digital tape. During header and record gap, of 1 and 31 IBM word lengths respectively, no format is recorded.

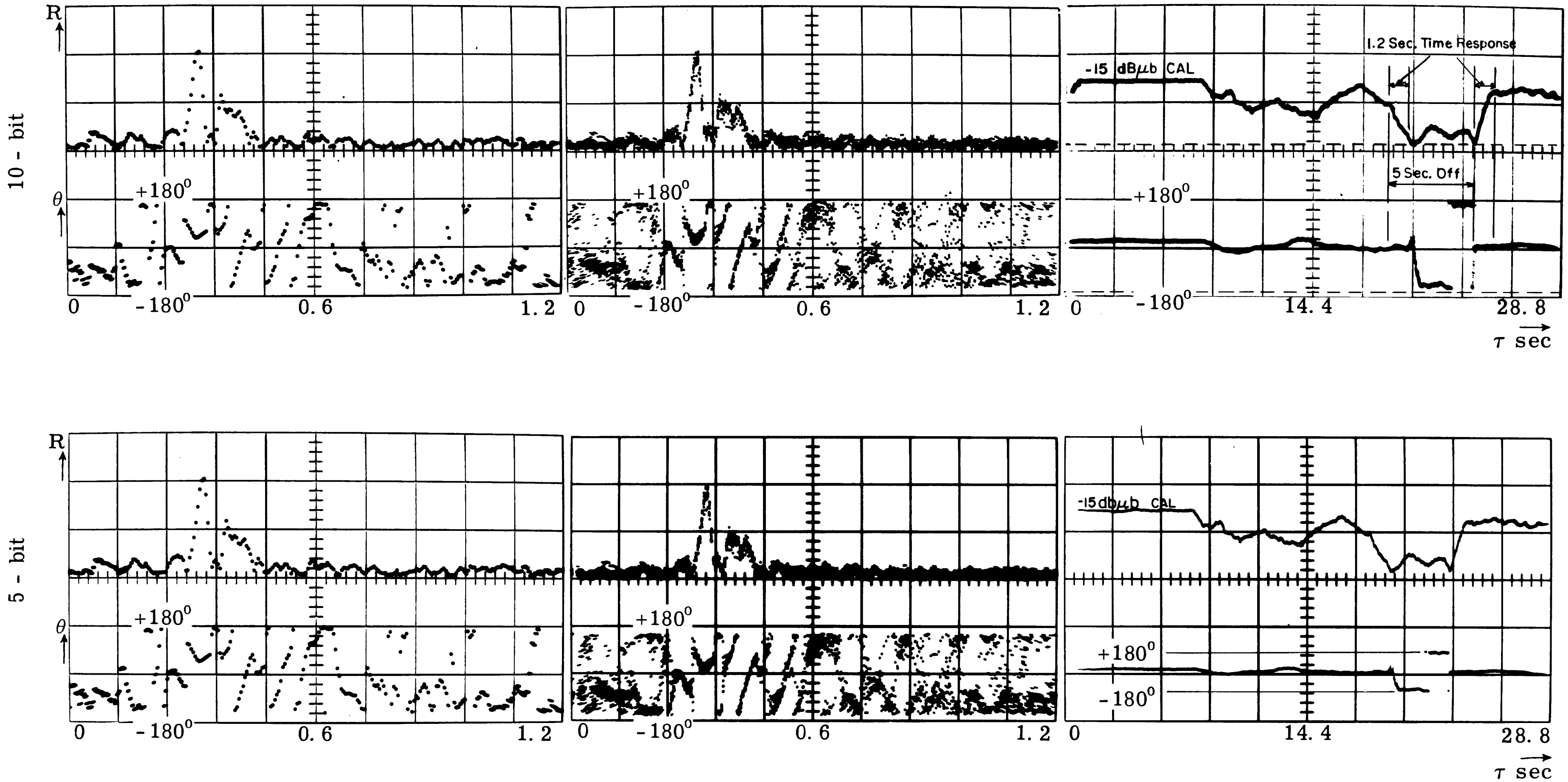
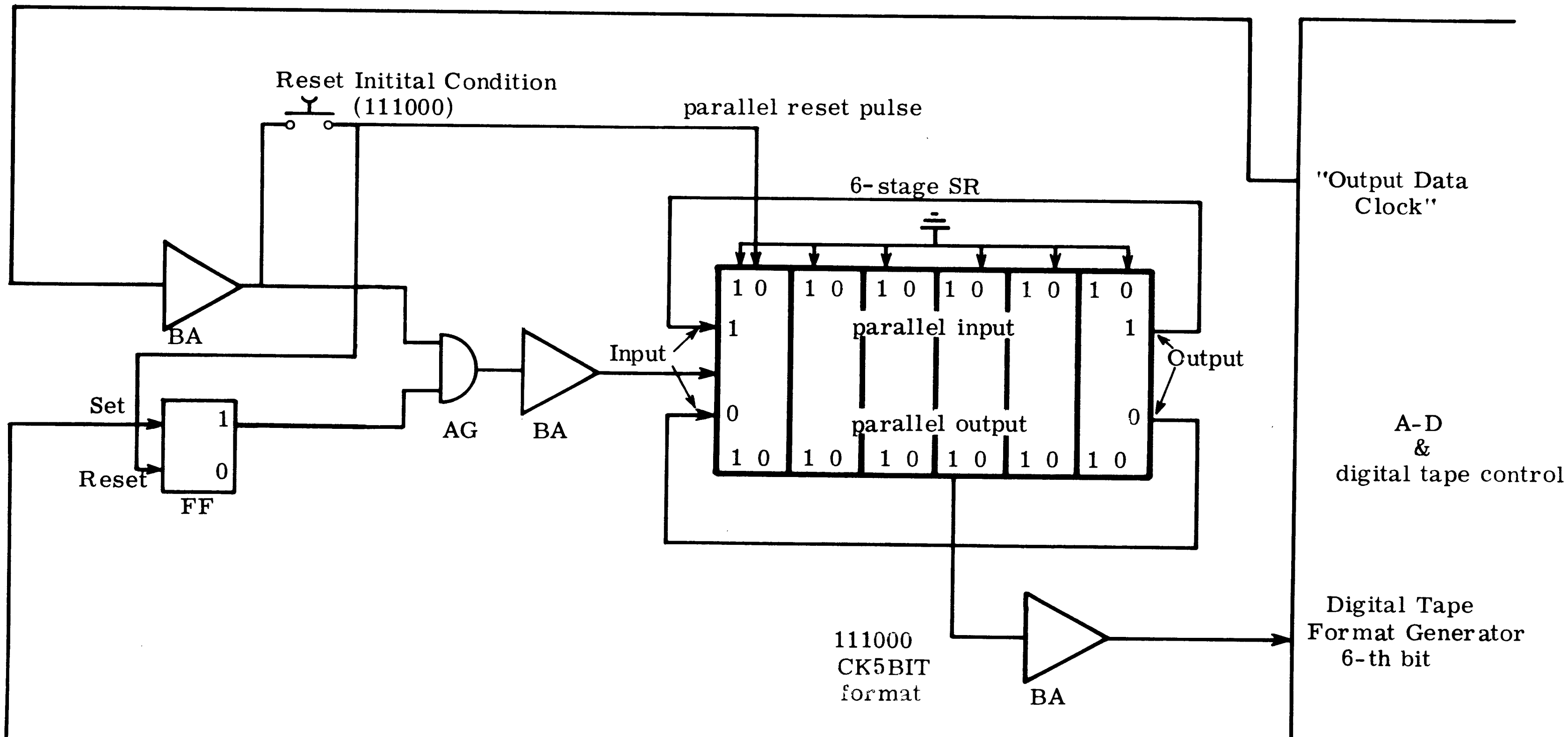


Fig. 3. Five- and ten-bit processed data BMSEQ, 3 February 1965 1445-1450 hours, see Ref. 3



Key: FF = flip-flop
AG = AND gate
BA = buffer amplifier
SR = shift register

Fig. 4. CK5BIT format generator

3.2.3 Analog and Digital Recording Format. A detail of the analog recording format is given in Fig. 5. For the 24-hour continuous reception, the format consists of 12-minute files of analog data starting with $39\frac{1}{105}$ sec CAL and $19\frac{1}{21}$ msec SIL (Sec. 2.2). The length of the digital records was chosen as fifteen 1.2-sec periods, or 18 sec of analog recording. Forty such records, separated by an externally timed record gap in which 186 bytes or samples (111 msec of analog data) are consistently omitted from each record, form one file. The digital recordings are started such that CAL + SIL end in the second record and the last record ends with the beginning of CAL from the next file. With the 8 times speed-up in playing back the analog data, the digital LD recording of one file takes $1\frac{1}{2}$ minutes. Since the LD recording time of a complete digital tape is a little over 6 minutes, four files could be recorded on one tape.

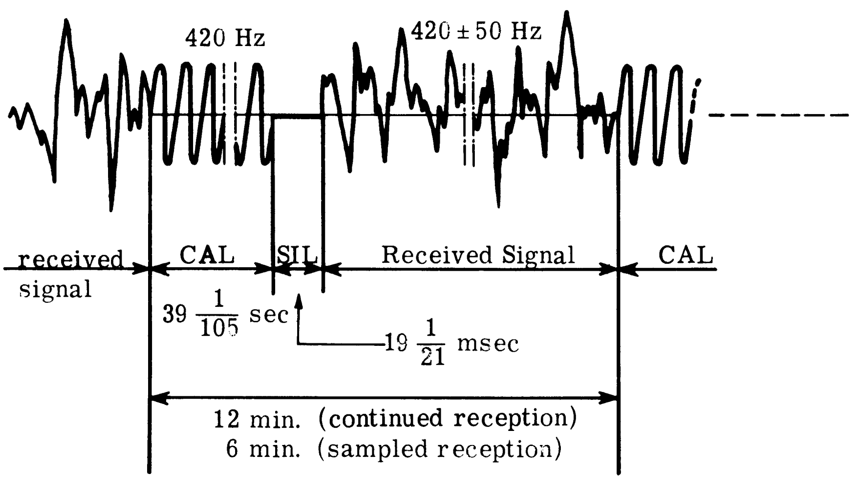


Fig. 5. Detail of analog recording

The analog recordings of the 24-hour sampled reception have essentially the same format, however, with a duration of 6 minutes per file. Each file contains twenty 18-sec records; eight files were recorded on one digital tape.

3.3 The Computer Program

The program used to process the digitally recorded data consists of a main program written in MAD, calling the UMAP subroutines as described in Ref. 3. "Buffering," the simultaneous performance of processing and the operations writing and reading tape, lowers the execution time to the actual LD reading time of the 5-bit input tapes. The following sections give a summary of the essential subroutines and the adaptations made, and describe the coherent processing method, the buffering process, and the 5-bit checkbyte (CK5BIT) routine. The flow diagram of Fig. 6 illustrates the text.

3.3.1 Summary of and Adaptations in the Essential Subroutines. The essential subroutines are PRES5, CW1, CIRAV, MCOR1, POLAR, and JR1PAC. PRES5, the 5-bit adaptation of CMPRES, completes the phase coherent digital demodulation into the low-pass Cartesian components x(t) and y(t) from the received signal described by the equation

$$\begin{aligned} r(t) &= R(t)\cos[\omega_0 t - \theta(t)] \\ &= x(t)\cos\omega_0 t + y(t)\sin\omega_0 t \end{aligned} \qquad (3.1)$$

The digital data is compressed by a factor of 4, the output returning one Cartesian sample pair per two carrier cycles ($\frac{1}{210}$ sec) from the original two sample pairs per cycle.

In CW analysis the data is exposed to a 1.2-sec correlation with, or filter matched to, CW transmission. In this process the data, by means of a sliding averaging procedure, is added over 1.2-sec periods, each time displacing the summation interval an amount $\Delta\tau = \frac{1}{210}$ sec. The output consists of 3504 Cartesian pairs $[\phi x(\tau), \phi y(\tau)]$. Because of the 1.2-sec initial summation and the 111-msec record gap, a 16.7-sec output is returned from each 18-sec input record.

In SEQ analysis the data is coherently averaged over fourteen 1.2-sec periods by means of CIRAV, and the resulting 1.2-sec period correlated with a stored version of BMSEQ in MCOR1. As shown in Sec. 2.1, the AMSEQ signal consists of equal parts of CW and BMSEQ. The last 1.2-sec period of each 18-sec input record is omitted in SEQ analysis. The process is a 16.8-sec correlation between the received modulation and BMSEQ, or a 16.8-sec filter matched to BMSEQ. The 1.2-sec output is described by 252 pairs $[\phi_x(\tau), \phi_y(\tau)]$.

The Cartesian outputs of CW1 and MCOR1 are converted into the polar amplitude and phase values $R(\tau)$ and $\theta(\tau)$ by means of the routine POLAR. In JR1PAC the R-values are scaled down by a factor of 2^6 to enable 10-bit packing onto the digital output tapes and

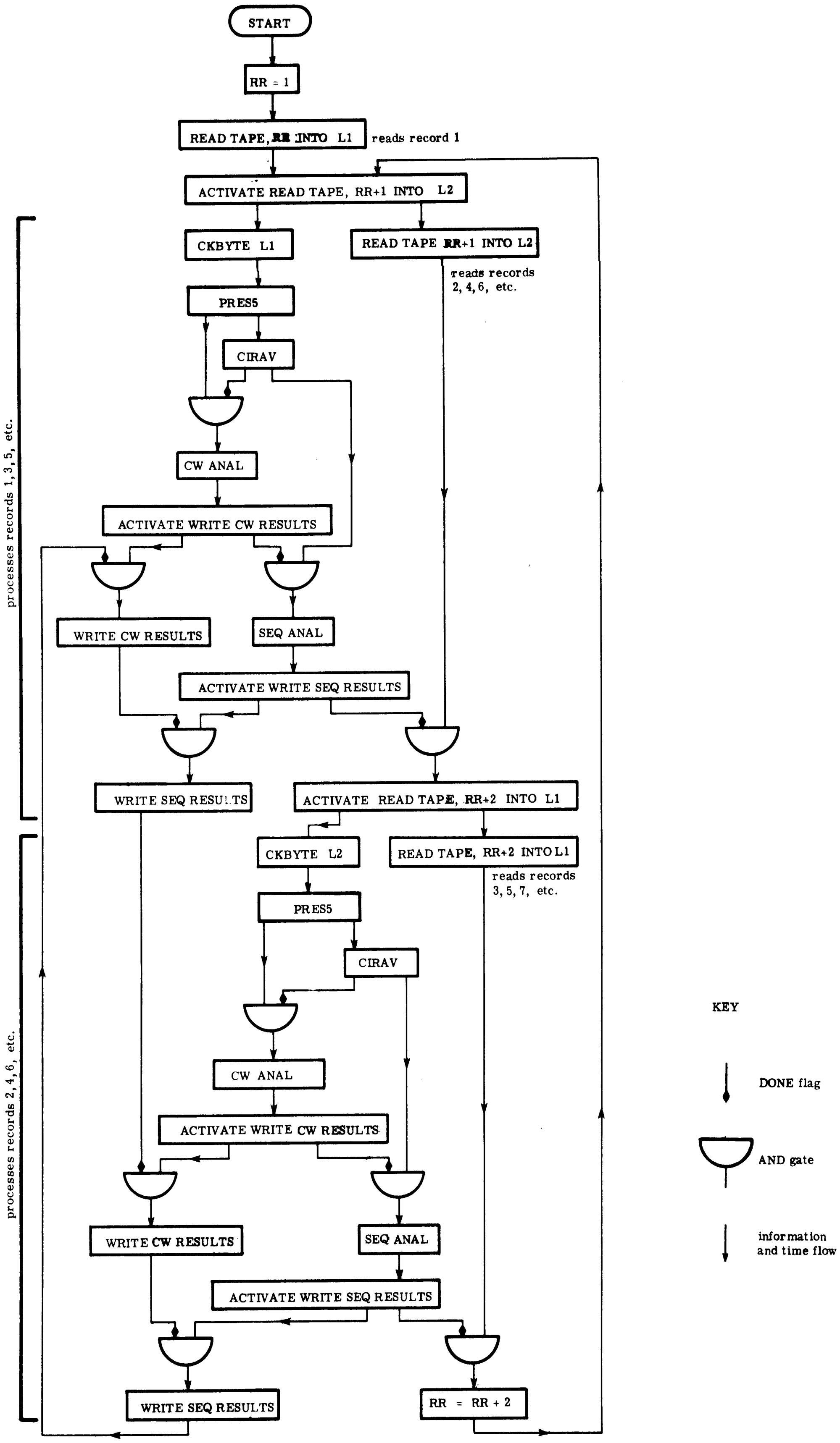


Fig. 6. Computer program flow diagram

display of the results through the D-A converter.

Comparing this processing system with that of Ref. 3, the essential changes are:

(1) 5-bit input

(2) 18-sec input records

(3) 16.7-sec output from 1.2-sec CW matched filter

(4) CIRAV over fourteen 1.2-sec periods

(5) 16.8-sec cross correlation between stored BMSEQ and received AMSEQ + noise

3.3.2 Coherent Processing Method. Coherent processing through all files is achieved by use of the CAL + SIL format. In the first record of each file, POLAR is called immediately after PRES5, yielding amplitude and phase of the unaveraged CAL. In the second record, when the value of the amplitude drops below half of its original value, CAL is considered to be ended. The number K of compressed CAL samples thus present in the second record is compared to a reference number K_0, and the difference, $\Delta K = K - K_0$, is divided by 252, the number of samples in one 1.2-sec CIRAV period. The remainder of this quotient, $\Delta K - n252$, is the number of samples that each CIRAV period has to be rotated in order to line up the correlation peaks obtained from different files. Coherency of records within a file is obtained by omitting, during the record gaps, a consistent number of samples which represents an integer number of carrier cycles. The phase angle of the CAL tone, θ_{CAL}, is compared to a reference $\theta = 0$, and the difference $\Delta\theta = \theta_{CAL}$ is algebraically added to each of the 252 output digits from SEQ analysis. Where necessary, 360^o is added to or subtracted from the new phase values such that $-180^o \leq \theta(\tau) < 180^o$. An attempt to correct the CW analysis phase output resulted in 360^o phase jumps between records which unfortunately were discovered only after completion of the entire processing.

3.3.3 Buffering and Tape Hanging Procedures. The flow diagram in Fig. 6 shows the buffering method applied. After the first record has been read into list 1, the reading of the second record into list 2 is started. While the first record is being processed and the results written on tape, the second record is read in. Within the processing of the first record another buffering process is applied by writing CW results while doing SEQ analysis. Next, the third record is read into list 1 while the second record is being processed, etc. Thus, complete processing of one record is being done during the reading of the next record. Execution time of the computer program, therefore, essentially equals the reading time of the LD tapes, 6 minutes per tape.

Because of the time absorbing tape-hanging process a special procedure was followed in cooperation with the computer operator. Two input tape units were used and addressed alternately in the program. At a pause sign occurring at the end of the tape the operator can have the computer continue immediately and thereafter change tapes on the unit previously used.

Standard processing procedure uses an input of ten 5-bit LD tapes covering 8 hours of analog data, and requires a reading time of 1 hour. One SEQ and two CW output tapes are needed; the total computer time is roughly 1 hour and 15 minutes for such an input.

3.3.4 Correction for Byte-Errors (CK5BIT). As mentioned in Ref. 3, the writing frequency used in MIMI digital recordings, 13,440 bytes per sec, does not exactly match the IBM standard LD writing frequency of 15,000 bytes per second. Although the MIMI frequency is within the permissible range, synchronization may not be perfect. While reading the data into the computer, either erroneously inserted bytes result because of anomalies on the tape, or actual bytes are omitted. Although this will not destroy the samples as in the 10-bit input of 2-bytes per sample, it will lead to interchange of x and y values in PRES5 and, consequently, cause 90° phase shifts within records, thus disabling appropriate averaging procedures.

By using the periodic 1 1 1 0 0 0 format recorded on the low order track 6 of the digital tape, "dropped" or "added" bytes can be detected and the data corrected. This is illustrated in the following examples:

									dropped byte			
bit number	6	12	18	24	30	36	6	12	18	24	30	36
input word	1	1	1	0	0	0	1	1	0	0	0	1
AND with	0	0	0	1	1	1	0	0	0	1	1	1
result	0	0	0	0	0	0	0	0	0	0	0	1
	correct IBM word						dropped byte indication					

							added byte					
bit number	6	12	18	24	30	36	6	12	18	24	30	36
input word	1	1	1	0	0	0	0 or 1	1	1	1	0	0
AND with	0	0	0	1	1	1	0	0	0	1	1	1
result	0	0	0	0	0	0	0	0	0	1	0	0
	correct IBM word						added byte indication					

Each input word is AND-ed with a word containing the format 0 0 0 1 1 1, the complement of the format recorded in the bits 6, 12, ..., 36. In the case of no byte error the resulting word will show all zero's in these bits; a dropped byte results in a 1 in the 36th bit, and an added byte results in a 24th bit. Errors located in other bits result in the same indications, either in the word where the error took place or in the next word.

To correct the input list, a fake byte of zero's is inserted in the case of a dropped byte or a byte is omitted in the case of an added byte, and the entire list is shifted accordingly. Because of the averaging procedures involved, the processing results are not affected by this correction method.

CK5BIT is called only in case of a parity-error; the routine quits when detecting more than 5 byte-errors in a record. The checking results "not called," "no byte error," "corrected byte error," or "too many byte errors" are indicated in the program printout in coded form.

3.4 Photographic Recording of the Results

The results of CW and SEQ analysis are played back via 10-bit D-A conversion, essentially as described in Ref. 3, Sec. 3.5.

The CW results are displayed and photographed as continuous traces of 8 or 10 R, θ-record pairs, one record pair per cm, using an external time base designed for this purpose (Fig. 7). The external sweep is obtained by adding a staircase signal to a sawtooth signal. The staircase voltage is generated by proportional summing of the flip-flop outputs from the record counter. Constant voltage increments occur every two records (one R, θ record pair). The sawtooth signal is formed by charging a capacitor in an RC circuit with large time constant during a record display. At the end of a record the capacitor is discharged immediately by a transistor shorting circuit activated by the "record gap" signal.

The sequence results were photographed both as single and as multiple exposures, using the digital time base (Ref. 3) for time consistent reproduction of the $252R(\tau)$ and $252\theta(\tau)$ output "dots". The photographic recording was facilitated by the design of logic circuitry for continuous triggering of D-A converter and camera shutter (Fig. 8). SEQ multiple exposures, series of SEQ single exposures, and CW multirecord exposures are taken automatically after a single pushbutton activation.

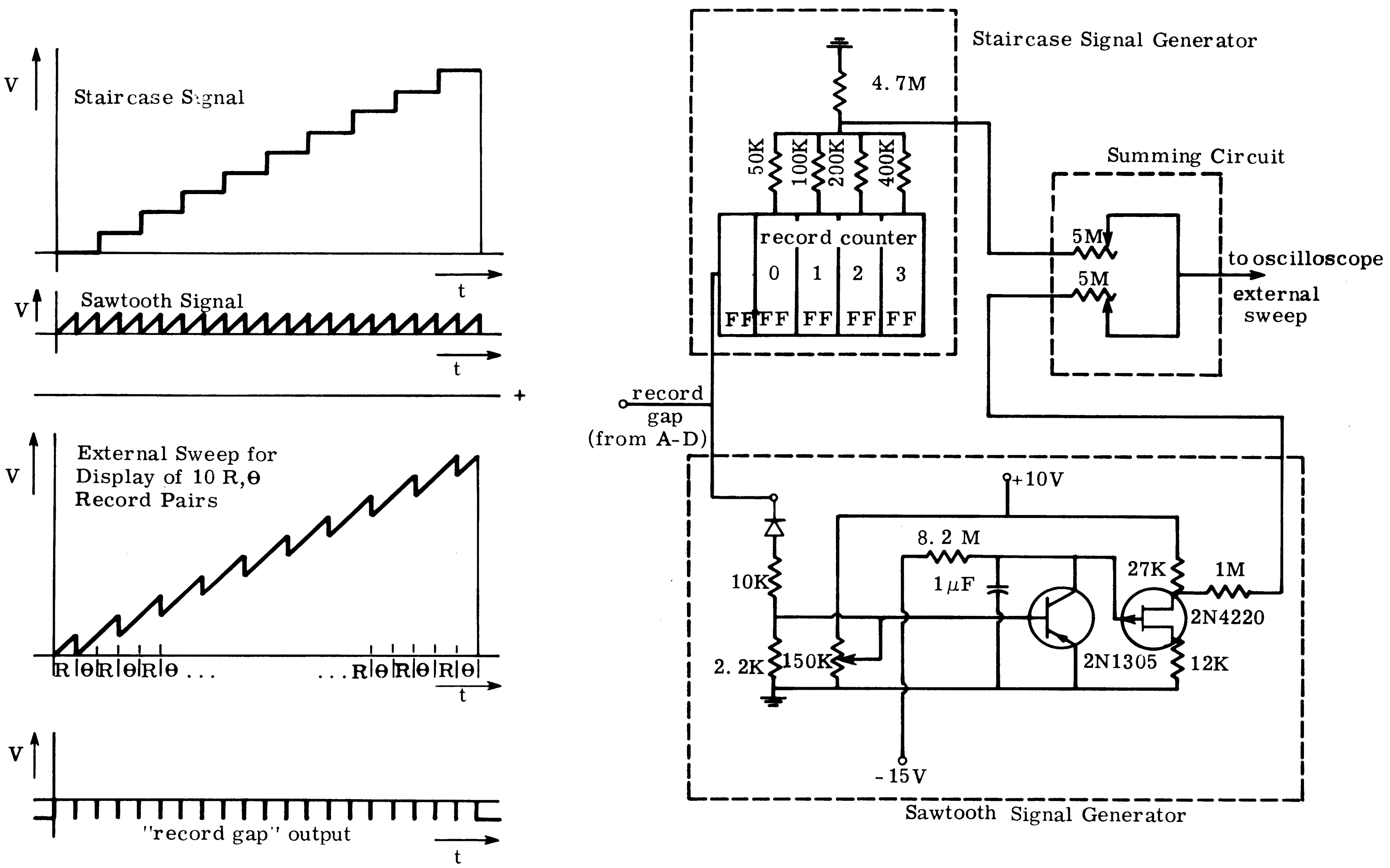
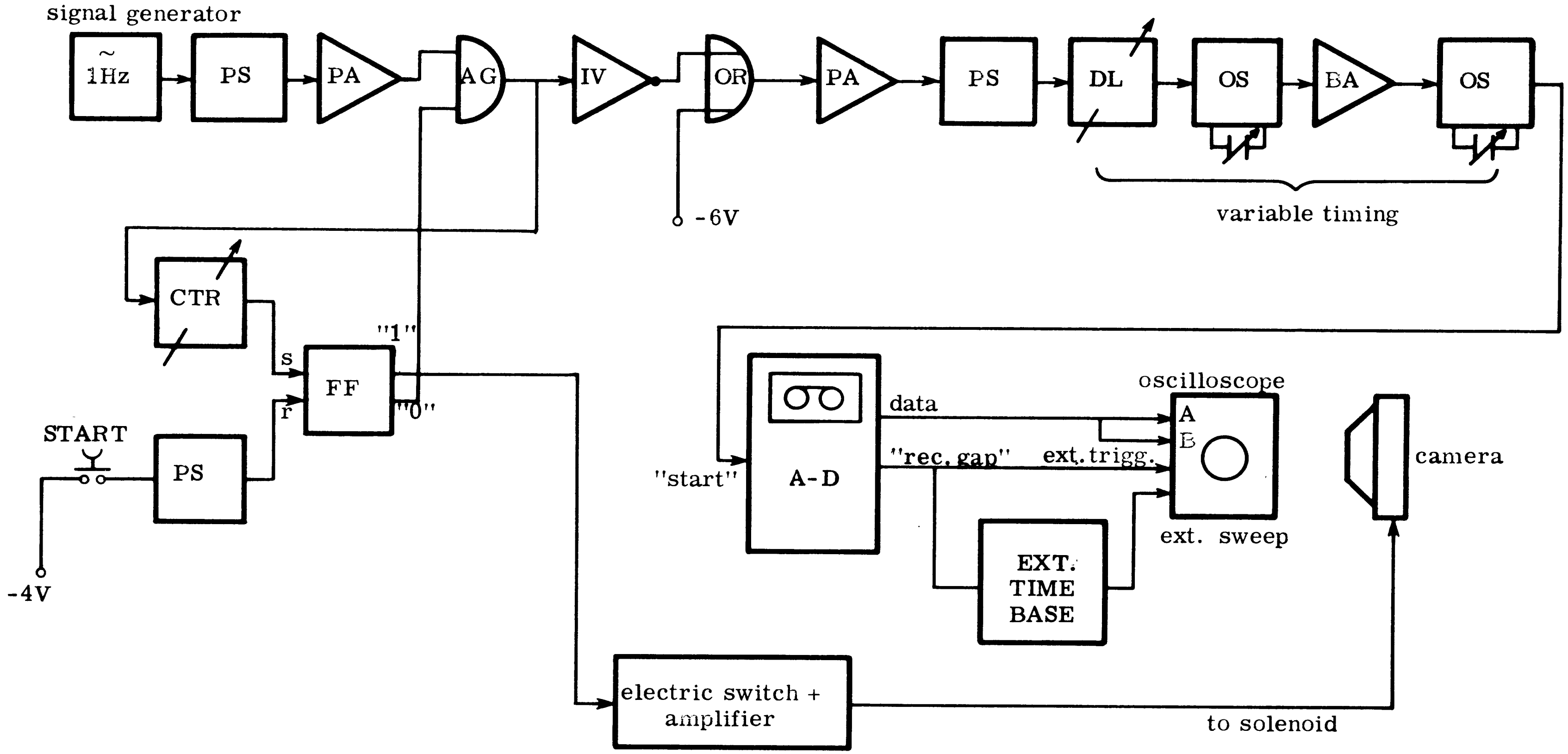


Fig. 7. Time base for CW multi-record oscilloscope display



KEY

PS = pulse standardizer	CTR = counter (presets number of records to be displayed)		
PA = pulse amplifier	FF = flip-flop	BA = buffer amplifier	
AG = AND gate	OR = OR gate	OS = one shot	
	DL = delay		

Fig. 8. Photographic recording circuit

4. CORRELATION AND FREQUENCY CHARACTERISTICS

This section describes some of the mathematical and physical consequences and considerations of the transmitted signal and the applied data processing system. Section 4.1 discusses the effects of the correlation performed in SEQ analysis. The frequency characteristics of transmitted signal and processing system are described in Secs. 4.2 through 4.4, using the derivations from Ref. 3, Chapter IV. As stated in this reference, the frequency band centered at the 420-Hz carrier frequency can be transferred to d.c. and back again. Appendix D contains the photographic results of correlations and frequency-analyses on simulated noisefree, single-path data. The frequency characteristics were obtained by the program "FAST" based on Tukey's Fourier Series Analysis (Ref. 5).

4.1 AMSEQ-BMSEQ Cross-Correlation

The result of cross-correlating the AMSEQ signal consisting of 32 "one" digits and 31 "zero" digits, with the BMSEQ signal consisting of 32 "plus one" digits and 31 "minus one digits," differs from the BMSEQ autocorrelation only in peak magnitude and in d.c. level. Both of the correlations result in a two-digit wide triangular peak per 1.2-sec period. In the BMSEQ autocorrelation, both the positive and the negative values contribute to the correlation values; in the AMSEQ-BMSEQ cross-correlation only the "one" digits contribute. Therefore, the BMSEQ autocorrelation results in a peak with magnitude 63 and a d.c. value of -1 outside the peak interval; the result of the AMSEQ-BMSEQ correlation is a peak with magnitude 32 and zero value outside the peak interval. In both correlations the resulting phase angle is zero during the peak interval. Outside this interval the phase angle is 180° for BMSEQ autocorrelation and is, since $\phi_x(\tau) = 0$ and $\phi_v(\tau) = 0$, undetermined in the AMSEQ-BMSEQ correlation. In the latter, therefore, the phase angle outside the peak interval is determined by the remaining noise values and is uniformly scattered over the range $-180^{\circ} \leq \theta(\tau) < 180^{\circ}$.

The difference in d.c. level is also shown in the AMSEQ and BMSEQ frequency characteristics. The spectral lines at d. c. (or 420 Hz) are plus and minus 18 db respectively, taking the value $\left|\frac{\sin x}{x}\right| = 1$ for $x = 0$ as a 0 db reference. Cross-correlation of AMSEQ and BMSEQ results in a $\left|\frac{\sin x}{x}\right|$ magnitude spectrum valid for all x.

4.2 AMSEQ Frequency Characteristic

As shown in Sec. 2.1, the AMSEQ signal can be considered as consisting of the signals CW and BMSEQ, both with equal amplitudes and power. The normalized AMSEQ magnitude spectrum, therefore, is that of the BMSEQ signal except for a difference in magnitude of the spectral line at 420 Hz (or d. c.). Because carrier power equals sideband power, the power density at 420 Hz (or d. c., $x = 0$) is 63 watts/Hz in the $\left(\frac{\sin x}{x}\right)^2$ spectrum. In the $\left|\frac{\sin x}{x}\right|$ AMSEQ magnitude spectrum, the spectral line at d. c. or carrier is $\sqrt{63}$ volts/Hz, i. e., + 18 db.

Summarizing, the AMSEQ magnitude spectrum is given by

$$A(x) = \left|\frac{\sin x}{x}\right| \quad \text{for } x \neq 0$$

and because most of the sideband power passes through the 63-line frequency band between -4db points,

$$|A(0)| = \sqrt{63} \tag{4.1}$$

where

$|A(x)|$ = magnitude in the AMSEQ spectrum

$x = \frac{\pi f}{f_c}$

$f = \pm k\Delta f$

$\Delta f = \frac{1}{1.2}$ Hz

$k = 0, 1, 2, \ldots$

f_c = clock frequency of the sequence generator = 52.5 Hz

4.3 Processing Characteristics and Signal-to-Noise Ratio Gain

The frequency characteristics of the subroutines used in the data processing system are basically described in Ref. 3. This section gives a summary of these characteristics as applied in the present processing.

The routine PRES5 does not have a significant influence because the bandwidth of the main lobe is wider than that of the analog fixed filter at reception. The CW1 program is a 1.2-sec filter matched to the modulation (equal to 1) in CW transmission. In combination with the analog filter and PRES5 it forms a narrowband filter centered at carrier frequency. The effective bandwidth, measured between -4 db points, is $\frac{1}{1.2}$ Hz = 0.83 Hz.

The CIRAV characteristic has its main lobes at frequency intervals of $\frac{1}{1.2}$ Hz, coinciding with the spectral lines of the 63-digit maximal pseudo-random sequence. The effective bandwidth of the main lobes is determined by the number N of averaged 1.2-sec periods. In the present processing this number is N = 14, resulting in an effective bandwidth of $\frac{1}{16.8}$ Hz = 0.06 Hz around the sequence spectral lines.

The MCOR1 characteristic is described by the magnitude spectrum of BMSEQ. It is a $\left|\frac{\sin x}{x}\right|$ spectrum and the d.c. magnitude (at x = 0) is 18 db less than the max value $\left|\frac{\sin x}{x}\right| = 1$. Together with CIRAV it forms a 16.8-sec filter matched to the bi-phase sequence modulation.

The signal-to-noise ratio gain in CW analysis is in the order of 24 db; in sequence analysis, 36 db.

4.4 System Characteristics

The system of transmission, ocean, reception, and processing is pictured as 3 successive filters. The uncertain characteristics of transducer, ocean, and reception are combined in one filter with frequency characteristic or transfer function O(f). The transfer function of AMSEQ is indicated as A(f), that of the BMSEQ matched filter as B*(f).

In a linear system the total transfer function is obtained by multiplication of the transfer functions of the components, in which process the sequence of multiplication may be changed. Therefore, if we could assume O(f) to be linear, the total transfer function would become

$$
\begin{aligned}
H(f) &= A(f)O(f)B^*(f) \\
&= O(f)A(f)B^*(f) \qquad (4.2)
\end{aligned}
$$

where

$H(f)$ = total transfer function

$A(f)$ = AMSEQ transfer function

$B^*(f)$ = complex conjugate of $B(f)$

$B(f)$ = BMSEQ transfer function

The complex conjugate of the BMSEQ transfer function is a consequence of the matched filtering process.

The product of $A(f)$ and $B^*(f)$ is the $\left|\frac{\sin x}{x}\right|^2$ spectrum, $x = \frac{\pi f}{f_c}$, in which the line at $x = 0$ has a magnitude of 1. Thus, if a linear system can be assumed between transmitted signal and processing, then the influence of this transmitted signal and the processing system in the propagation analysis is known and is given by the transfer function

$$A(f)B^*(f) = \left|\frac{\sin \frac{\pi f}{f_c}}{\frac{\pi f}{f_c}}\right|^2 \tag{4.3}$$

The total transfer function thus becomes

$$H(f) = O(f)\left|\frac{\sin \frac{\pi f}{f_c}}{\frac{\pi f}{f_c}}\right|^2 \tag{4.4}$$

5. RESULTS

5.1 Summary of Experiment and Processing

A 63-digit maximal pseudo-random "on-off" sequence with a period of 1.2 sec is used to amplitude modulate the 420-Hz carrier wave transmitted at MIMI-A. After propagation through the Straits of Florida the signal, buried in noise, is received at MIMI-B, at a distance of 43 nautical miles. The signal is amplified, filtered with a fixed pass band of 100 Hz centered at carrier frequency, and recorded on analog tape, together with a 1680-Hz reference sine wave from the MIMI-B precision oscillator. The 420-Hz carrier is derived from the 1680-Hz MIMI-A precision oscillator. Since both oscillators have a stability of about one part in 10^{10}, they are considered to be frequency coherent.

At MIMI-C the analog data is sampled at a rate of 4 times carrier frequency using the recorded reference as a sampling clock. The received signal, expressed as

$$r(t) = R(t)\cos[\omega_0 t - \theta(t)] \tag{5.1}$$

is, by means of this sampling and the PRES5 routine, demodulated digitally into the low pass Cartesian components x(t) and y(t), 252 values per 1.2-sec period for each component. This method of demodulation, and the subsequent separate processing on x- and y-components preserve both the amplitude and the phase information. In this process the data is split into 18-sec input records.

Since AMSEQ = CW + BMSEQ, continuous wave and sequence analysis can be performed simultaneously. CW analysis yields information about the low frequency modulation of the 420-Hz carrier by the ocean, sequence analysis probes the multipath sound propagation.

In CW analysis, a 1.2-sec filter is matched to CW transmission, and the data is averaged over 1.2-sec periods, displacing each period in time in 252 steps, $\Delta\tau = \frac{1.2}{252}$ sec $= \frac{1}{210}$ sec. The Cartesian results, 3504 values $\phi_x(\tau)$ and 3504 values $\phi_y(\tau)$, are converted into polar coordinates, $R(\tau)$ and $\theta(\tau)$, the amplitude and phase of the CW matched filter output or the low frequency modulation of the carrier wave. The effective bandwidth (the pass band between -4 db points) of this CW filter is 0.83 Hz centered at carrier frequency. The signal-to-noise ratio gain is in the order of 24 db. The output is displayed on the oscilloscope as a continuous trace of 8 or 10 record pairs, 1 record pair per cm. Each 18-sec input results in a 16.7-sec output; thus, in the display the time displacement per cm is τ = 16.7 sec/cm.

In sequence analysis the 16.8-sec filter matched to BMSEQ is obtained by coherent averaging, over fourteen 1.2-sec periods, the 252 x- and 252 y- samples from each period in CIRAV. The resulting periods are correlated with the digitally stored version of the 63-digit bi-phase sequence, the time displacement τ ranging from 0 to 1.2 sec in 252 steps, $\Delta\tau = \frac{1}{210}$ sec. The resulting 252 Cartesian pairs $[\phi_x(\tau), \phi_y(\tau)]$ are converted into the polar coordinates $R(\tau)$ and $\phi(\tau)$, the amplitude and phase of the BMSEQ matched filter output. The cross-correlation of AMSEQ and BMSEQ results in a triangular peak described by 8 output dots; the correlation function outside the peak interval is zero. A 1.2-sec output is obtained from each 18-sec input; τ = 120 msec/cm on the oscilloscope screen. The display is photographed as single exposures and as multiple exposures of 7 to 10 (R, θ)-record pairs per frame.

The frequency characteristic of the sequence analysis is a $\left|\frac{\sin x}{x}\right|$ spectrum with spectral zero's at ±52.5 Hz. The effective bandwidth around the spectral lines, determined by the CIRAV routine, is 0.06 Hz. In AMSEQ the d. c. (or carrier) magnitude is 18 db more, in BMSEQ 18 db less than the value $\left|\frac{\sin x}{x}\right| = 1$ for $x = 0$. Applying a BMSEQ matched filter to an AMSEQ signal thus results in a $\left|\frac{\sin x}{x}\right|^2$ power density spectrum valid for all frequencies. The signal-to-noise ratio gain in sequence analysis is in the order of 36 db.

Coherent processing of all data is obtained by means of inserted coherent calibration signals in the analog recording derived from the 1680-Hz MIMI-B reference oscillator.

5.2 Presentation of the Results

The 24-hour continuous reception of 11 and 12 August is divided into coherent 12-minute files, each file being processed as 40 coherent digital input records. In the 24-hour sampled test of 12 and 13 August, 6-minute reception samples were recorded on analog tape every two hours, and the total of these samples processed as 12 coherent files of 20 coherent input records each. Because the first two records of a file are used only for processing-coherency, and mainly consist of CAL-tone, they are in general omitted from the output. In the CW results these records were maintained in the "sampled" test, and in the "continuous" test until 1800 hours.

The results of the 24-hour continuous test are presented in sets of four CW and four SEQ pictures, printed together as one 12-minute file per page, in Appendix A. The results of the sampled test are printed as two CW and two SEQ pictures per 6-minute file, 2 files per page, in Appendix B. In the CW output the last record shows the -25 dbμb CAL tone. Because of the large quantity of processed data, the SEQ output is only printed as multiple exposures; 35 mm microfilms containing multiple and single SEQ exposures and the multi-record CW exposures are available at CEL. Copies or prints can be supplied upon request. Because the last record of a file partially consists of CAL tone, it would diffuse the multiple SEQ exposures, and therefore it has been omitted. In general, the multiple exposures contain the output records 3 through 39 of each file; some high level noise records have been excluded. Because of their very particular phase pattern, which in most cases is a linear sweep, certain of these "noisy" records are selected and assembled in Appendix C as single exposures.

For relative comparison of the output signals, the oscilloscope sensitivity settings, and the 14 db digital recording attenuations are indicated. In the CW pictures a 360° phase range covers 0.9 cm on the oscilloscope; in SEQ pictures, 1.8 cm. The 360° steps in the CW phase displays are due to a processing error as mentioned in Sec. 3.3.2.

Due to the necessary analog tape changes at MIMI-B, to processing errors at MIMI-C, and to delayed CAL signals in the analog recording, the following data of the "continuous" test were deleted: 1645-1648, 1800-1812, 2000-2015, 2227-2239, 0251-0303, 0451-0503, 0715-0727, 1139-1151, 1239-1345 hours; the records 14-40 of the file 0815-0827 hours; and the records 13-40 of the file 0953-1003 hours.

The 370-Hz - 470 Hz band noise levels, taken from the on-line Sanborn graphic recording of the "raw" reception, are occasionally indicated in the CW pictures. The dynamic range of these noise levels is plotted as a vertical line for each file in Fig. 9.

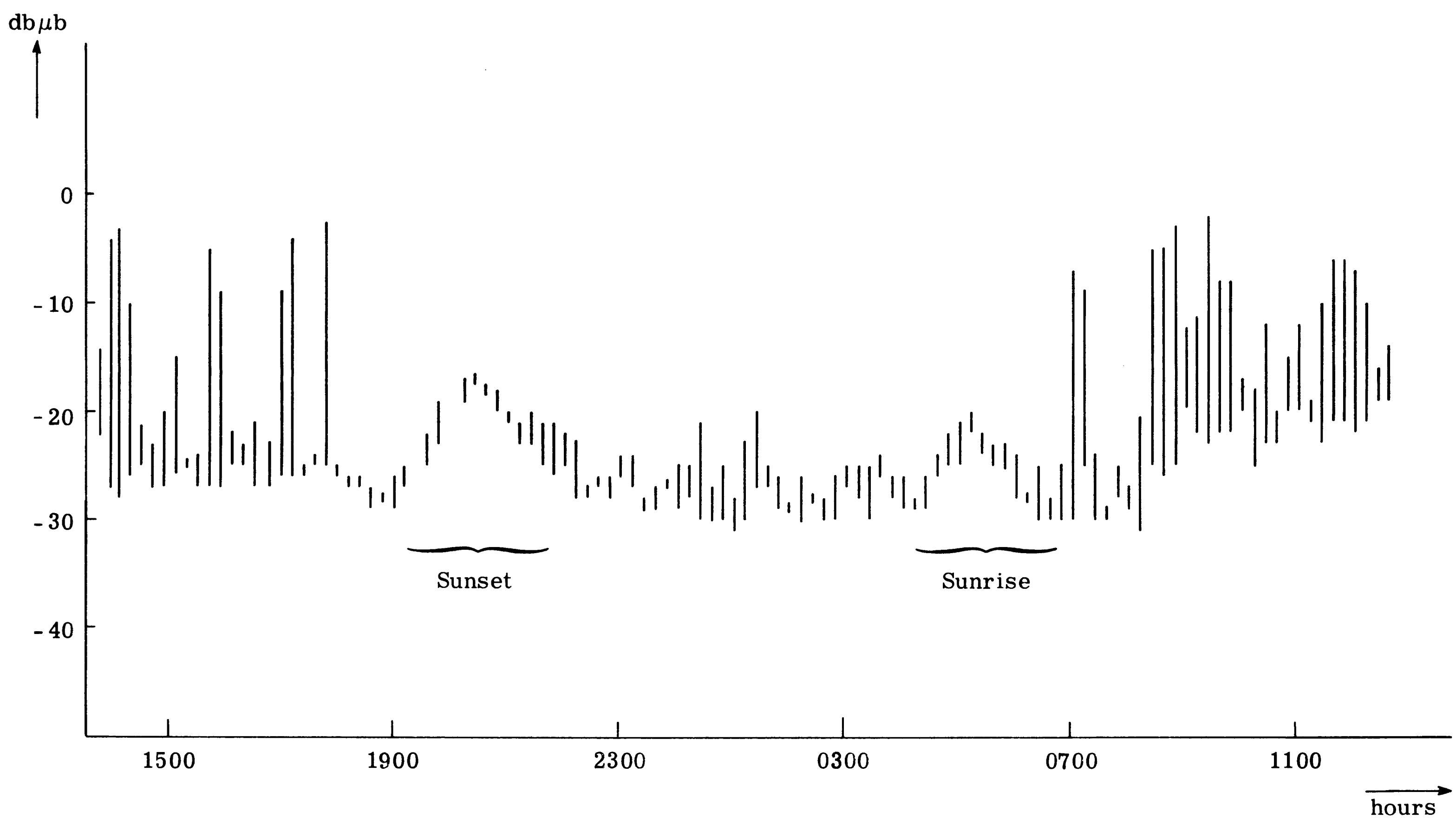


Fig. 9. Dynamic noise levels in the band 370 Hz - 470 Hz on 11 and 12 August 1967

Most high level noise originated from boats and rain; the biological noise increased considerably during sunrise and sunset.

5.3 Discussion of the Results

The essential phenomena of CW and SEQ data are described in Ref. 3. In comparison with the 3, 4 February 1965 experiment, the results presented in this report show similar properties. However, a total of 14 db transmission and processing loss has to be taken into account.

The values of this experiment are in particular the continuity of a full day of reception, and the fact that AMSEQ enables a cross check between CW and SEQ data. The "sampled" test is a model for future long term experiments. The following sections discuss briefly some of the properties of CW and SEQ data, both individually and with relation to each other.

5.3.1 CW Analysis Results. The results obtained from the CW analysis again show the 0.1 Hz - 0.3 Hz surface modulations as observed in earlier experiments. High amplitude outputs have a very stable phase. In general the phase varies gradually at rates up to 15°/min; in some cases it changes faster, at rates up to 90°/min. At several moments the signal fades out, the pictures showing a low amplitude and a rapidly changing phase. The ambient noise in the 370 Hz - 470 Hz frequency band normally varies slightly about the -25 dbμb level; boats and rain occasionally increase this level with 20 to 25 db, most of the time destroying the signal which then results in a violently changing amplitude and a scattered phase.

5.3.2 SEQ Analysis Results. The sequence analysis results show that all receptions consist of a number of sound arrivals indicating a propagation along physically different paths. According to the phase patterns these arrivals have durations of roughly 120 to 500 msec. As a consequence of the AMSEQ-BMSEQ cross-correlation the phase is randomly scattered outside the main arrivals; the patterns do not show a more or less constant value in that region as observed in some of the BMSEQ autocorrelated receptions of 3, 4 February 1965. Similar to those results the present SEQ analysis outputs contain pieces of a constant, parabolic and linear phase, and discontinuities. The combination of a narrow peak and a constant phase marks a separate single path arrival of the entire frequency band transmitted on the AMSEQ signal. Non-separated arrivals result in wider peaks and a varying phase. The linear phase sweeps, at rates of 8π to 40π rad/sec suggests the reception of signals with most of their energy contained in bands about -4 Hz to -20 Hz measured from carrier frequency. Most of the single exposures obtained from high noise receptions, presented in Appendix C, show a similar sweep.

Sudden shifts of the arrival patterns ("peak shifts") seem to occur every six minutes over a consistent amount of time; approximately 6 mm to the left on the oscilloscope screen, i.e., -72 msec. As mentioned in Ref. 3, peak shifts were found to be caused by equipment at MIMI-A. Except for these shifts and for signals destroyed by noise, the arrival patterns are rather stable; major changes occur only after intervals of 6 to 36 minutes.

5.3.3 Relationships between CW and SEQ Analysis Results. Considering the CW analysis and SEQ analysis output simultaneously, the following features are observed:

(a) A low CW signal does not necessarily imply a low SEQ signal.

(b) SEQ analysis outputs consisting of a number of correlation peaks may coincide with weak CW signals, depending upon the phase relations of the individual peaks.

(c) The appearance of linear phase sweeps in the SEQ signal in most cases coincides with a decrease in the CW signal.

(d) The gradual changes of the CW phase are consistent with the record-to-record variations in the SEQ phase, seen as a vertical spread of the dots in the multiple exposures.

The points (a) and (b) may be explained by regarding the frequency spectra of the received signal. If the ocean functions as a filter, and most of the arriving signal energy is contained in a certain sideband while the carrier component is rather low, this sideband may still yield a considerable correlation peak. In that case the SEQ phase pattern will be marked by a linear sweep; the rate of this sweep supposedly reflects the center frequency of the sideband concerned. Concerning point (b), the propagation along physically different paths will cause interference of the individual sound arrivals. Signals may either support or weaken each other, depending upon their phase relations.

6. CONCLUSION

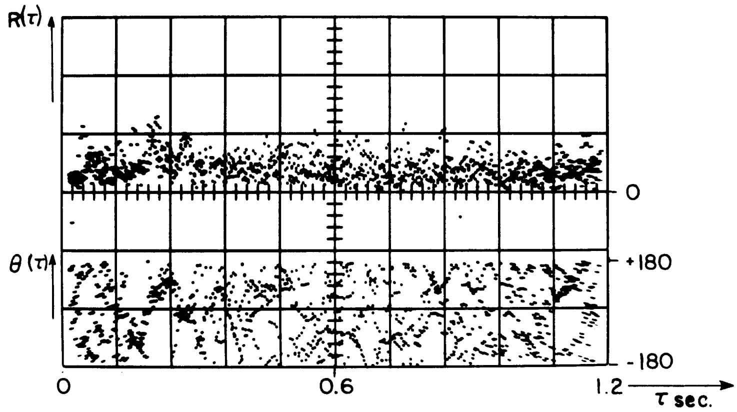
AMSEQ, the amplitude modulation of the 420-Hz carrier by a 1.2-sec, 63-digit maximal pseudo-random sequence, and the subsequent processing by means of digital correlation techniques, yield simultaneous information about the behavior of the carrier frequency (CW analysis) and the multipath sound propagation (SEQ analysis) in the ocean. The "continuous" test shows the gradual propagation changes in the 370 Hz - 470 Hz frequency band; the "sampled" test in a model for planned long-term experiments.

The results of the CW analysis confirm the phenomena of surface modulation and phase stability as observed in earlier experiments. The SEQ analysis yields a variety of sound arrival patterns; the patterns are consistent over intervals of 6 to 36 minutes and show arrival durations of 120 to 500 msec. According to these results the receptions may consist of a number of arrivals, each containing the entire transmitted frequency band, or arrivals containing only parts of this frequency band.

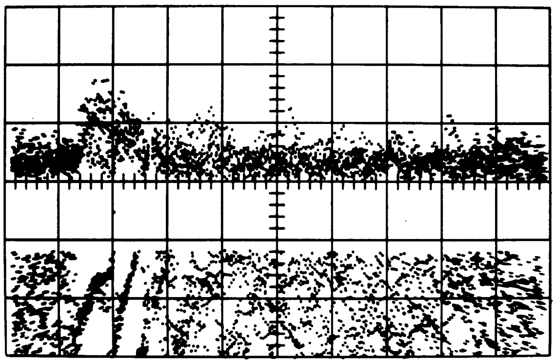
Relating the CW and SEQ analysis results to each other it is learned that, supposedly because of these frequency characteristics or because of interference, the SEQ analysis output may still be quite high where the CW signal has a rather low amplitude. Fast computer programs for Fourier transformation of the processed data are in progress and will enable a more extensive study in the frequency domain.

APPENDIX A

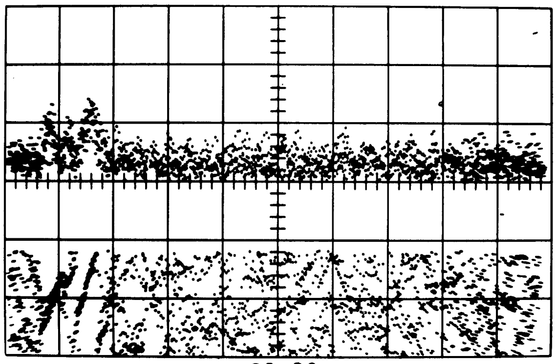
RESULTS OF THE 24-HOUR CONTINUOUS TEST



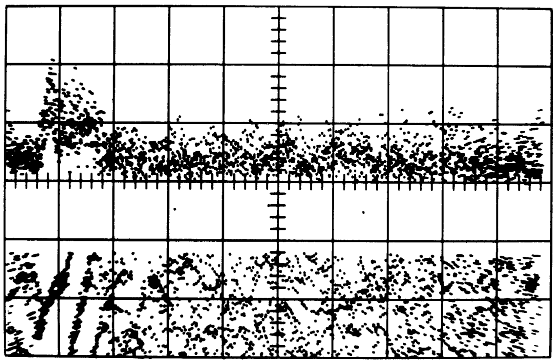
6-9



11-21



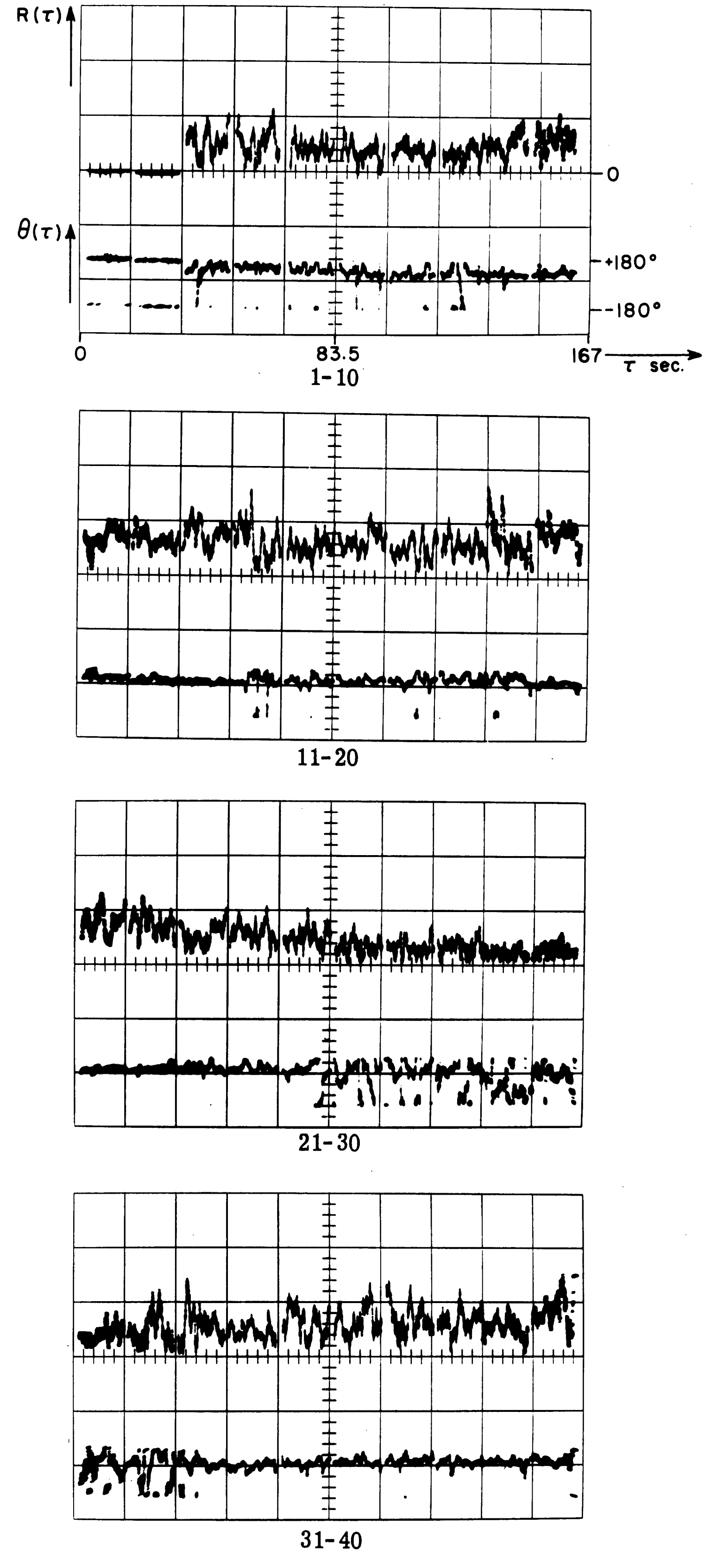
23-30



31-39

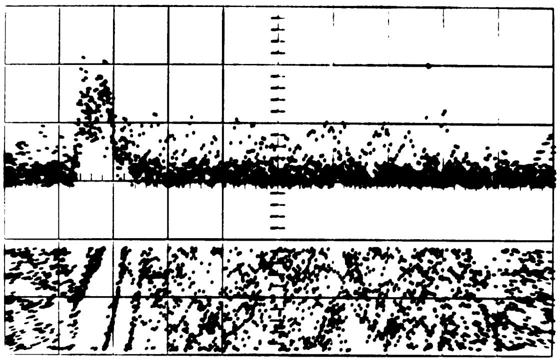
SEQ, R = 0.5 V/cm

AMSEQ 11 August 1966 1345 - 1357 hours

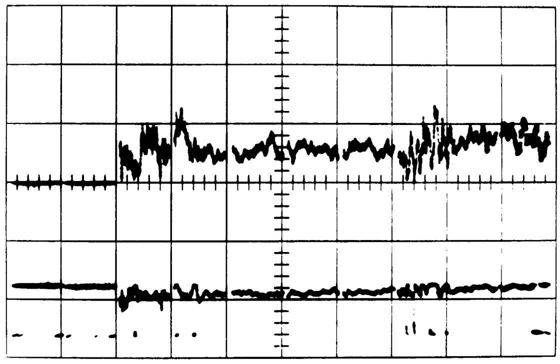


CW, R = 0.2 V/cm

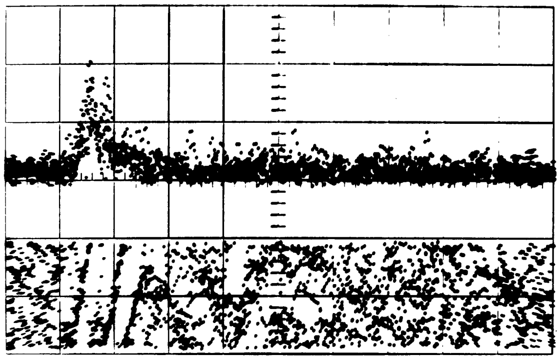
AMSEQ 11 August 1966 1345 - 1357 hours



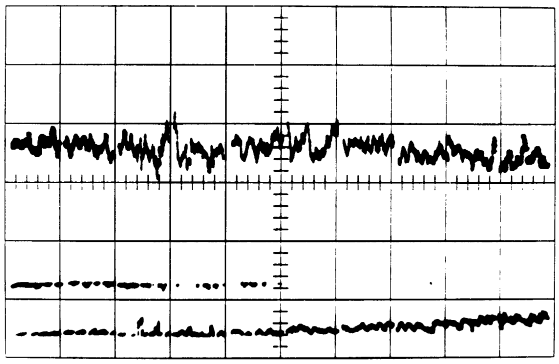
3-12



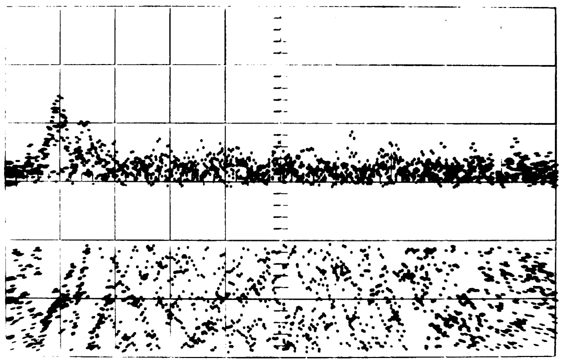
1-10



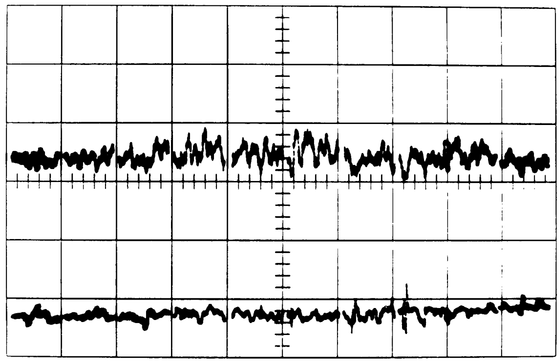
13-22



11-20



24-29



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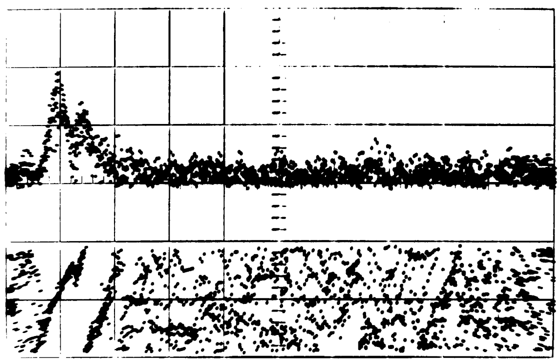
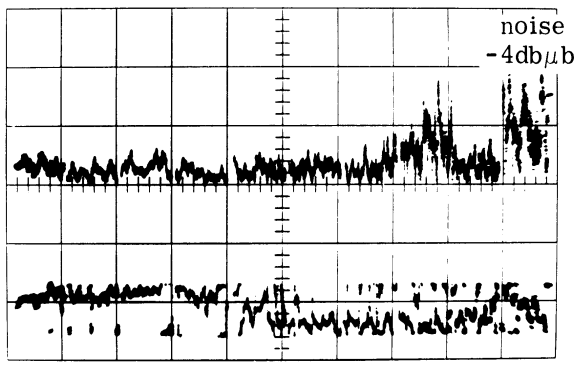


30-36

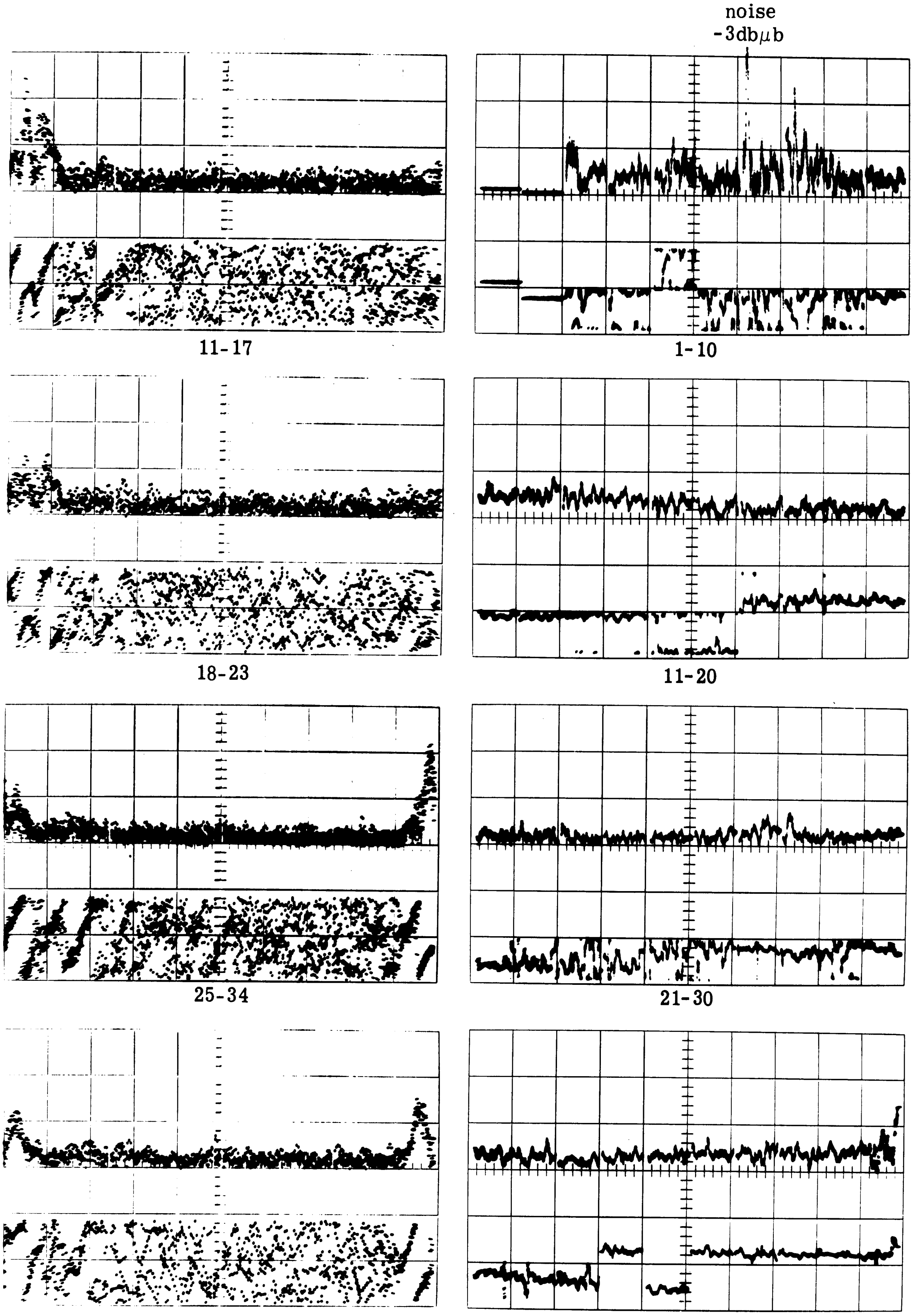


31-40

SEQ, R = 0.5V/cm

CW, R = 0.2 V/cm

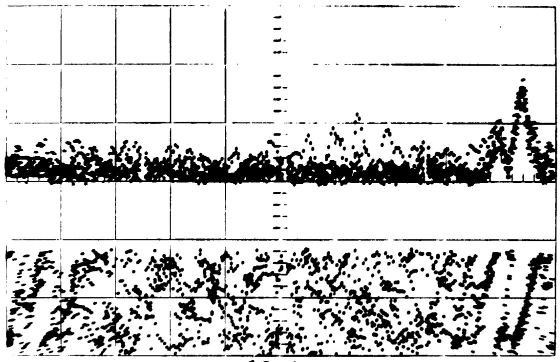
AMSEQ 11 August 1966 1357 - 1409 hours



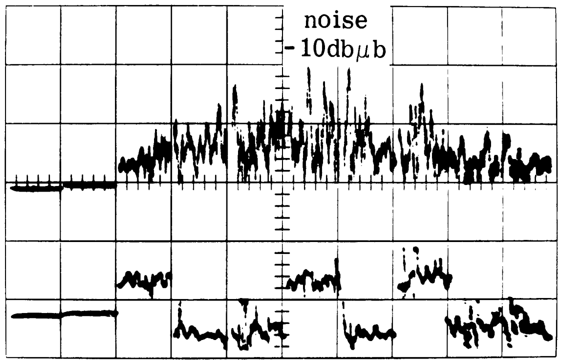
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

AMSEQ 11 August 1966 1409 - 1421 hours



10-16



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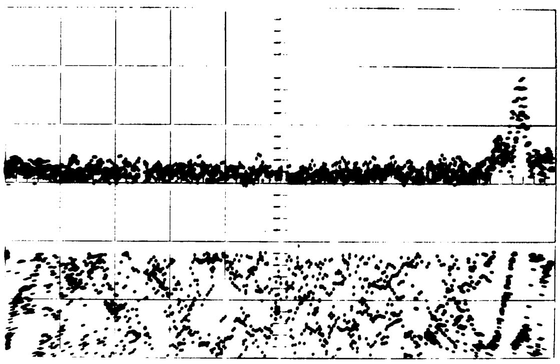

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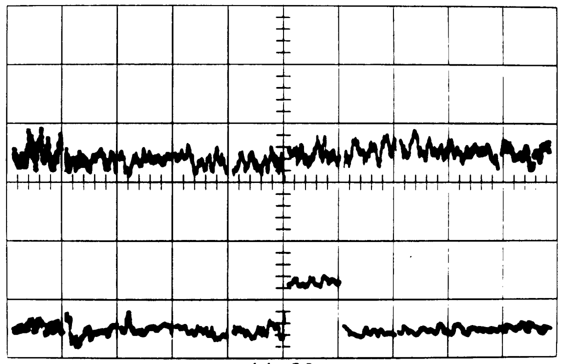

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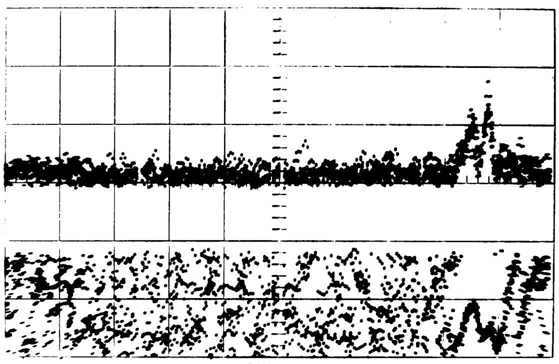

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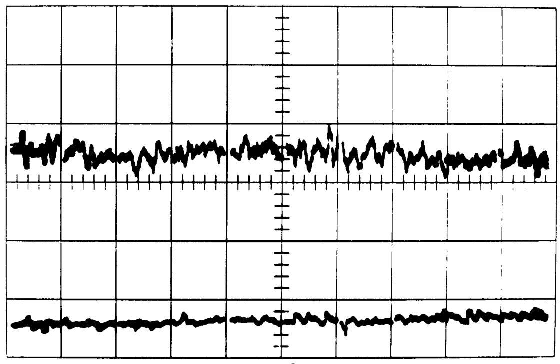

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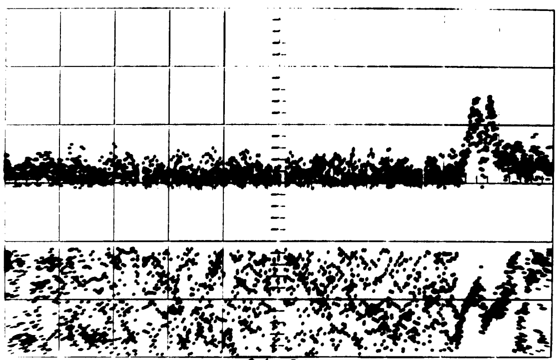

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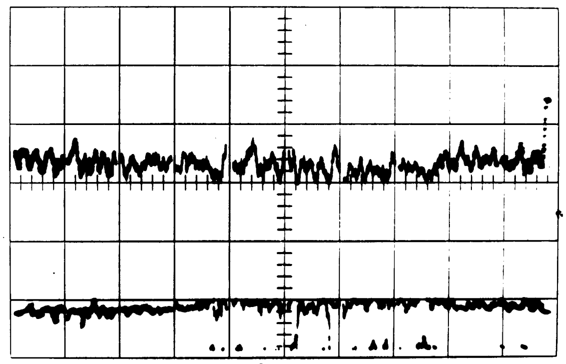
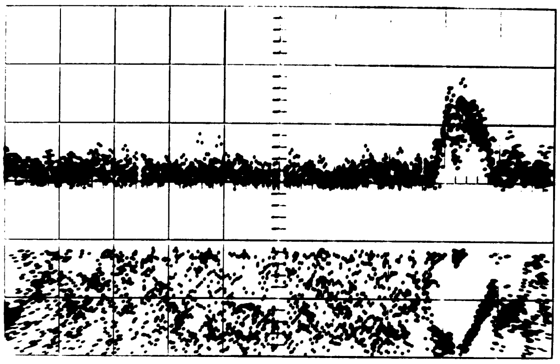


31-40

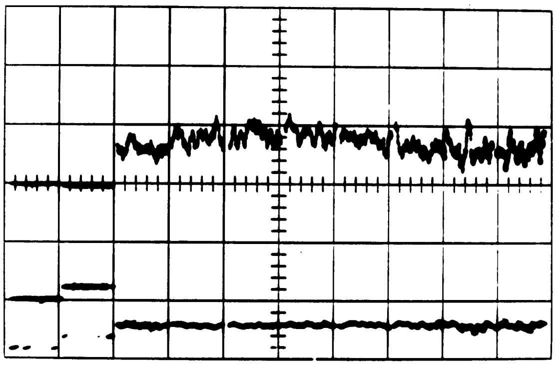
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

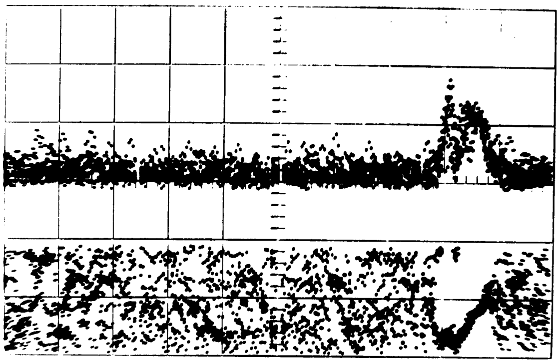
AMSEQ 11 August 1966 1421 - 1433 hours



3-12



1-10



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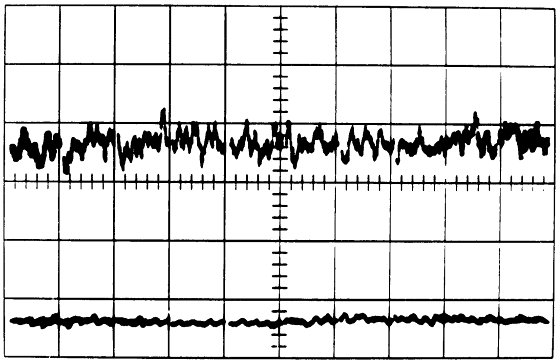

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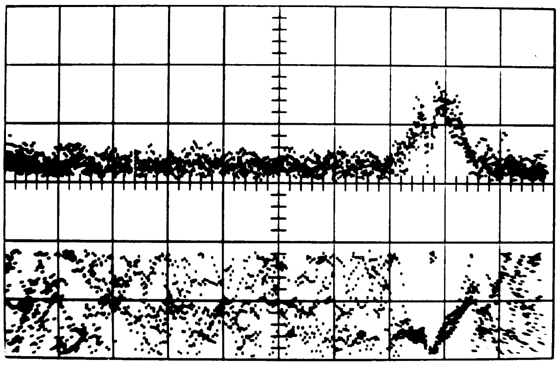

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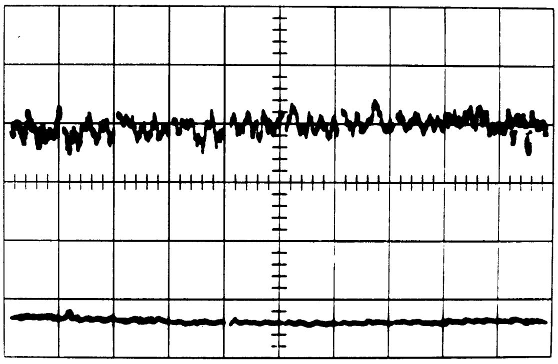

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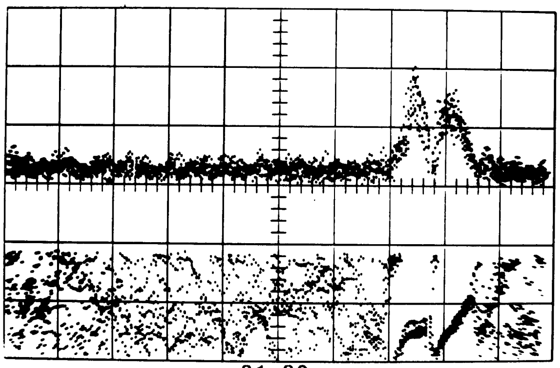

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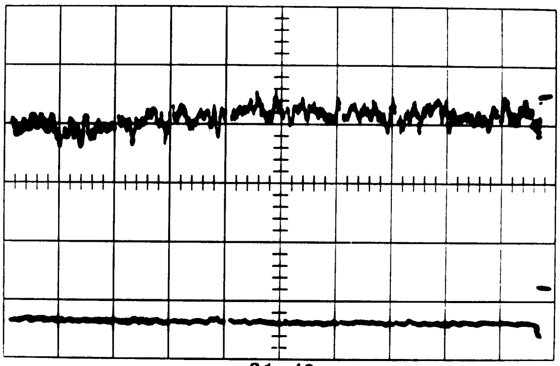
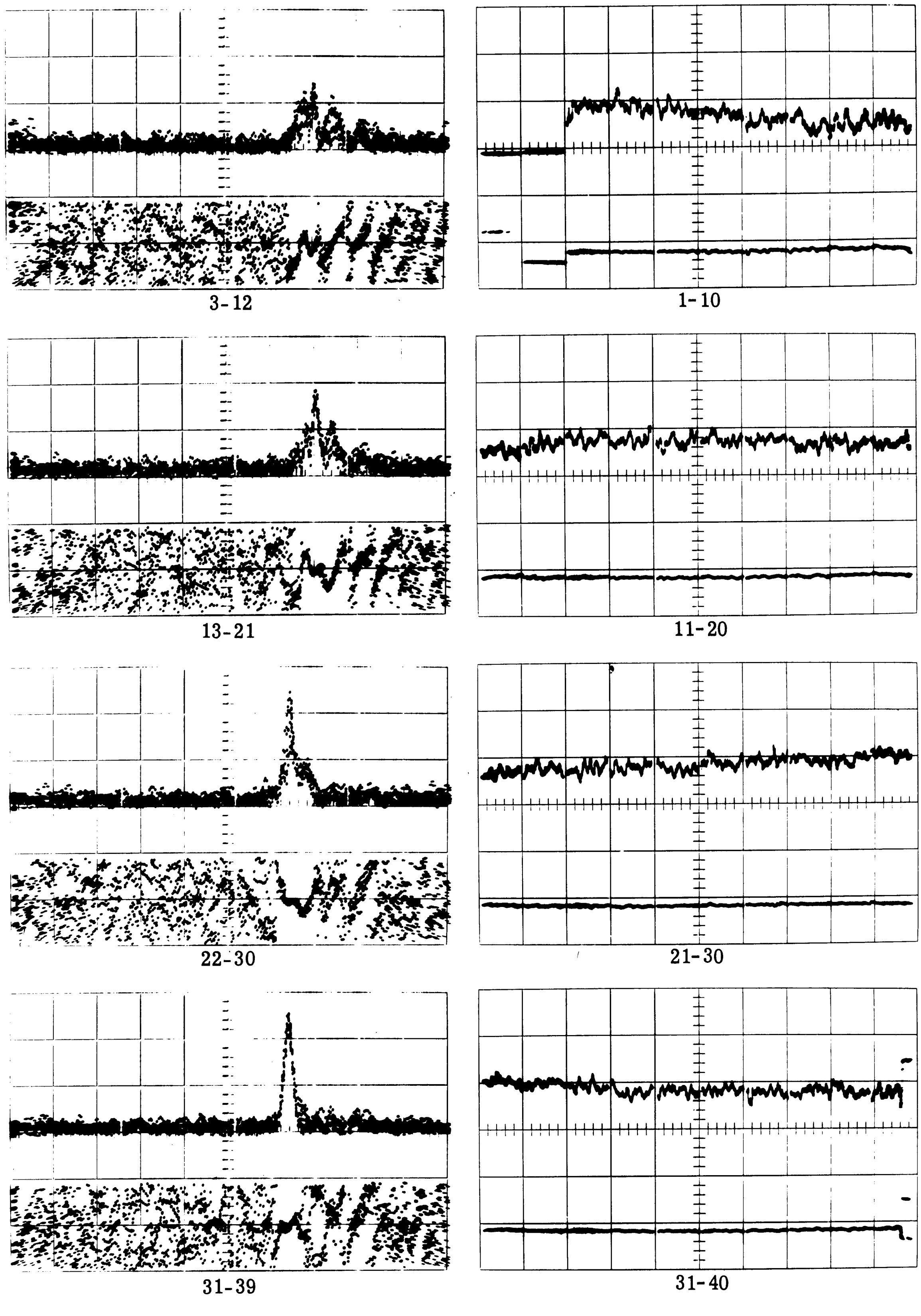


31-40

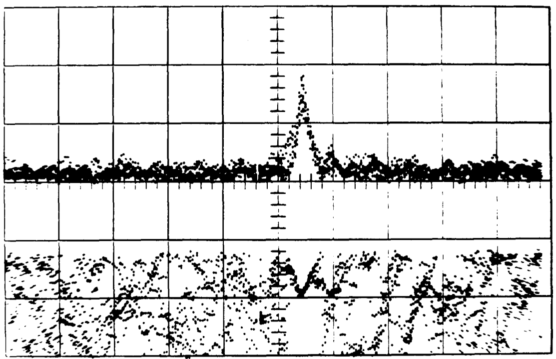
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

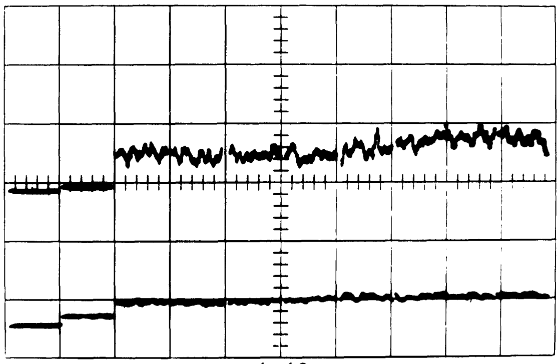
AMSEQ 11 August 1966 1433-1445 hours



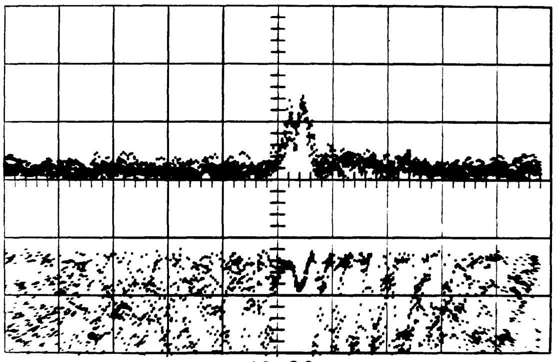
AMSEQ 11 August 1966 1445 - 1457 hours



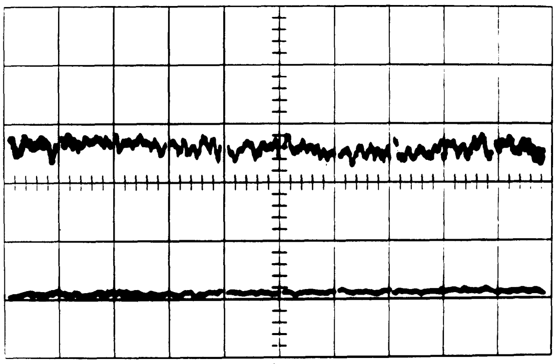
3-11



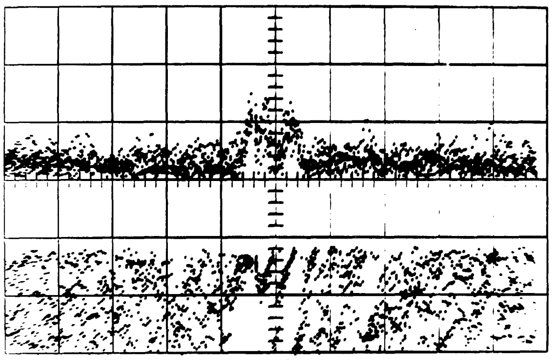
1-10



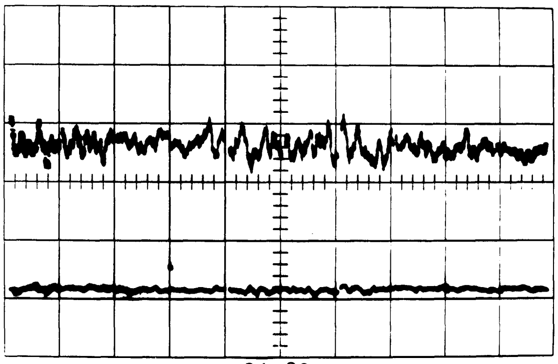
12-20



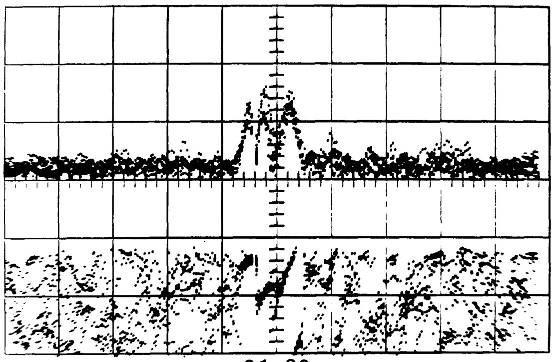
11-20



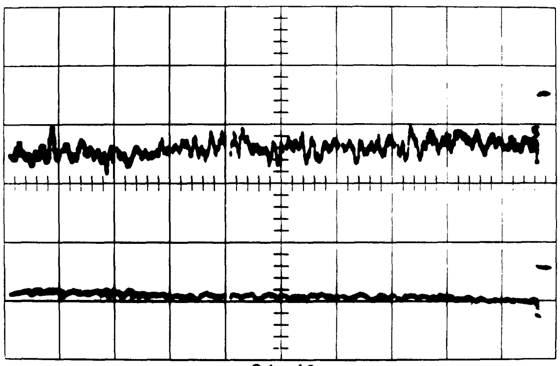
23-30



21-30



31-39

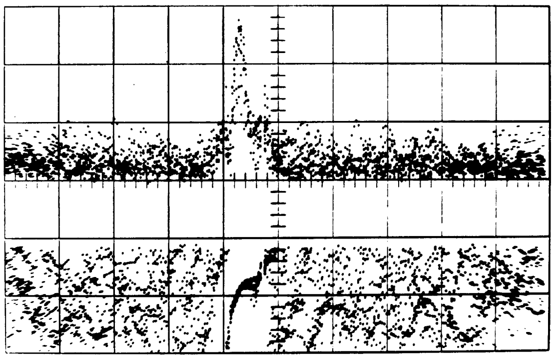


31-40

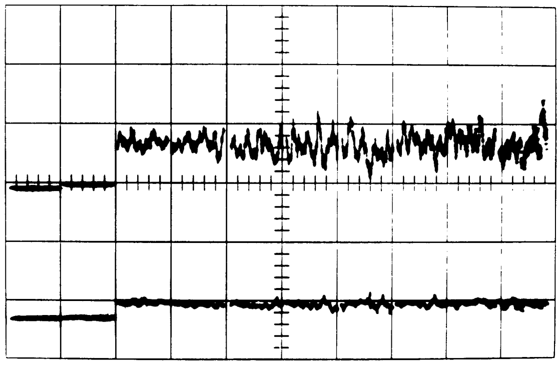
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

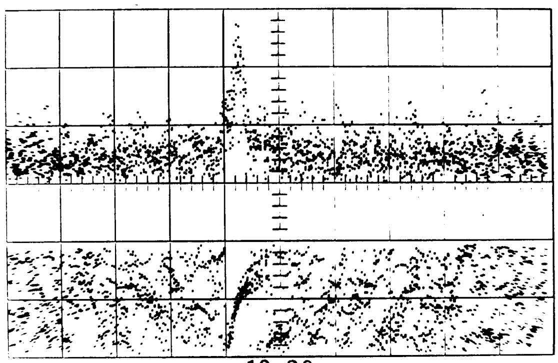
AMSEQ 11 August 1966 1457 - 1509 hours



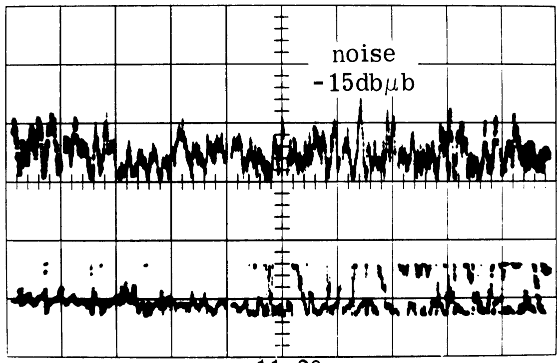
3-12



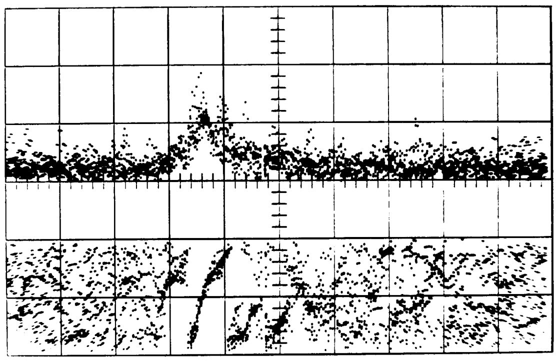
1-10



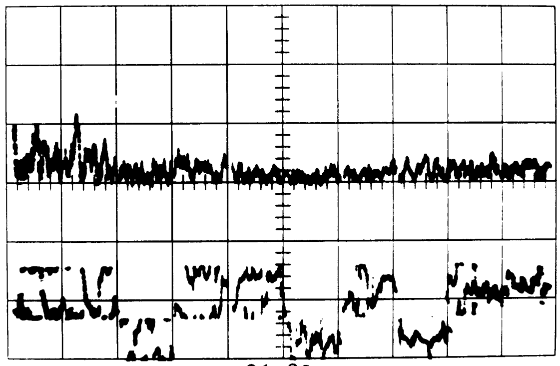
13-20



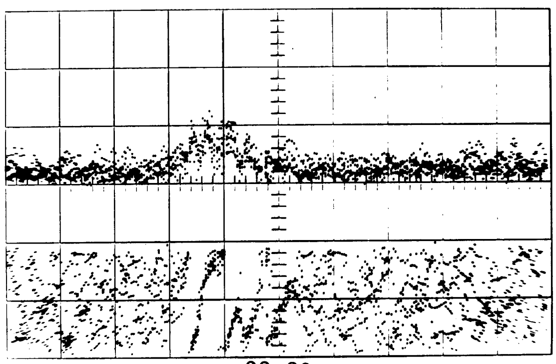
11-20



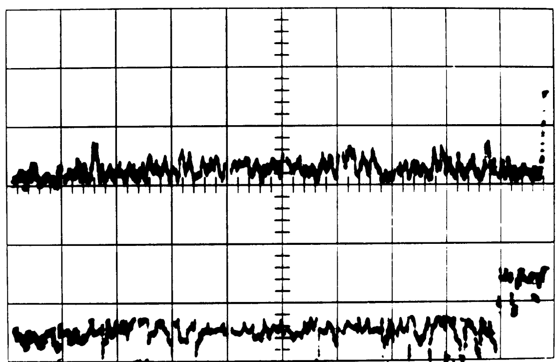
23-32



21-30



33-39

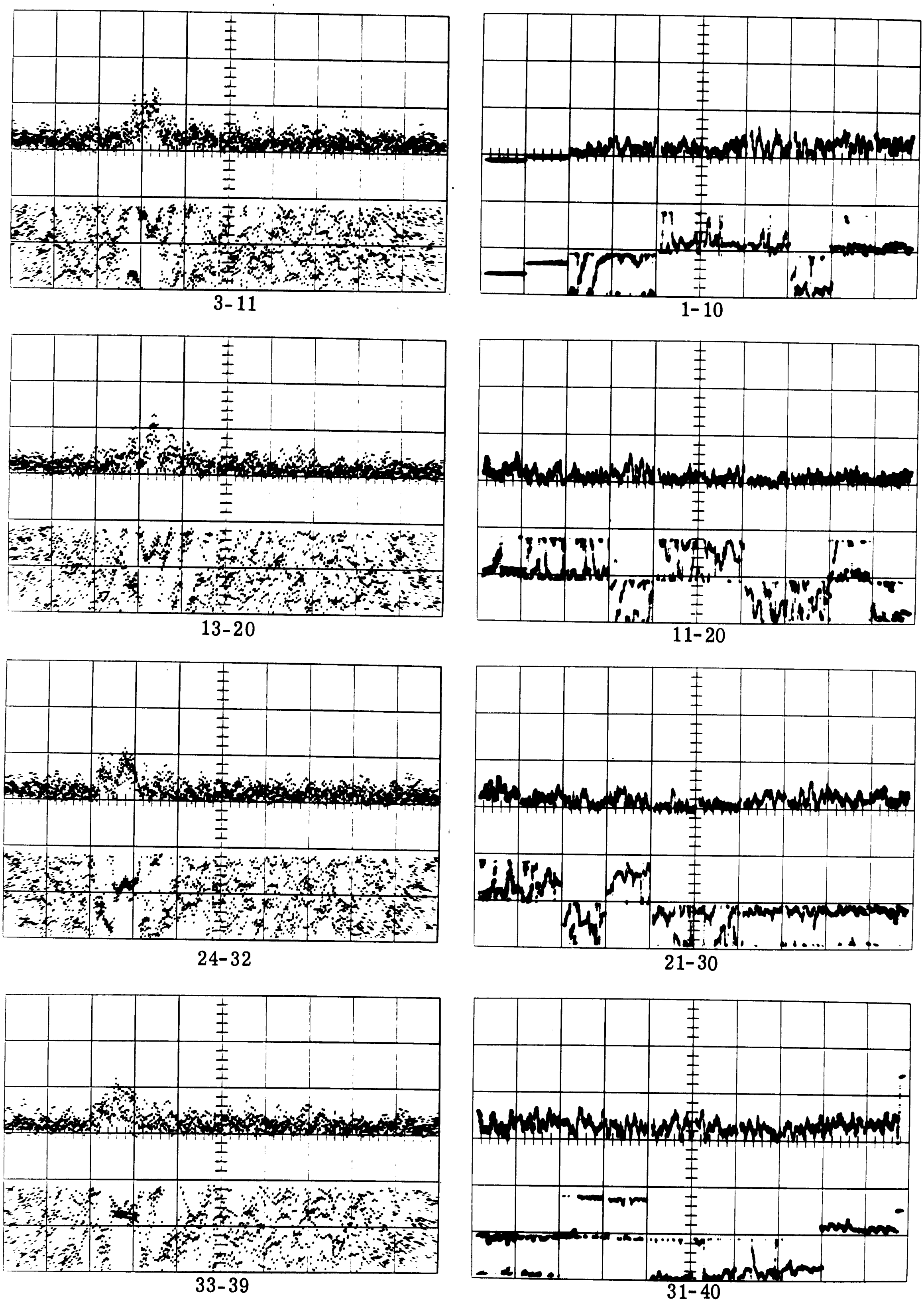


31-40

SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

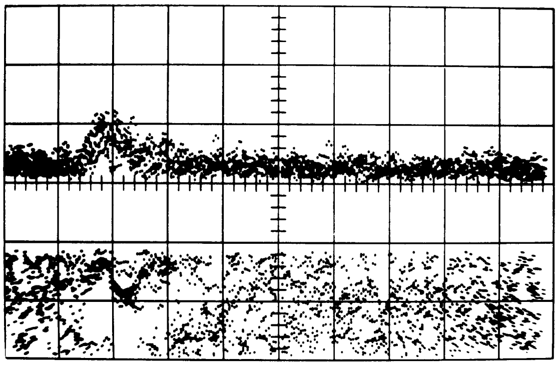
AMSEQ 11 August 1966 1509 - 1521 hours



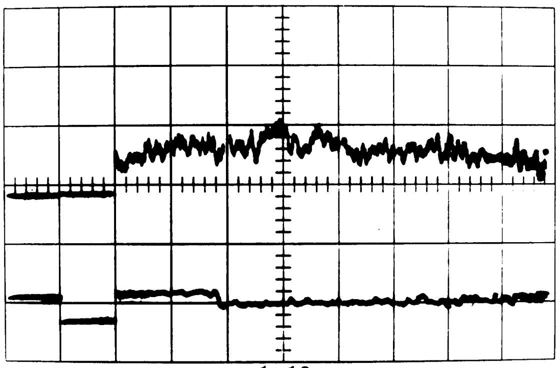
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

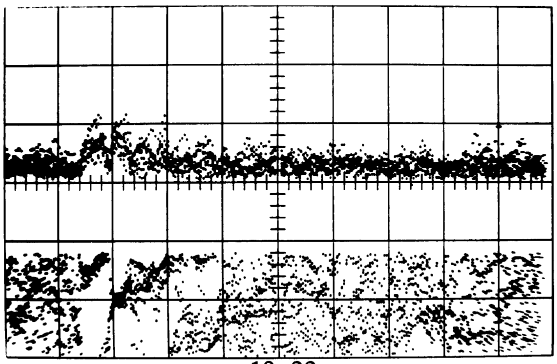
AMSEQ 11 August 1966 1521 - 1533 hours



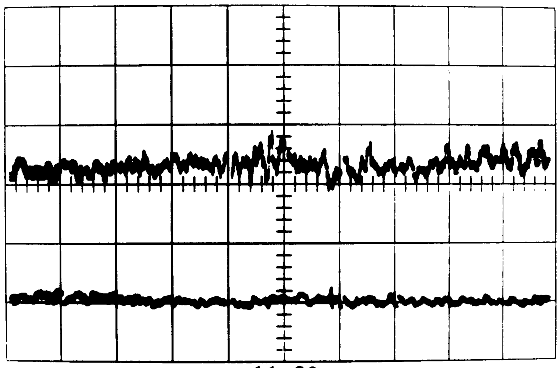
3-12



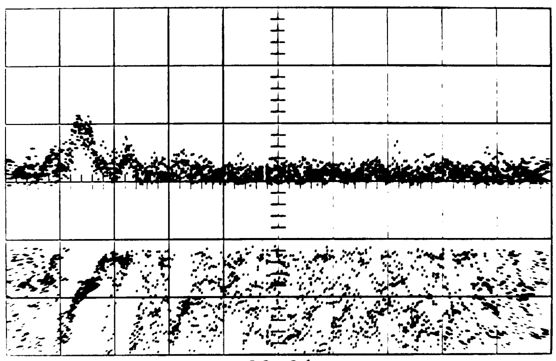
1-10



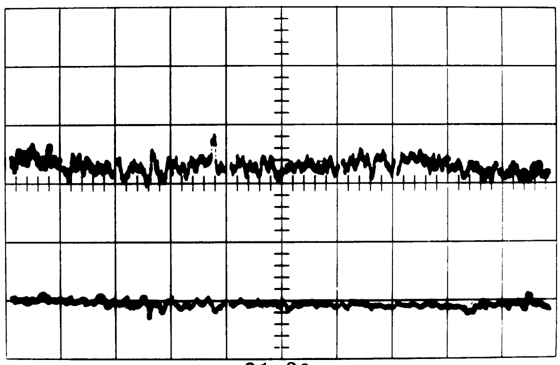
13-22



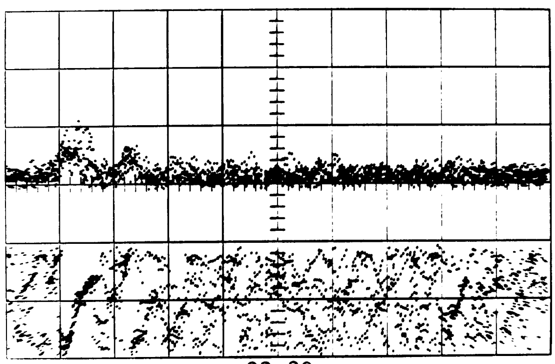
11-20



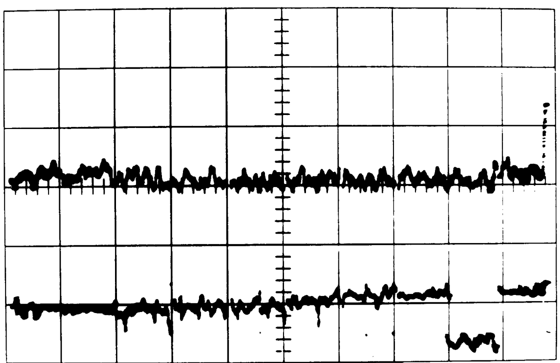
23-31



21-30



32-39

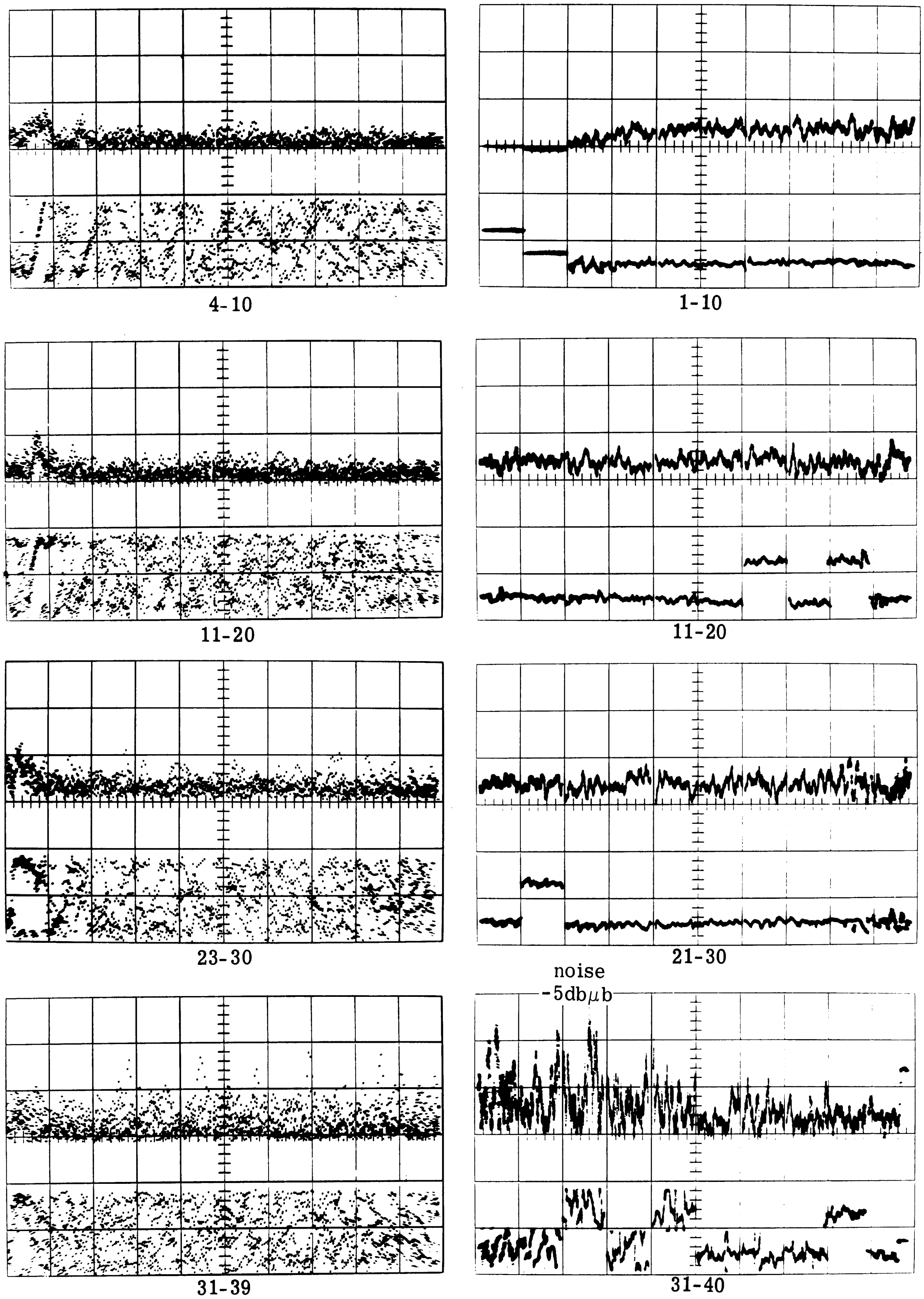


31-40

SEQ, R = 0.5 V/cm

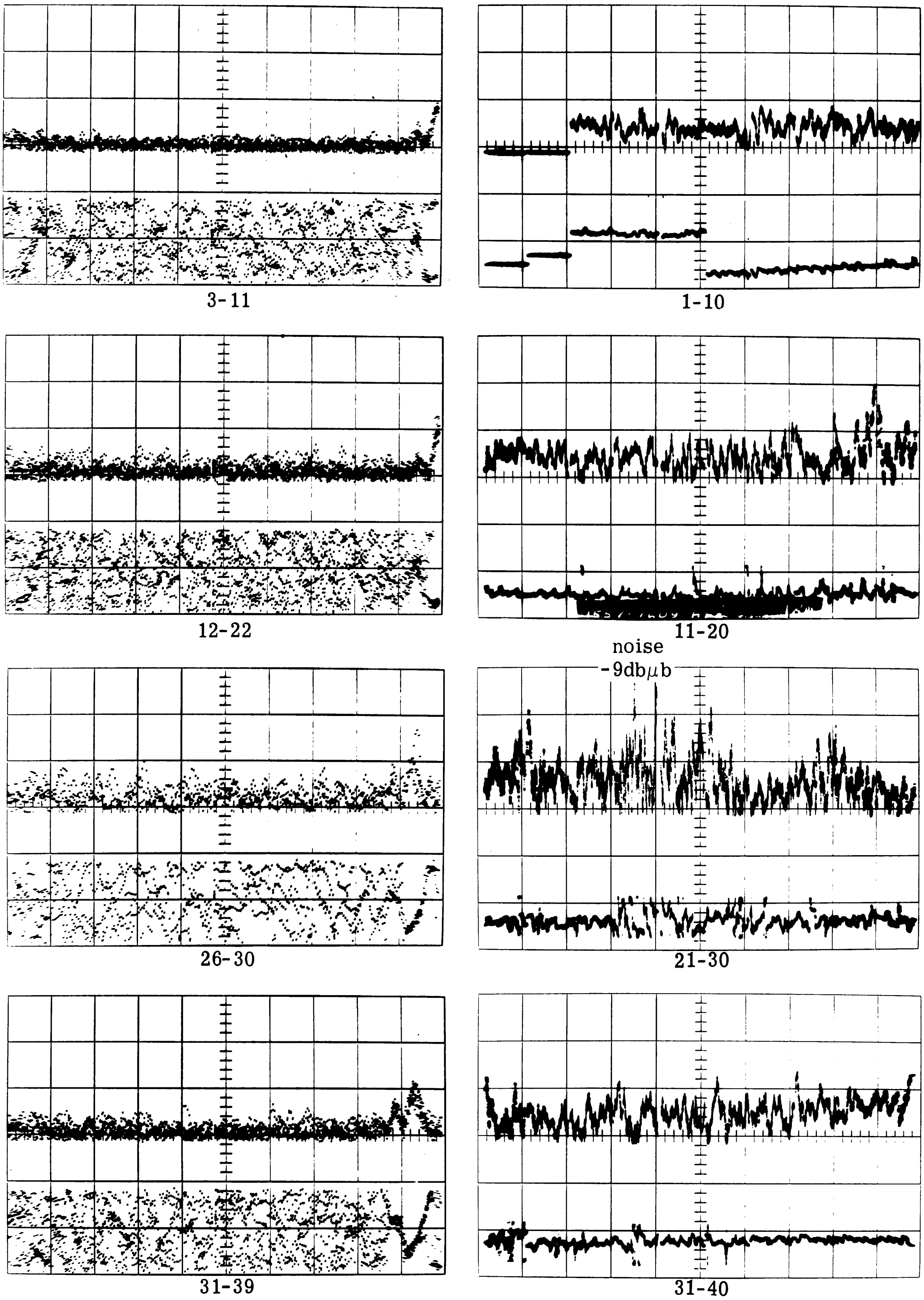
CW, R = 0.2 V/cm

AMSEQ 11 August 1966 1533 - 1545 hours



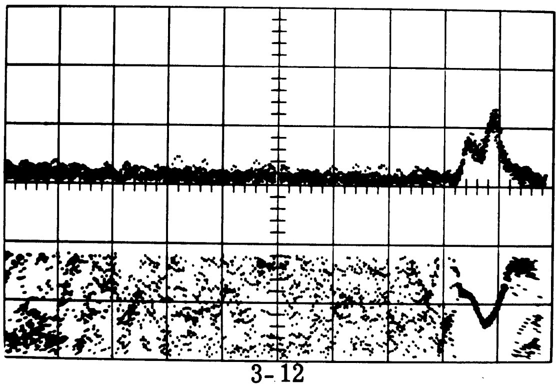
SEQ, R = 0.5V/cm CW, R = 0.2V/cm

AMSEQ 11 August 1966 1545 - 1557 hours

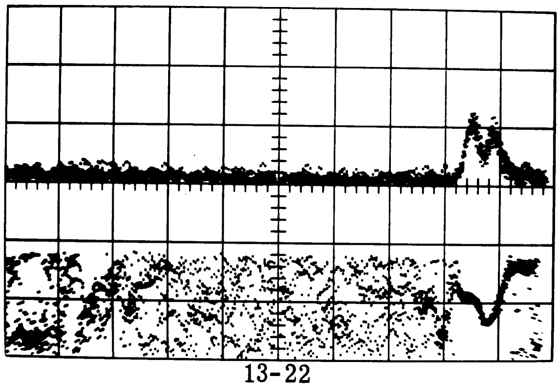


SEQ, R = 1.0V/cm   CW, R = 0.2V/cm

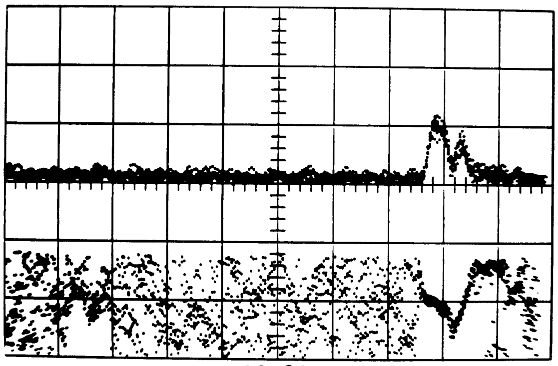
AMSEQ 11 August 1966 1557 - 1609 hours



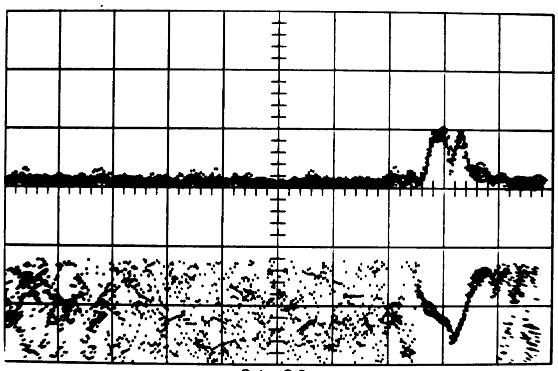
3-12



13-22

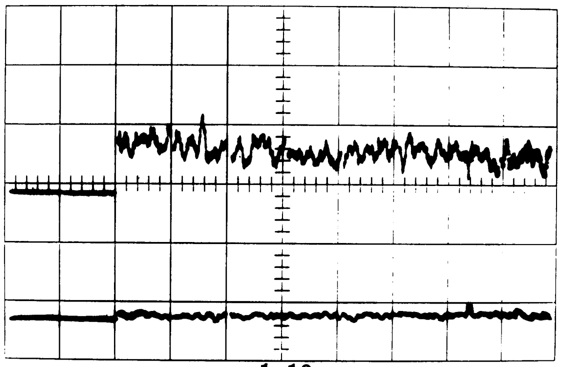


23-30

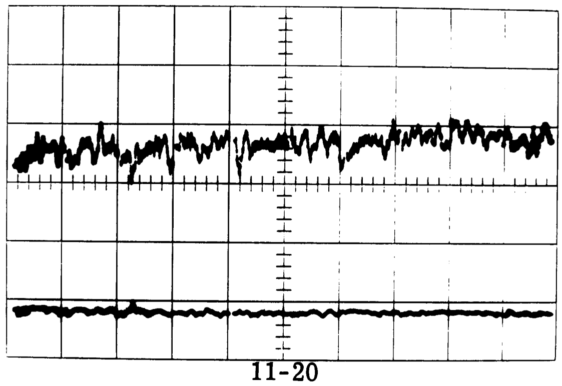


31-39

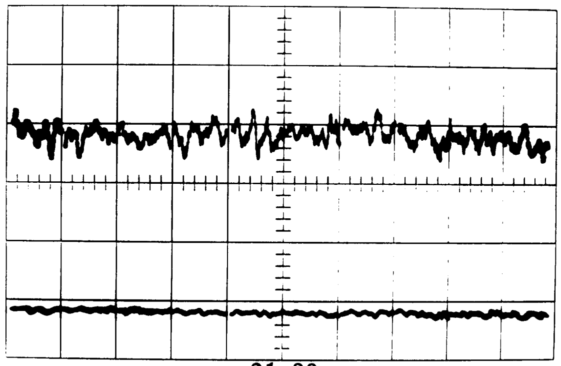
SEQ, R = 1.0 V/cm



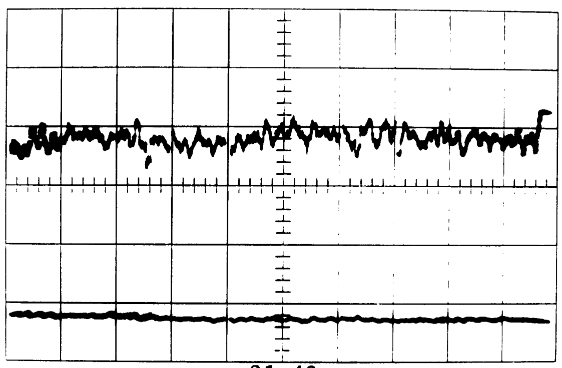
1-10



11-20



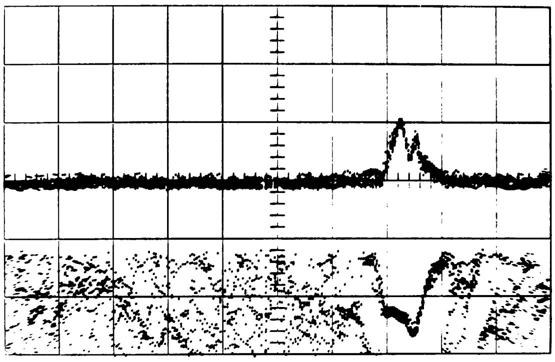
21-30



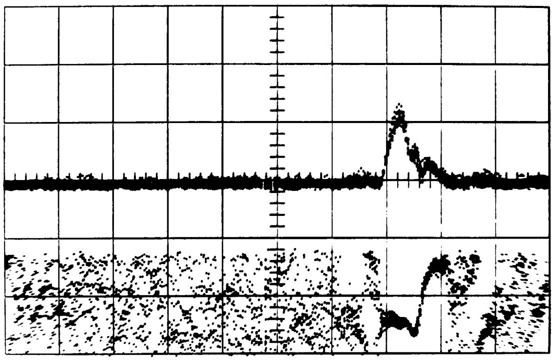
31-40

CW, R = 0.2 V/cm

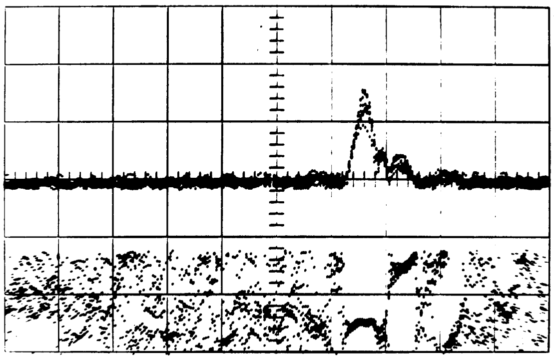
AMSEQ 11 August 1966 1609-1621 hours



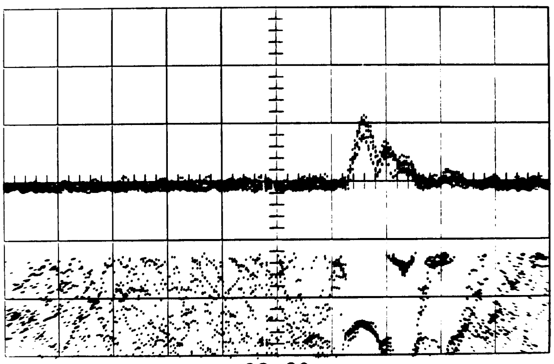
3-11



12-22

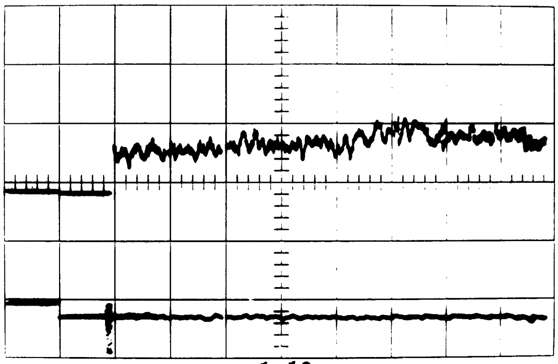


23-31

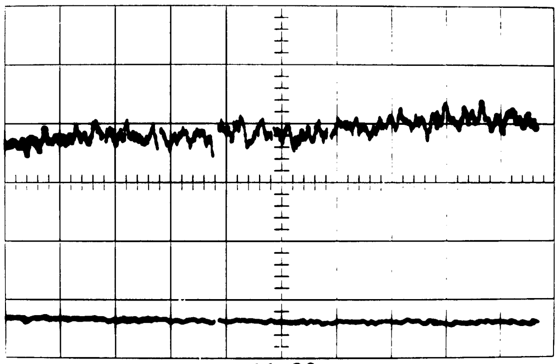


32-39

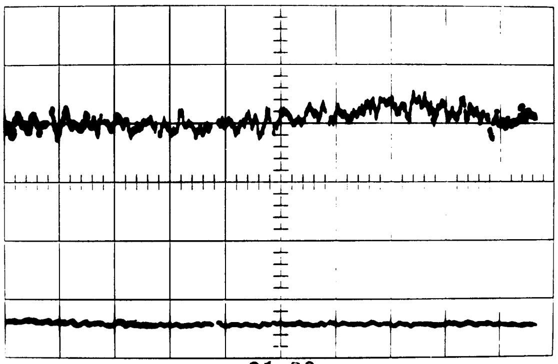
SEQ, R = 1.0V/cm



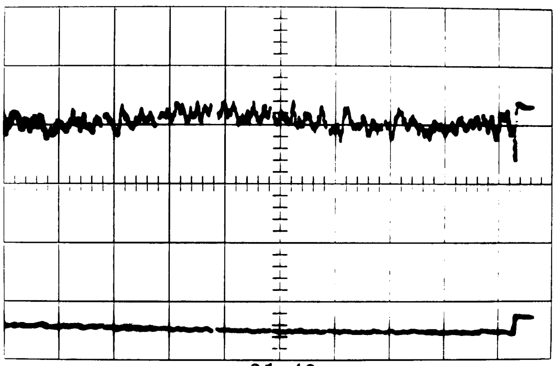
1-10



11-20



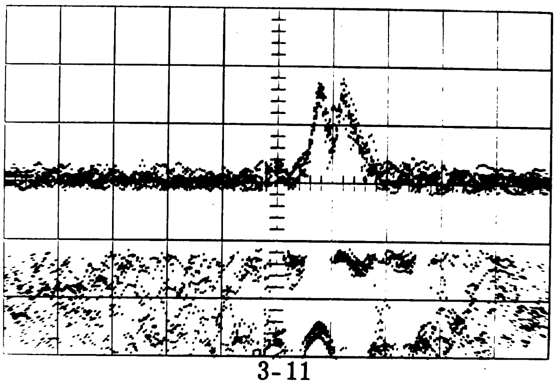
21-30



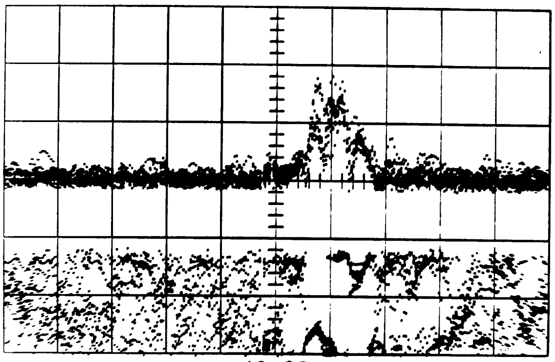
31-40

CW, R = 0.2V/cm

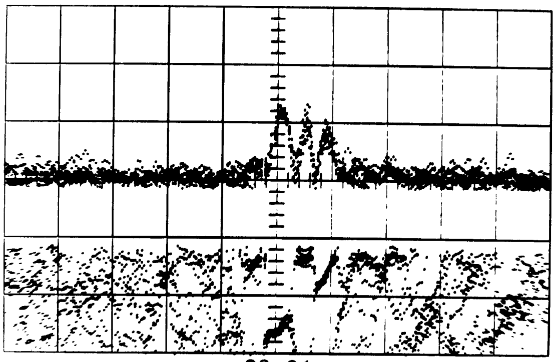
AMSEQ 11 August 1966 1621 - 1633 hours



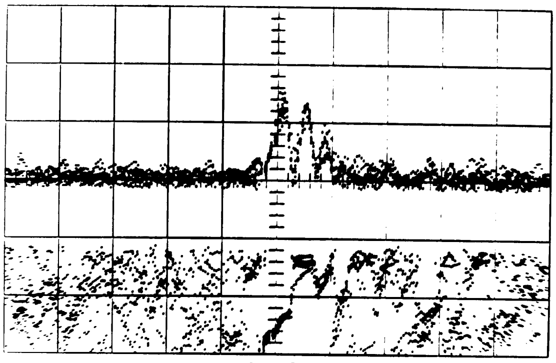
3-11



12-22

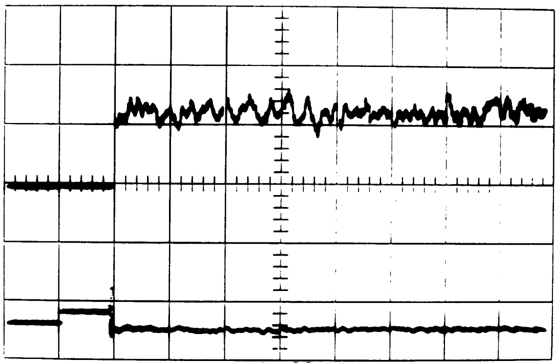


23-31

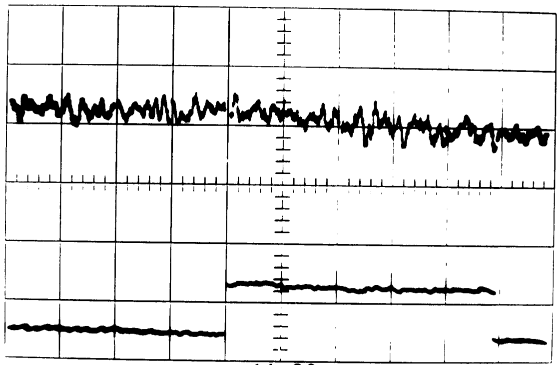


32-39

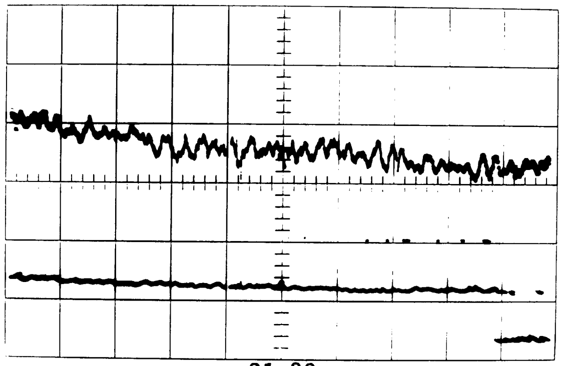
SEQ, R = 0.5 V/cm



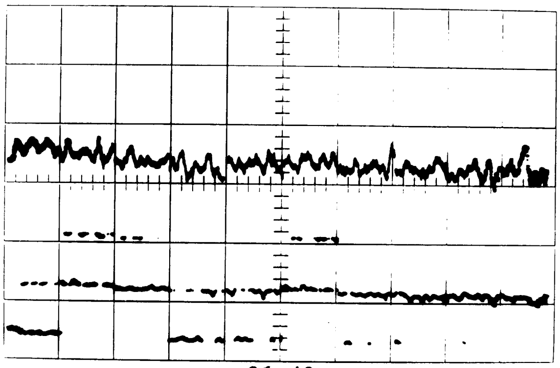
1-10



11-20



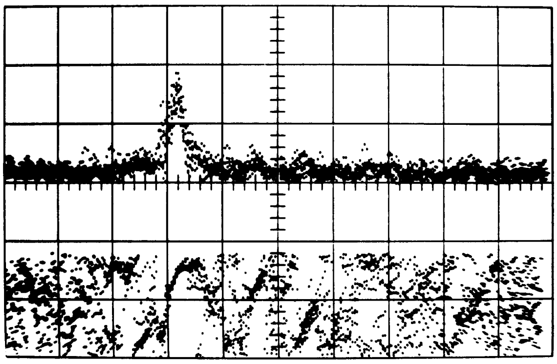
21-30



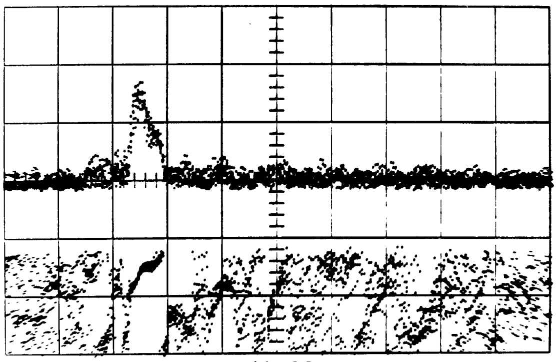
31-40

CW, R = 0.2 V/cm

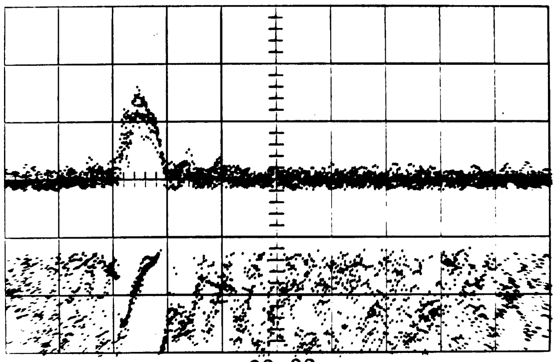
AMSEQ 11 August 1966 1633 - 1645 hours



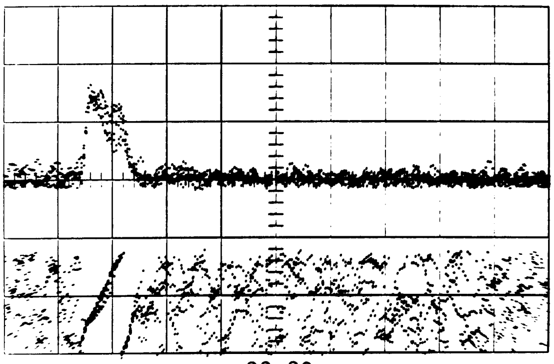
3-12



13-22

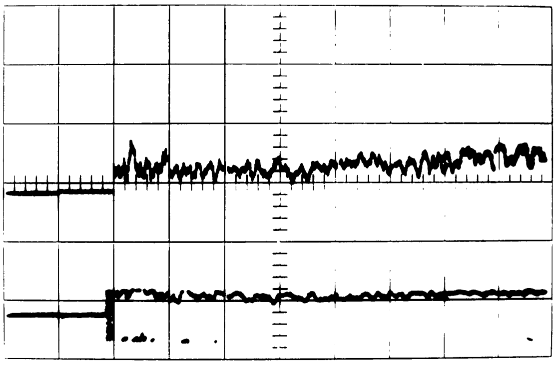


23-32

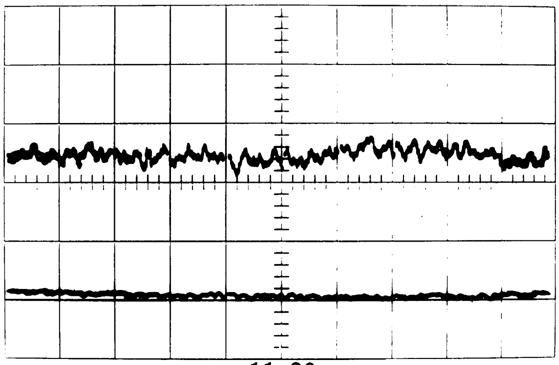


33-39

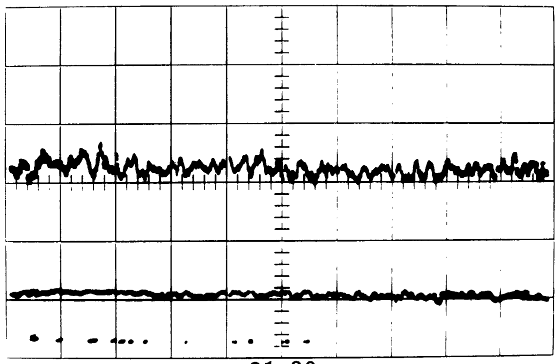
SEQ, R = 0.5 V/cm



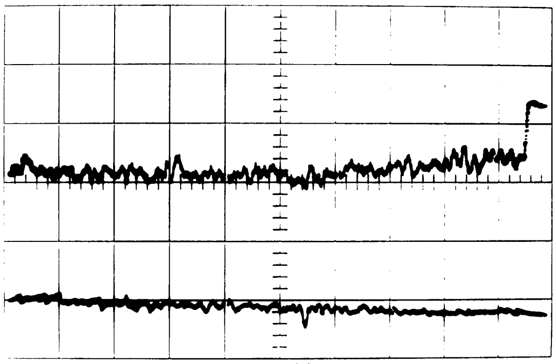
1-10



11-20



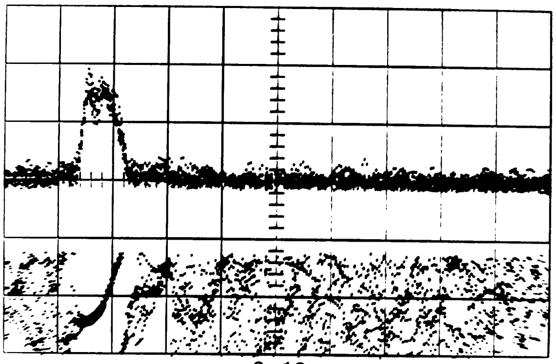
21-30



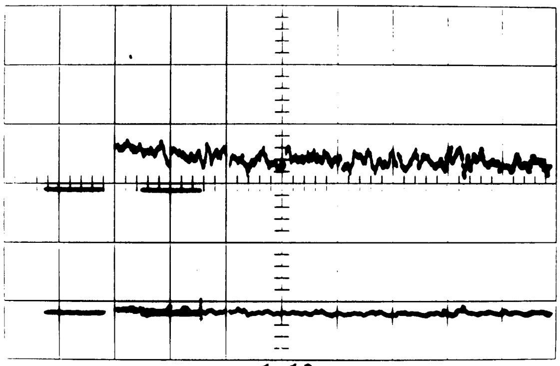
31-40

CW, R = 0.2 V/cm

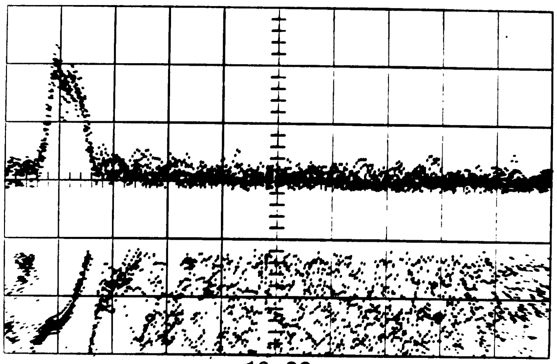
AMSEQ 11 August 1966 1648 - 1700 hours



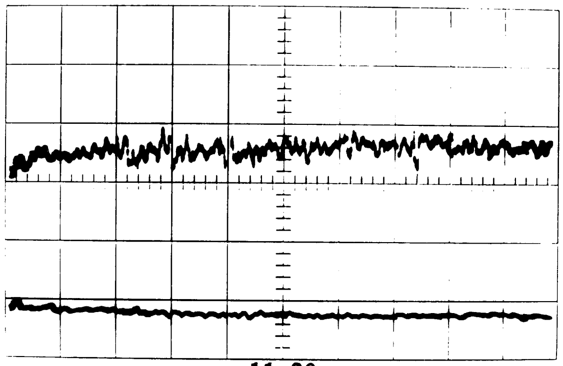
3-12



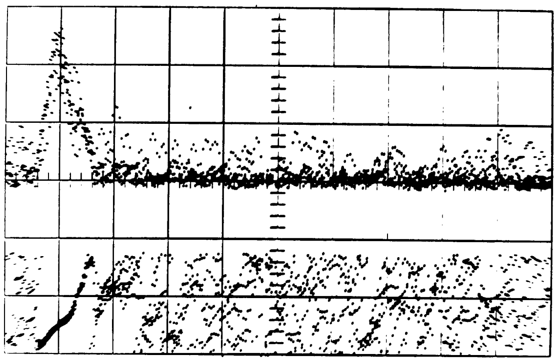
1-10



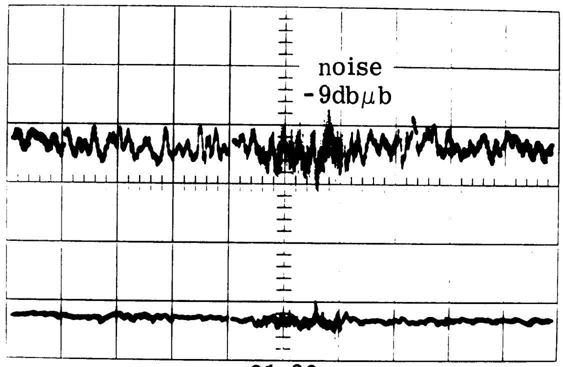
13-22



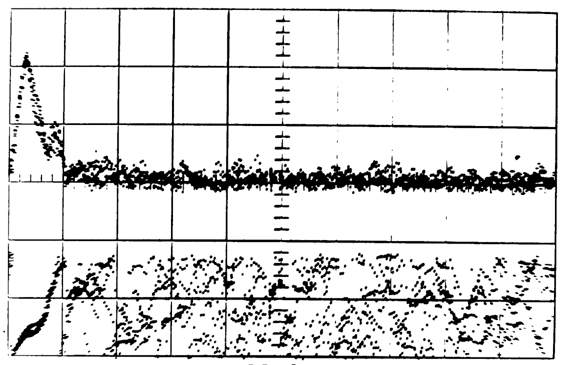
11-20



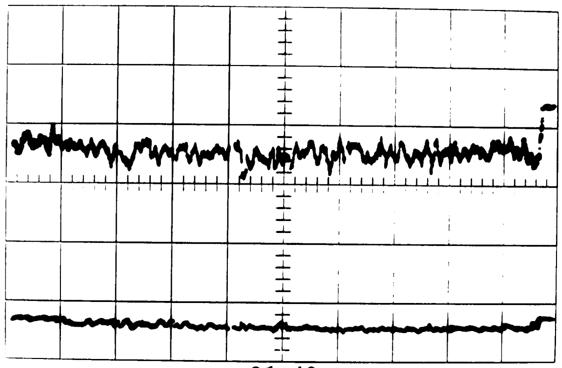
27-32



21-30



33-39

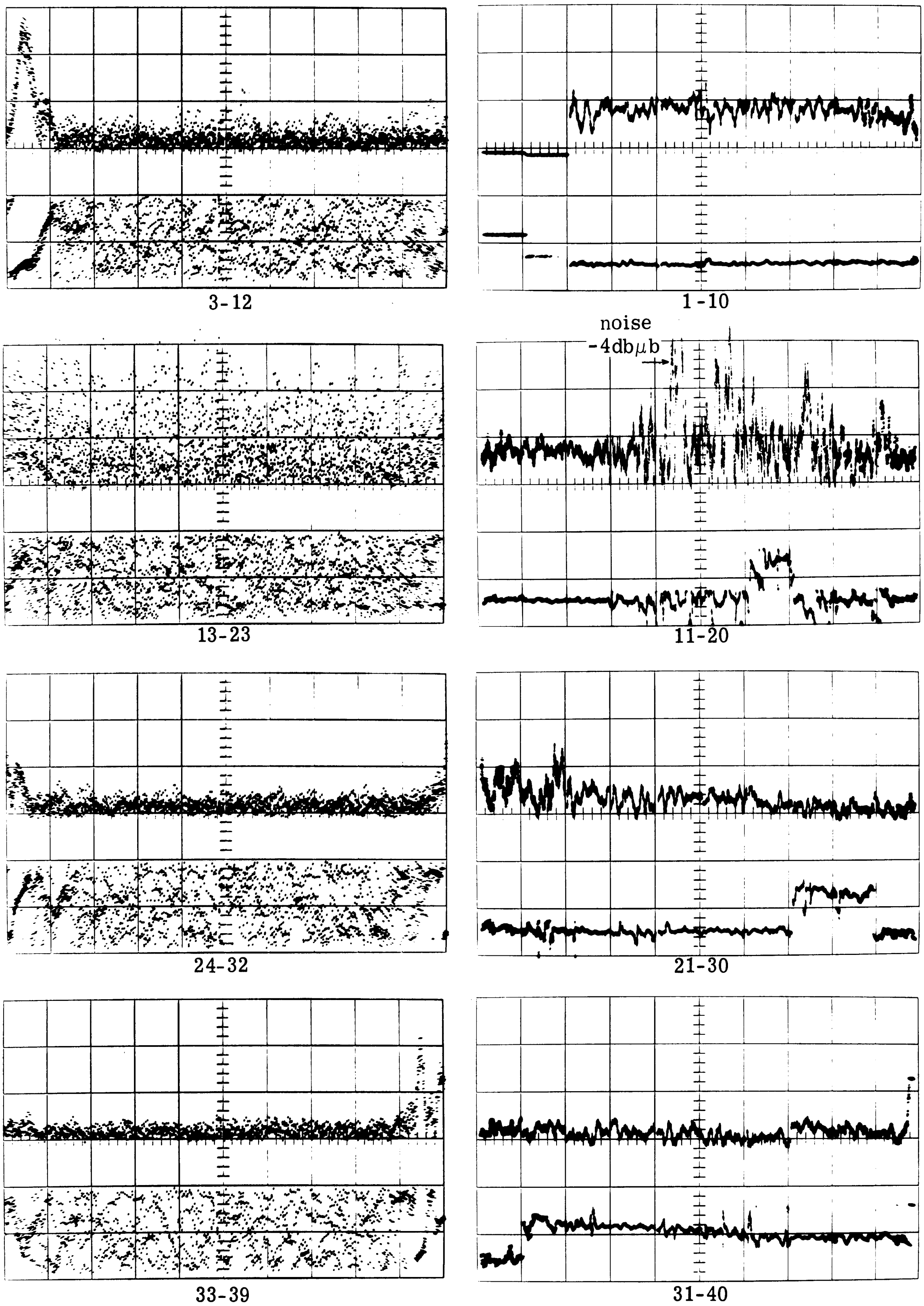


31-40

SEQ, R = 0.5 V/cm

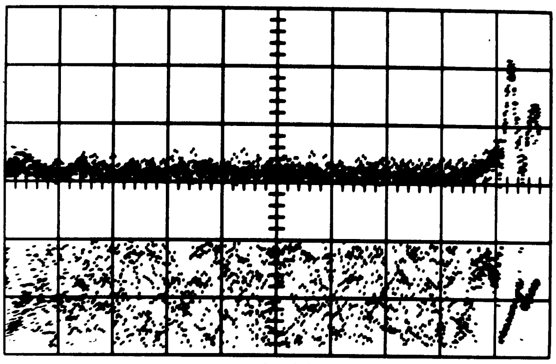
CW, R = 0.2 V/cm

AMSEQ 11 August 1966 1700 - 1712 hours

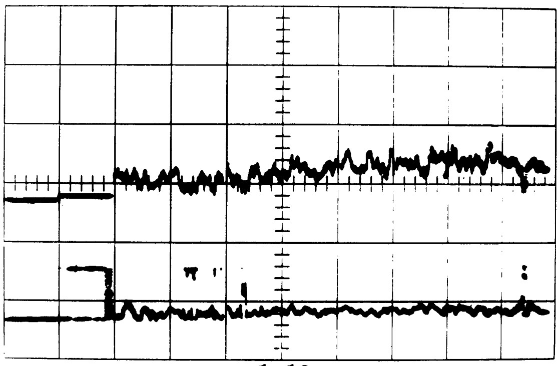


SEQ, R = 0.5 V/cm   CW, R = 0.2 V/cm

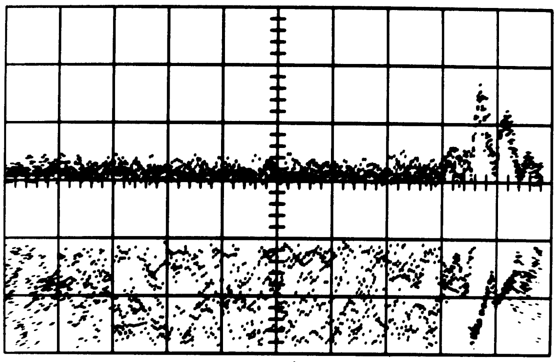
AMSEQ 11 August 1966 1712 - 1724 hours



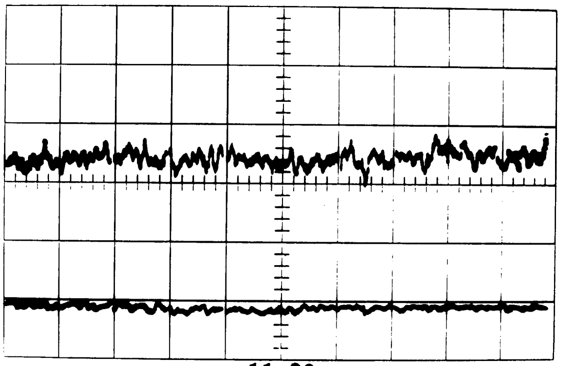
3-11



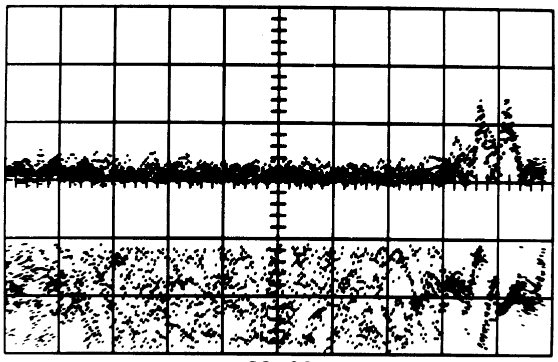
1-10



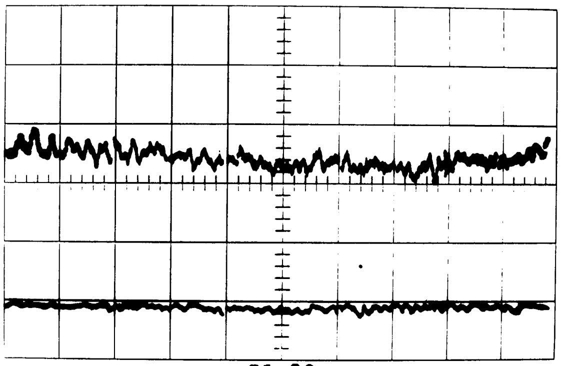
13-19



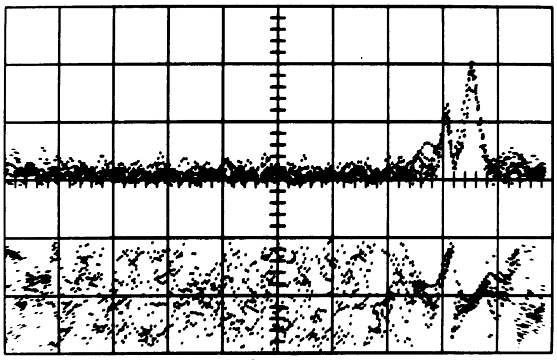
11-20



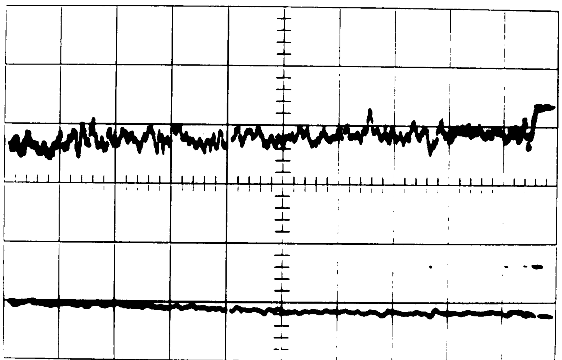
23-32



21-30



33-39

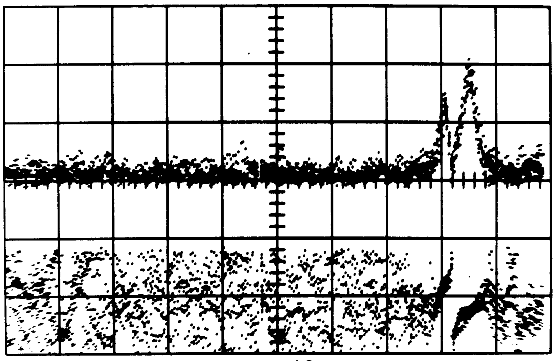


31-40

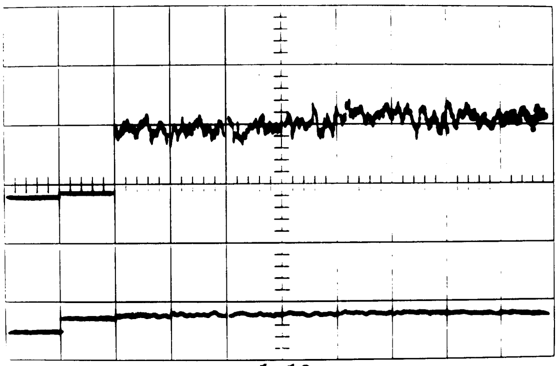
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

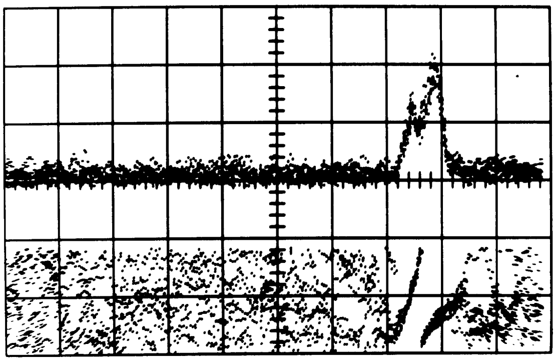
AMSEQ 11 August 1966 1724 - 1736 hours



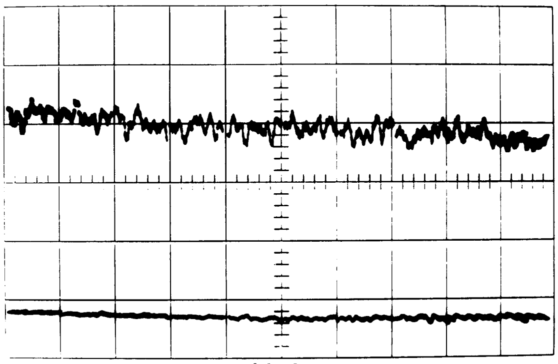
3-12



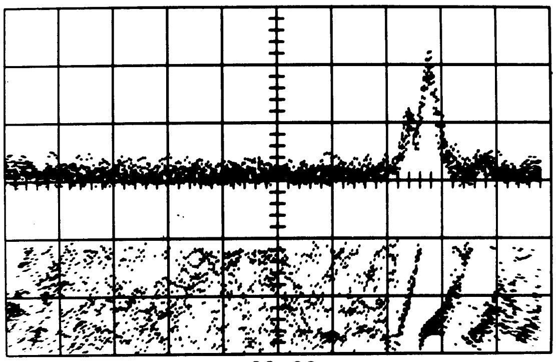
1-10



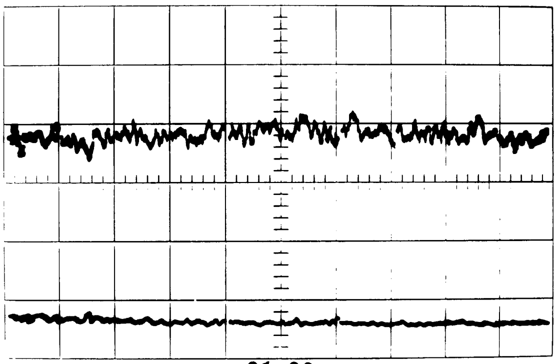
13-22



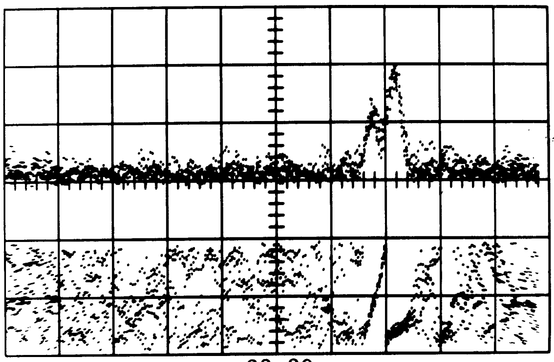
11-20



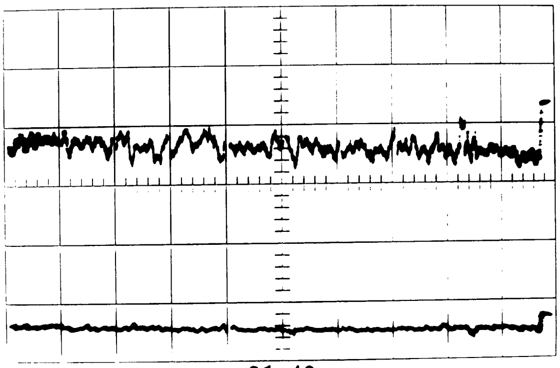
23-32



21-30



33-39

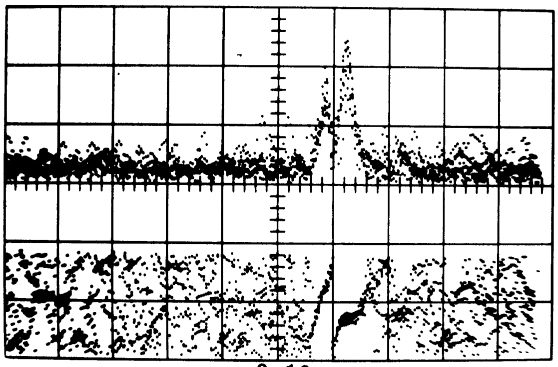


31-40

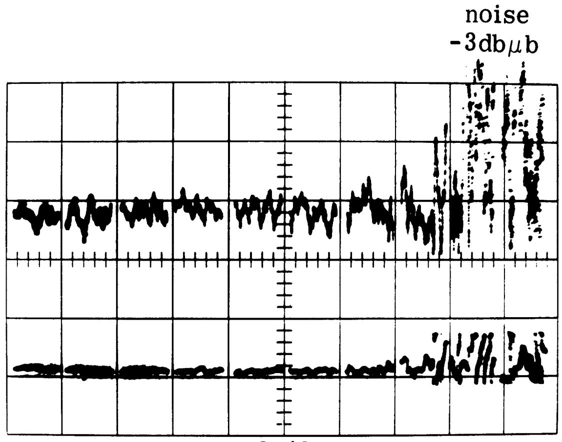
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

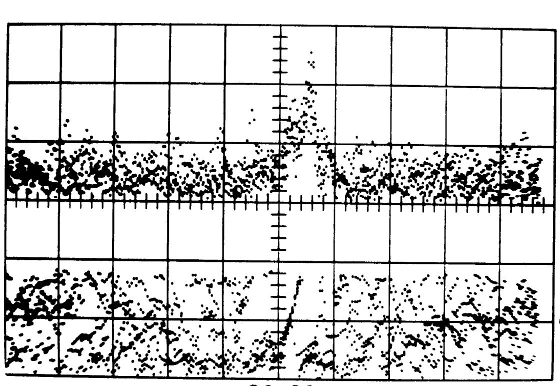
AMSEQ 11 August 1966 1736-1748 hours



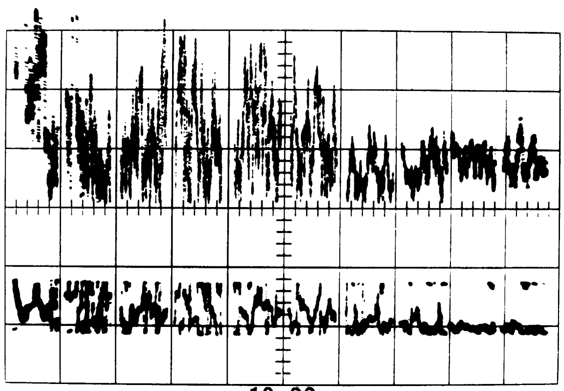
3-10



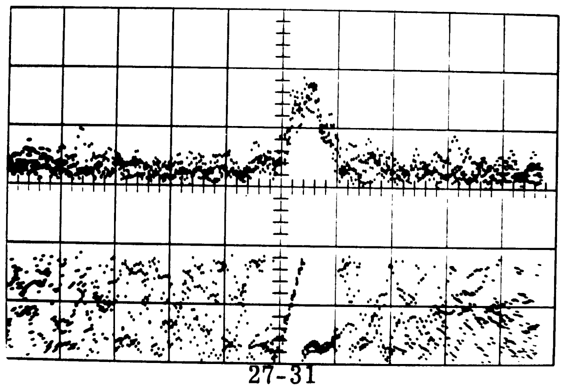
3-12



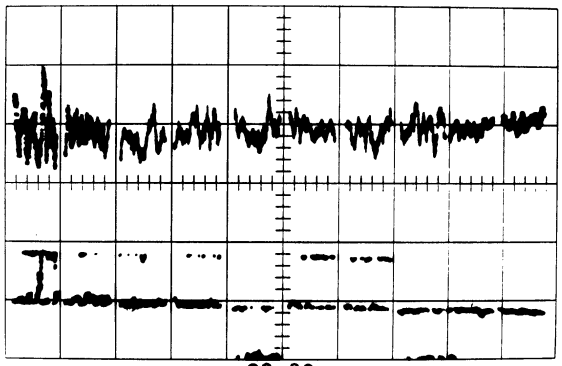
20-26



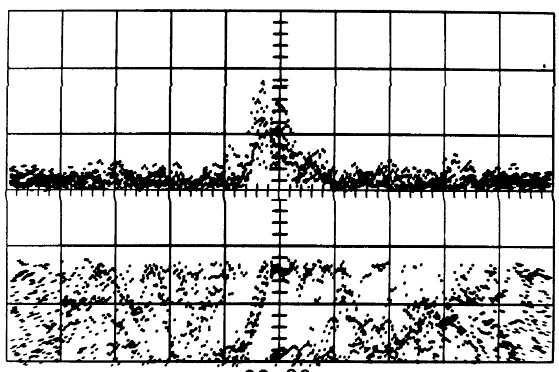
13-22



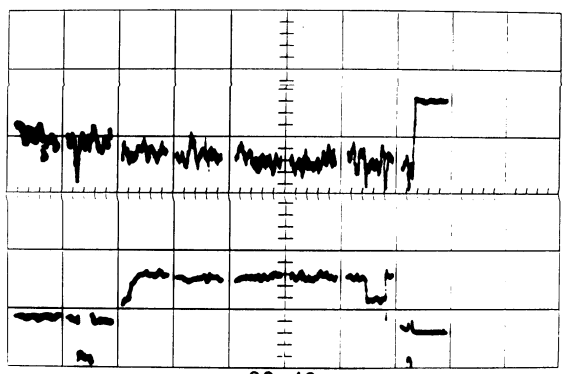
27-31



23-32



32-38

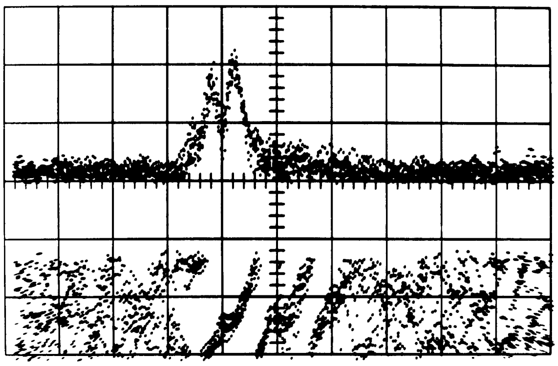


33-40

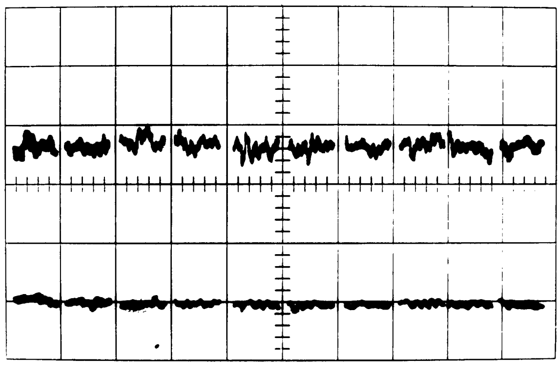
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

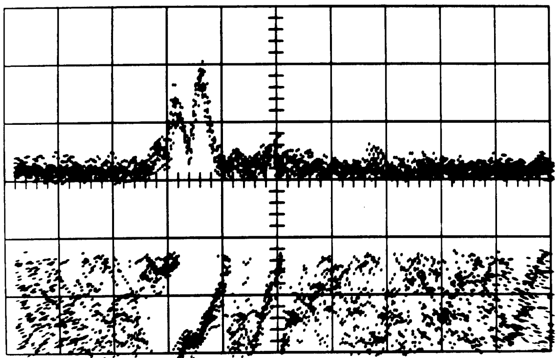
AMSEQ 11 August 1966 1748 - 1800 hours



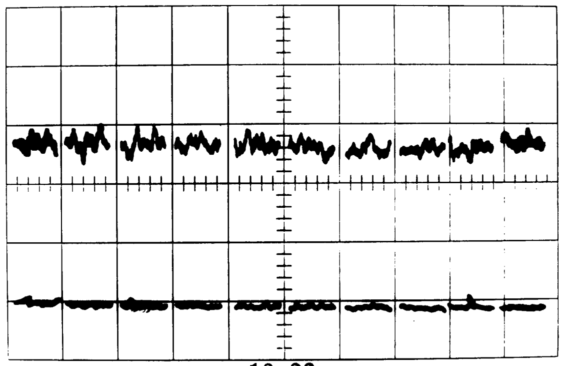
3-11



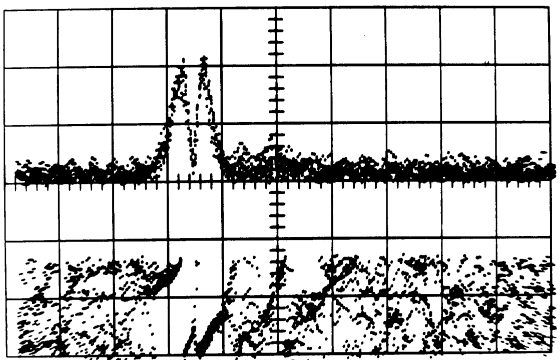
3-12



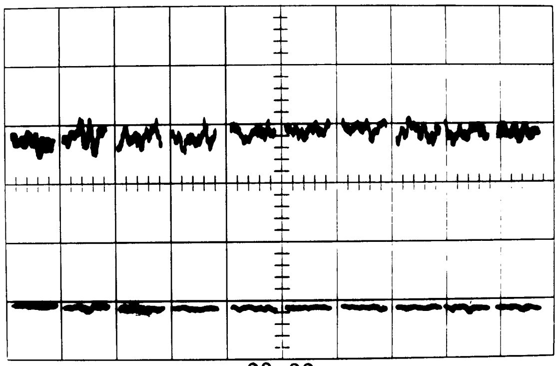
12-21



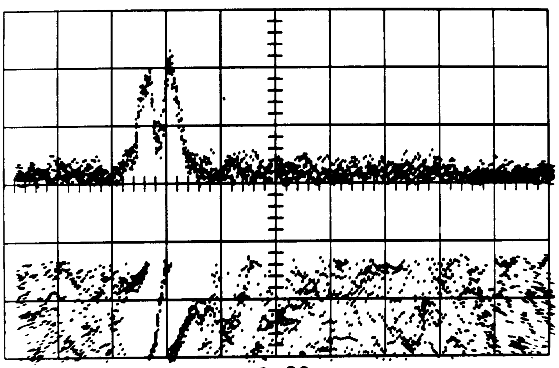
13-22



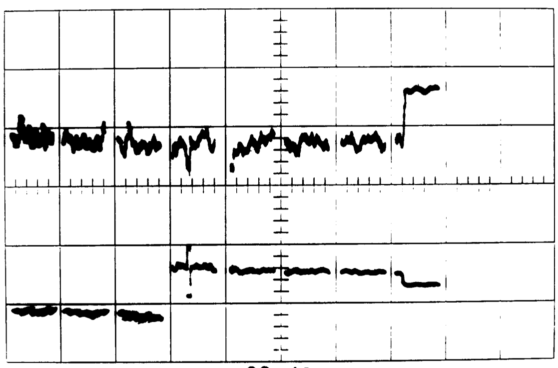
22-31



23-32



32-39

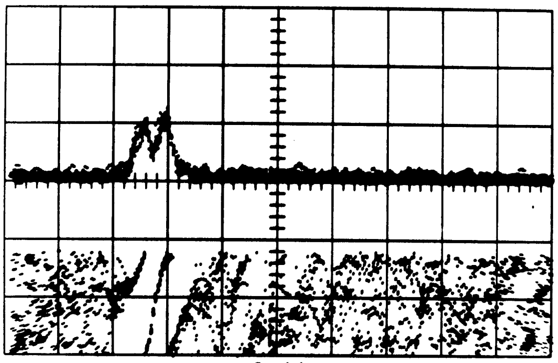


33-40

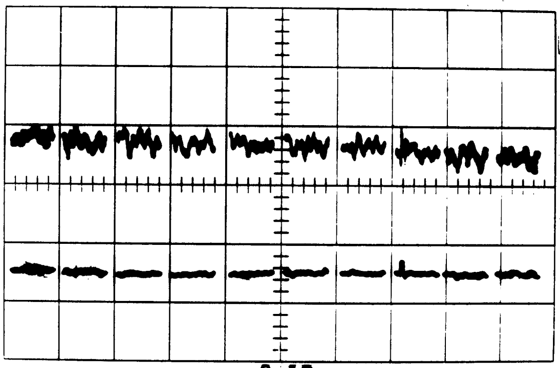
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

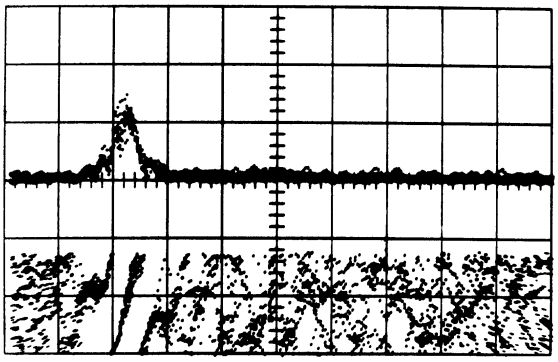
AMSEQ 11 August 1966 1812 - 1824 hours



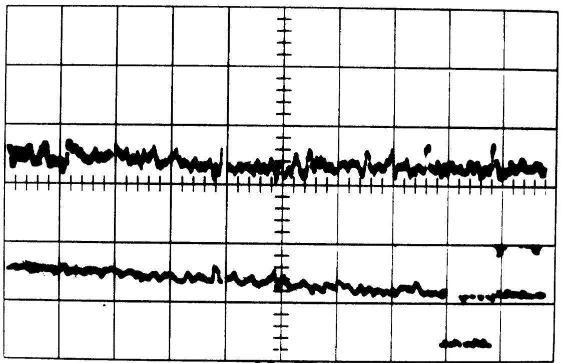
3-11



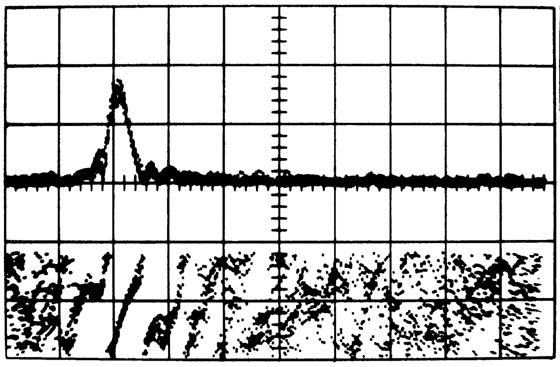
3-12



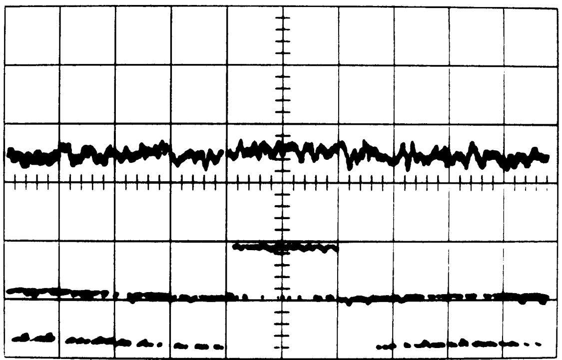
12-21



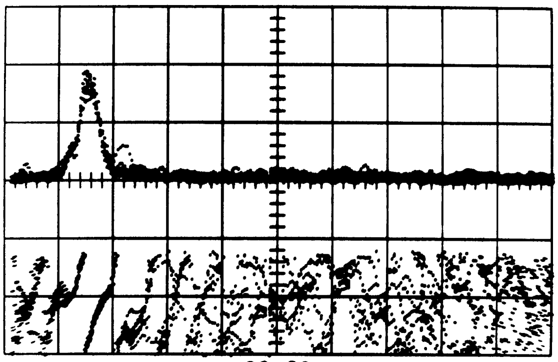
13-22



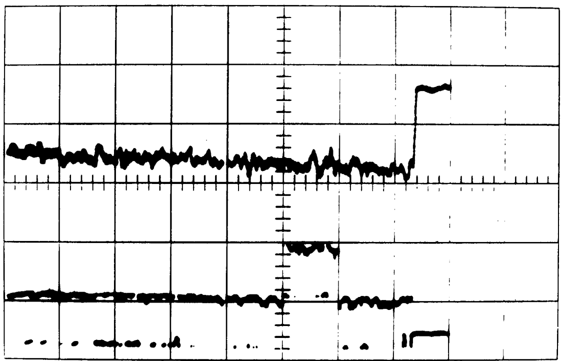
22-31



23-32



32-39

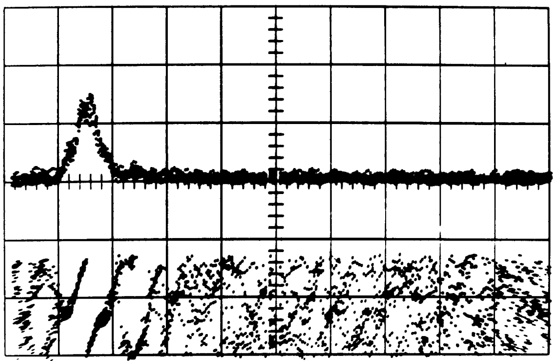


33-40

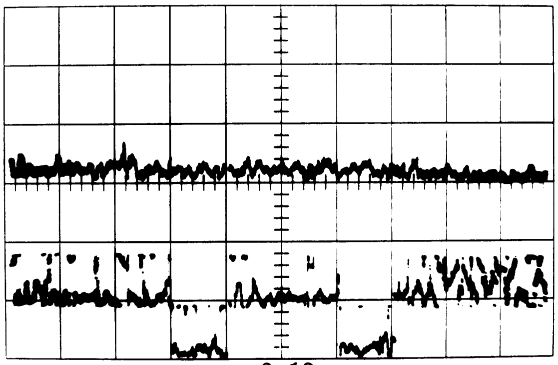
SEQ, R = 1.0 V/cm

CW, R = 0.2 V/cm

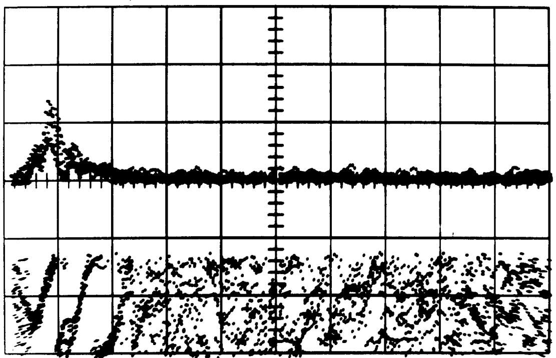
AMSEQ 11 August 1966 1824 - 1836 hours



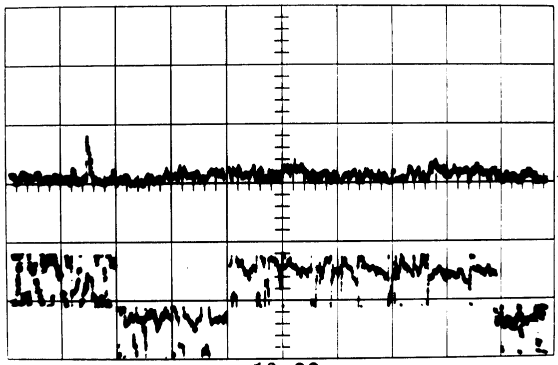
3-11



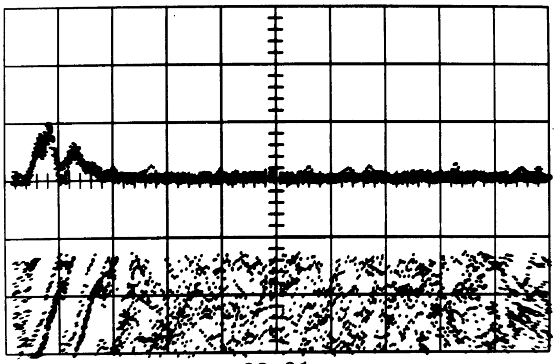
3-12



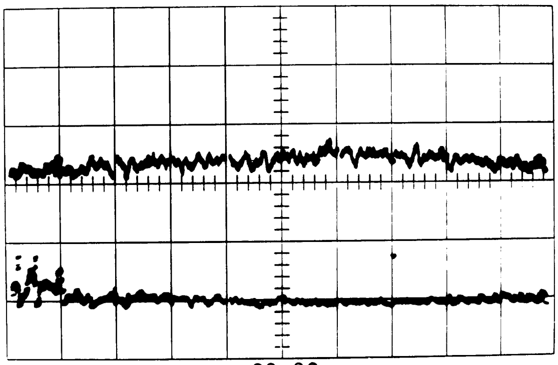
12-21



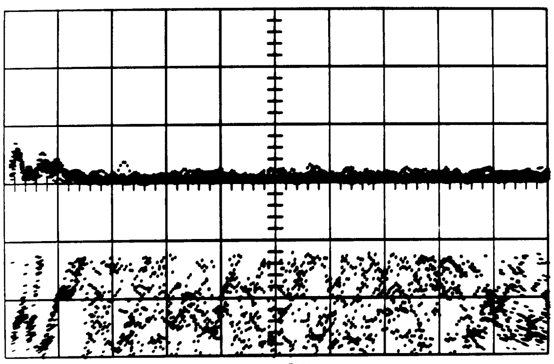
13-22



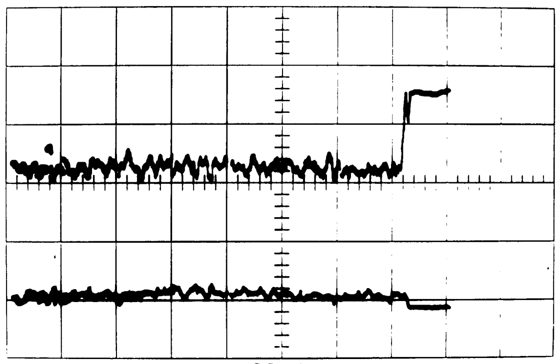
22-31



23-32



32-39

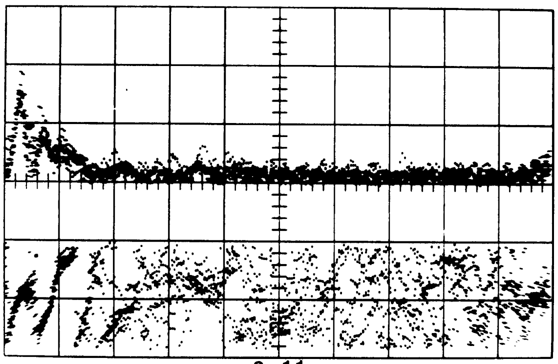


33-40

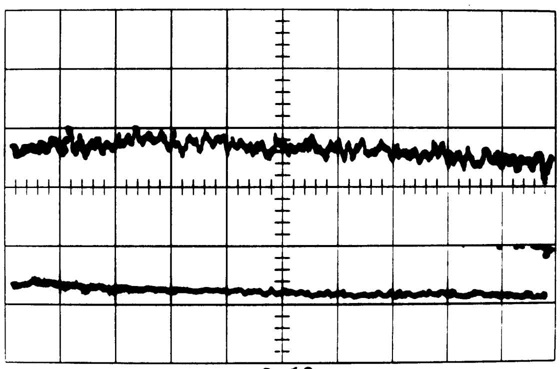
SEQ, R = 1.0 V/cm

CW, R = 0.2 V/cm

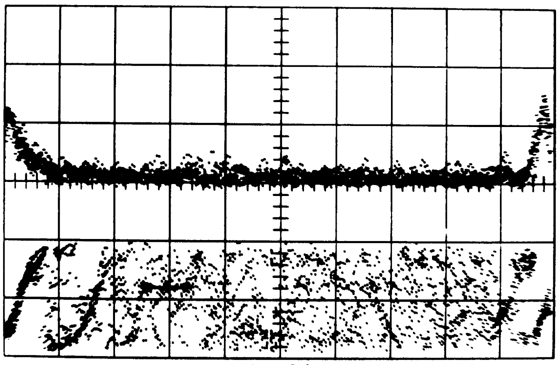
AMSEQ 11 August 1966 1836 - 1848 hours



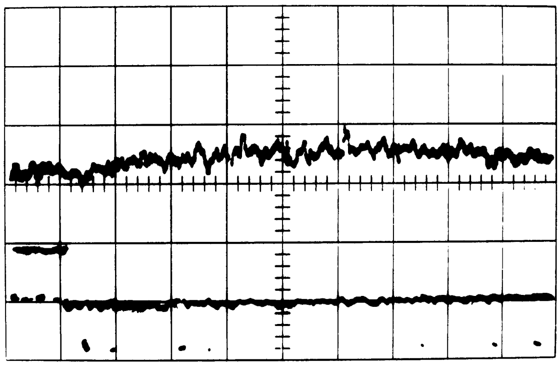
3-11



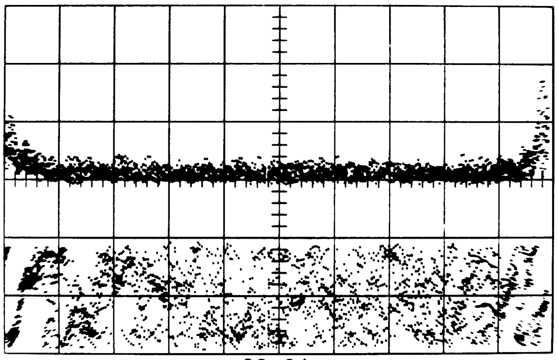
3-12



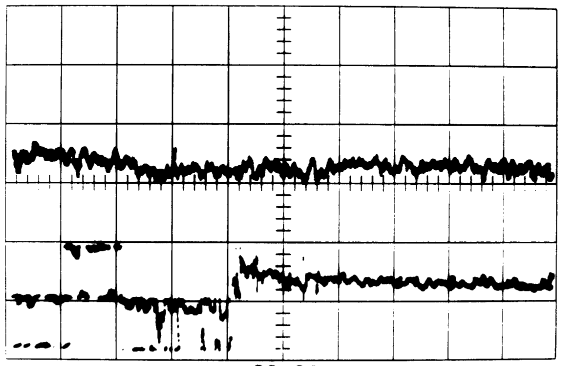
12-21



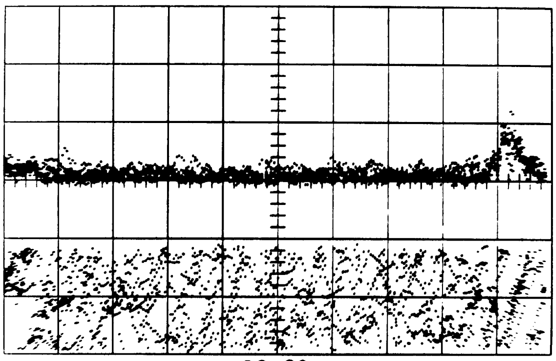
13-22



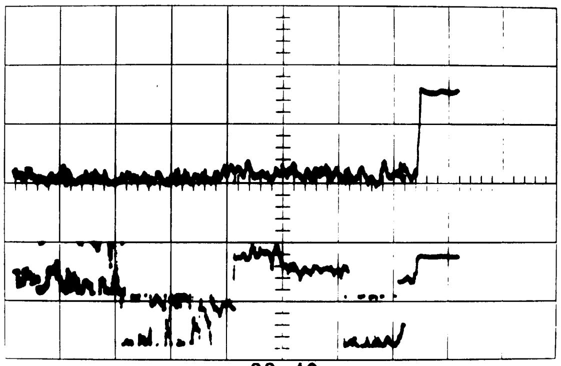
22-31



23-32



32-39

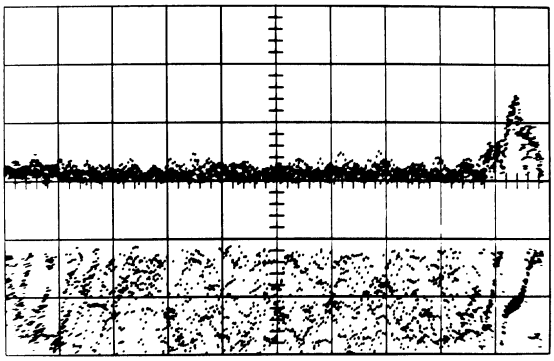


33-40

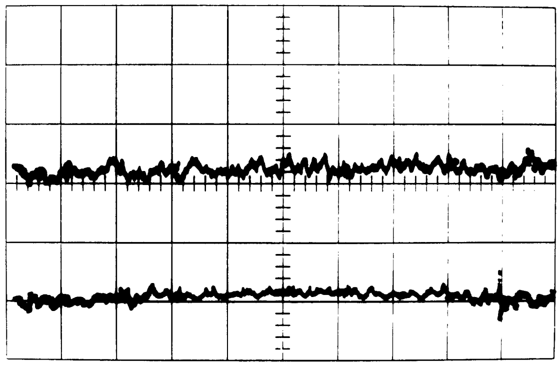
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

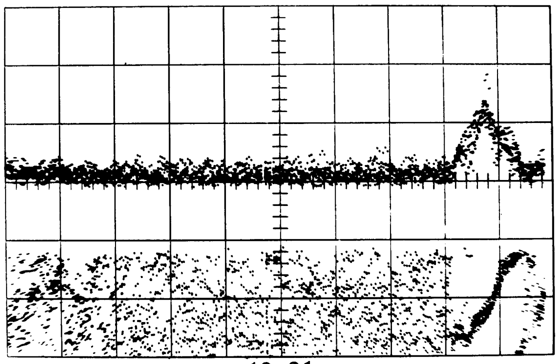
AMSEQ 11 August 1966 1848 - 1900 hours



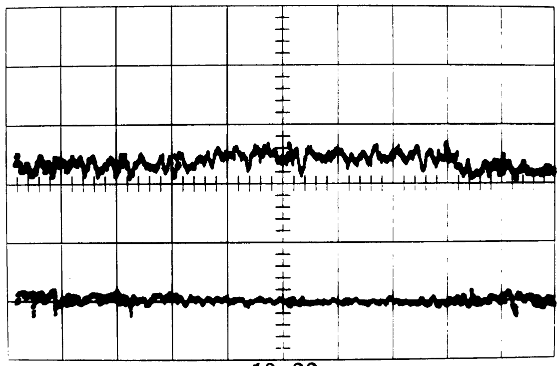
3-11



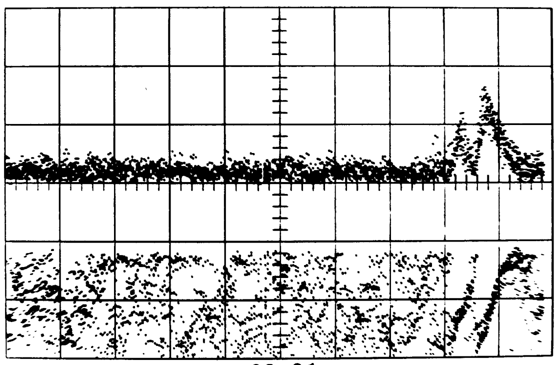
3-12



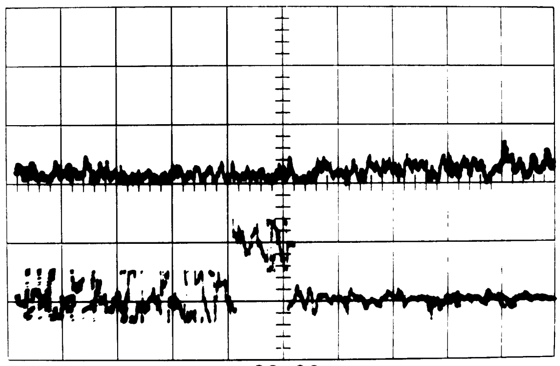
12-21



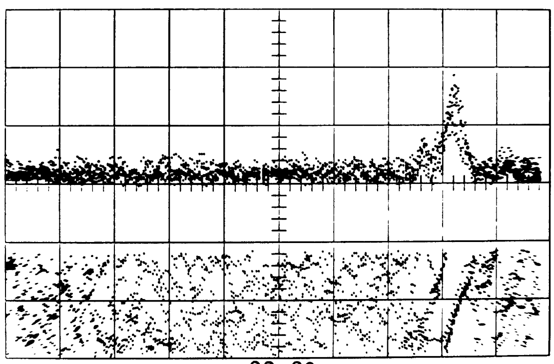
13-22



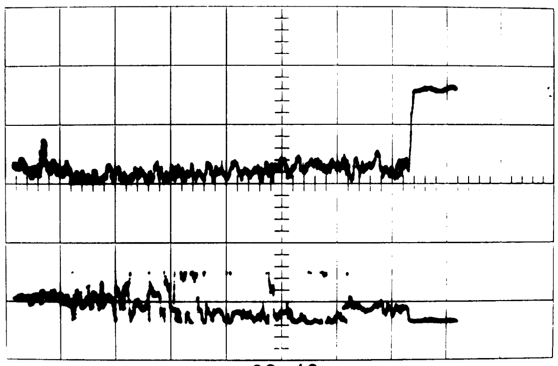
22-31



23-32



32-39

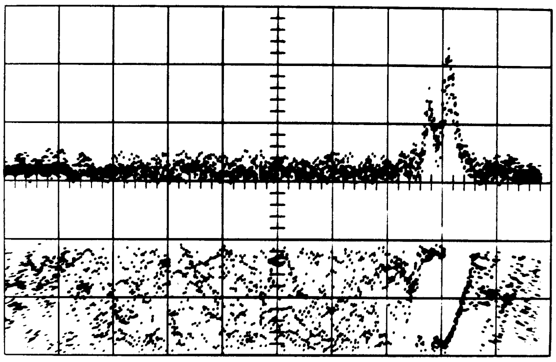


33-40

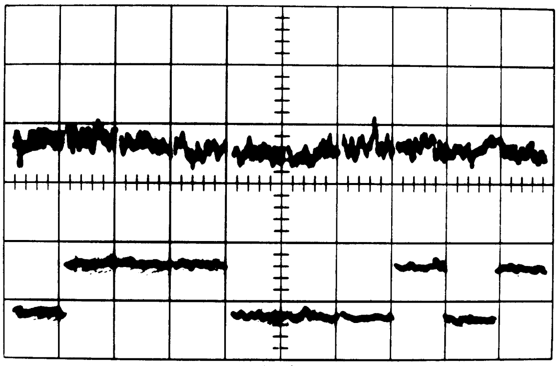
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

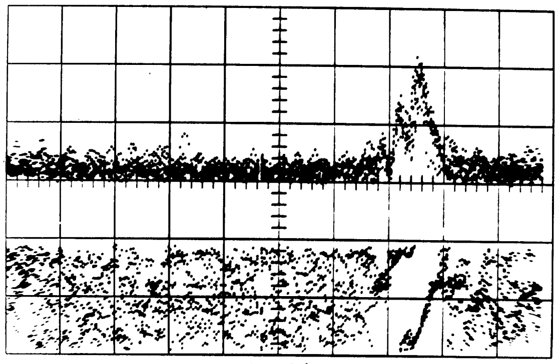
AMSEQ 11 August 1966 1900 - 1912 hours



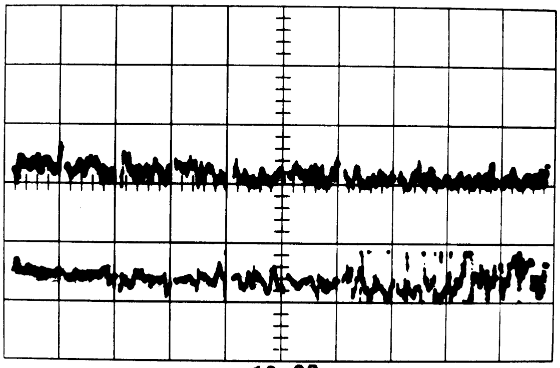
3-11



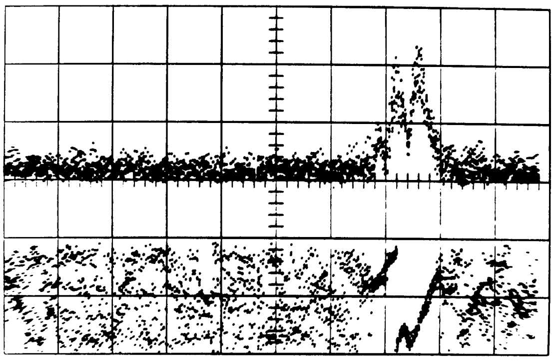
3-12



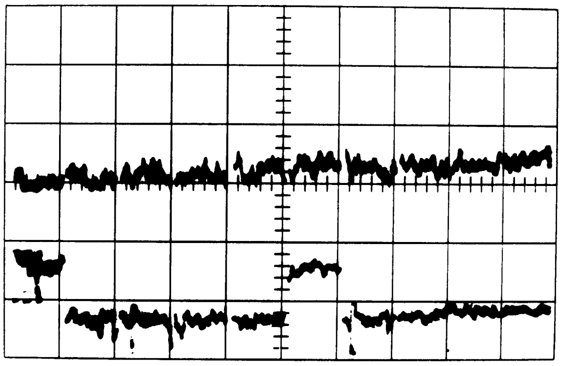
12-21



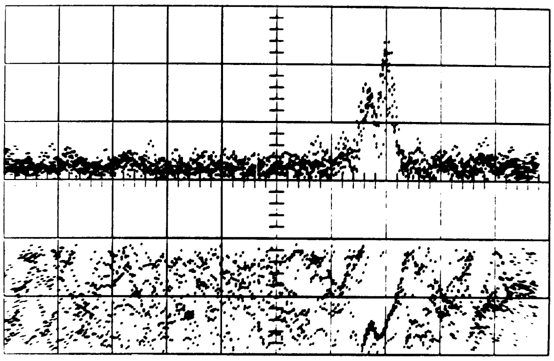
13-22



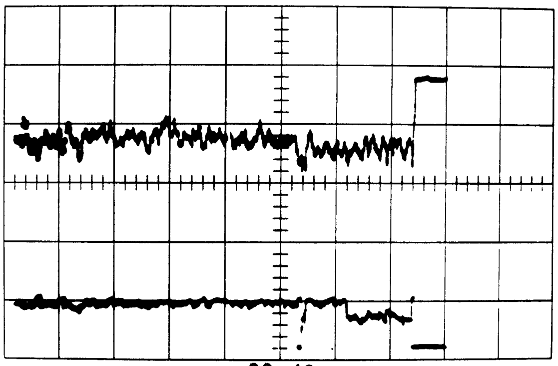
22-31



23-32



32-39

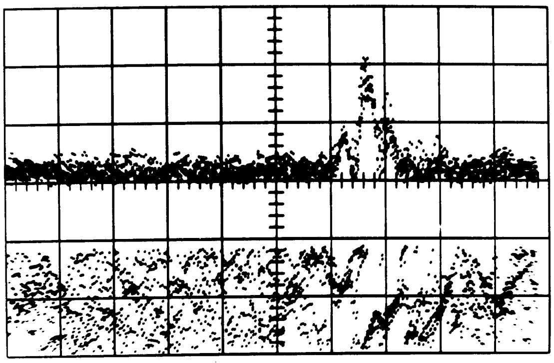


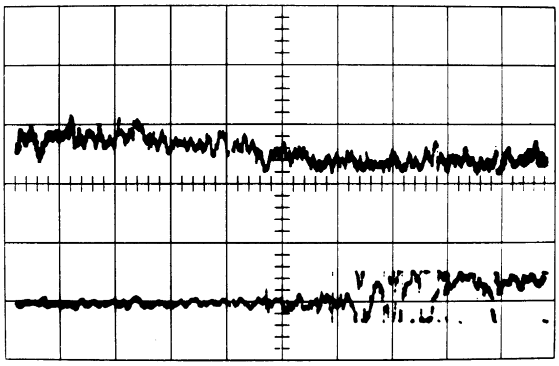
33-40

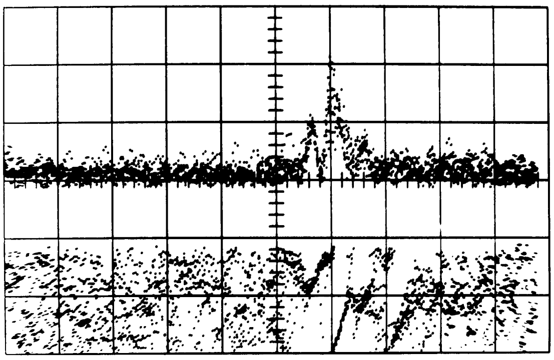
SEQ, R = 0.5 V/cm

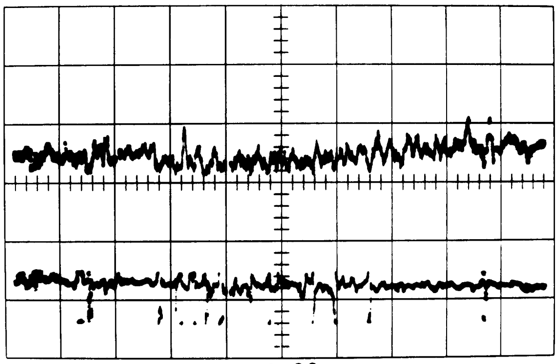
CW, R = 0.2 V/cm

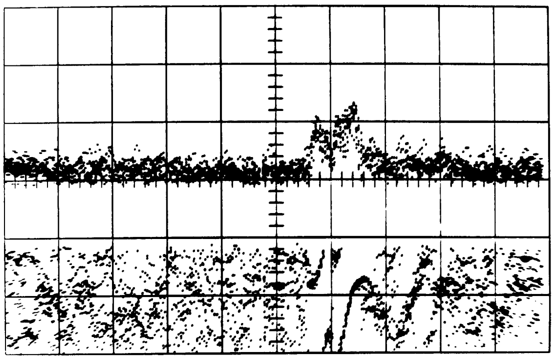
AMSEQ 11 August 1966 1912 - 1924 hours

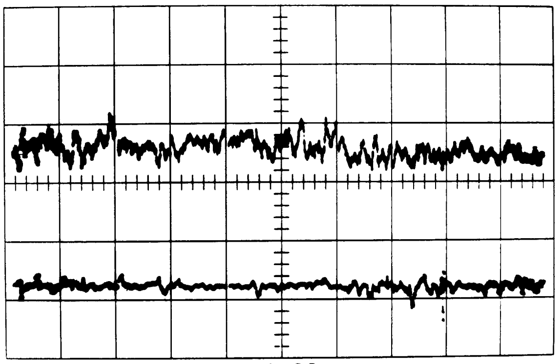

3-11

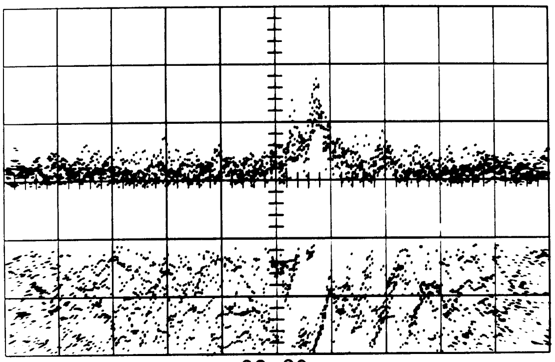

3-12

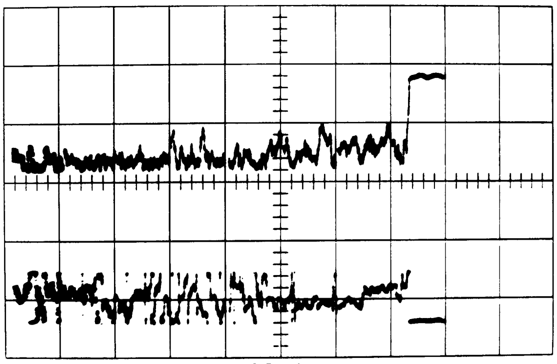

12-21


13-22


22-31


23-32

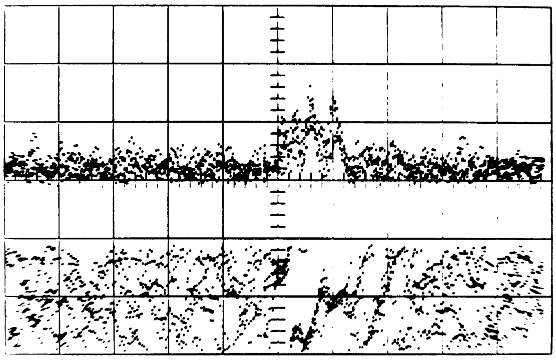

32-39


33-40

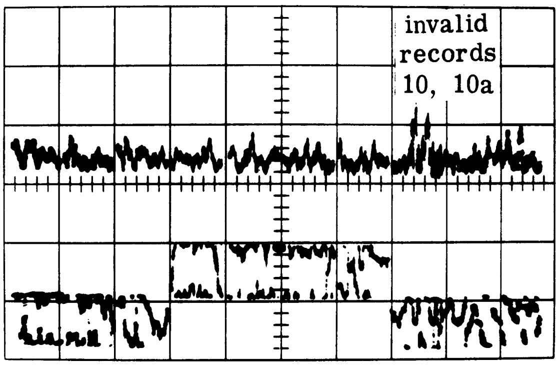
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

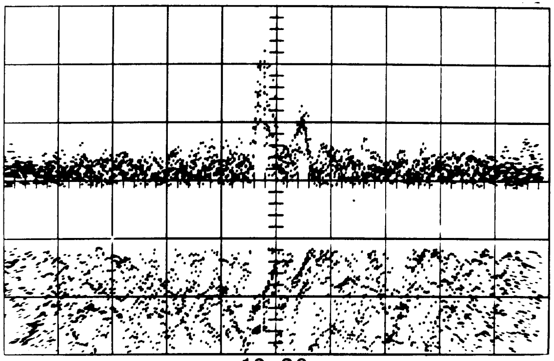
AMSEQ 11 August 1966 1924 - 1936 hours



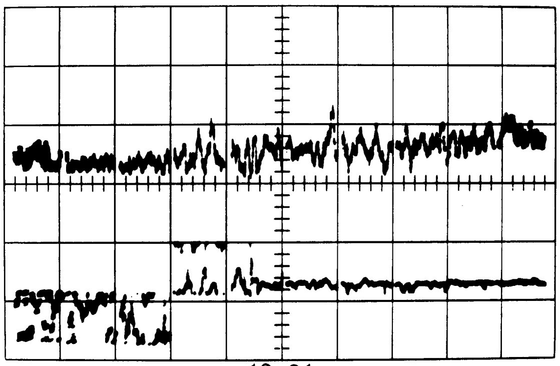
3-9



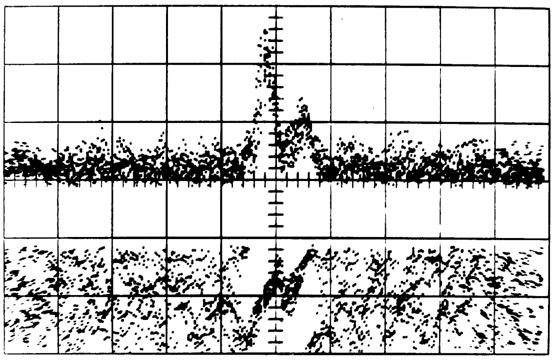
3-11



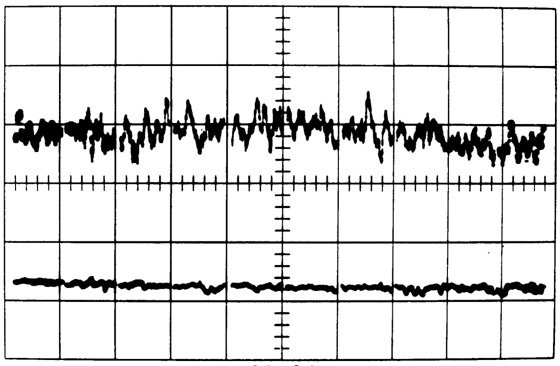
13-20



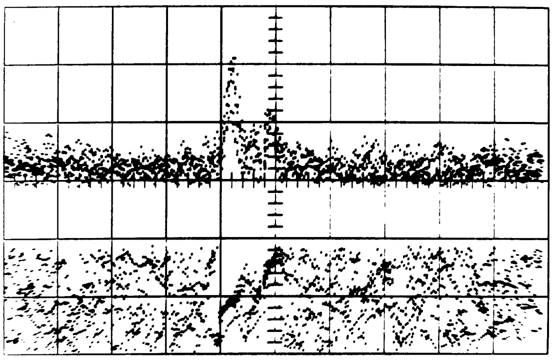
12-21



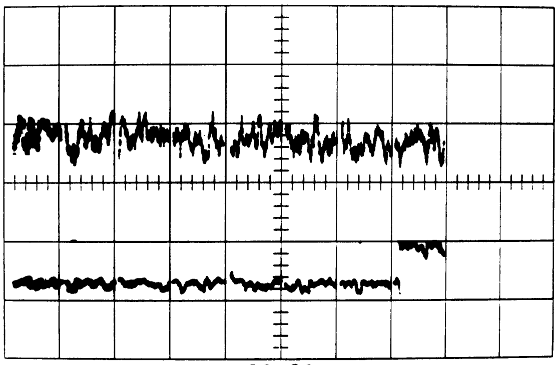
21-31



22-31



32-39

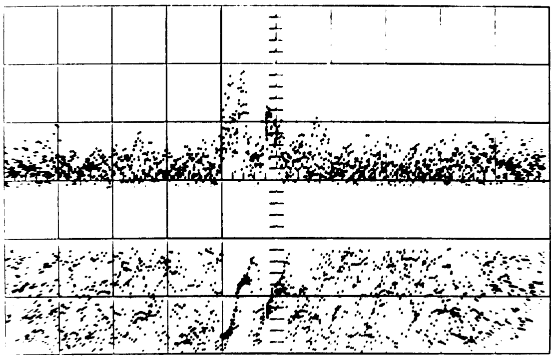


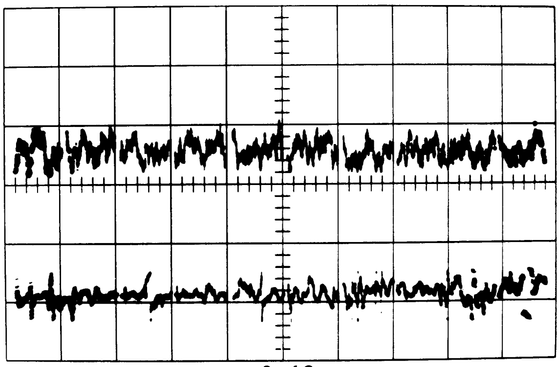
32-39

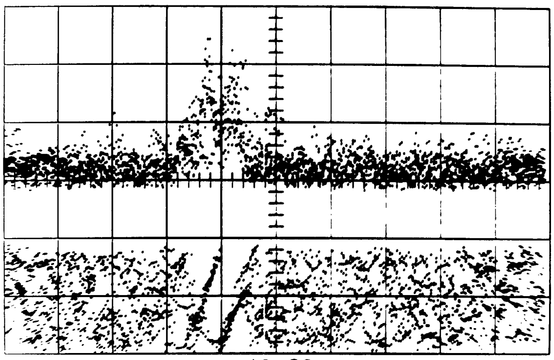
SEQ, R = 0.5V/cm

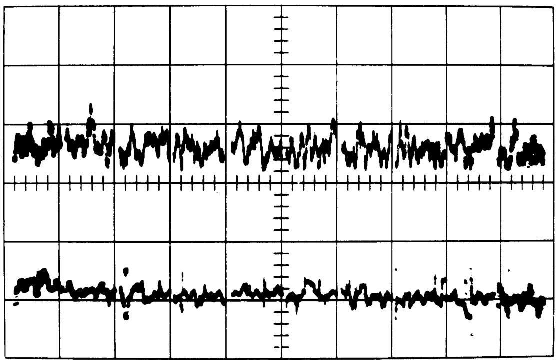
CW, R = 0.2V/cm

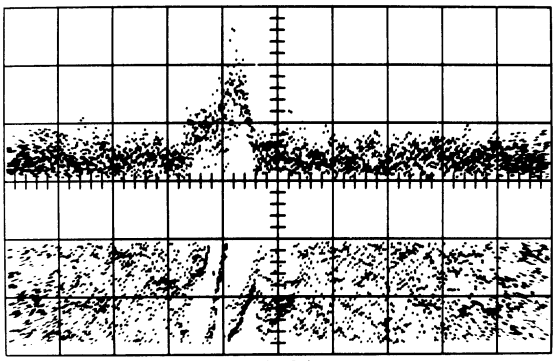
AMSEQ 11 August 1966 1936-1948 hours

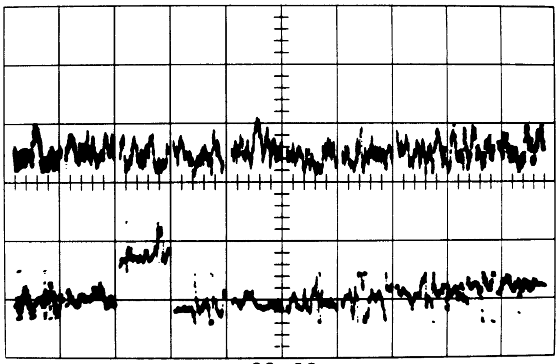

3-9

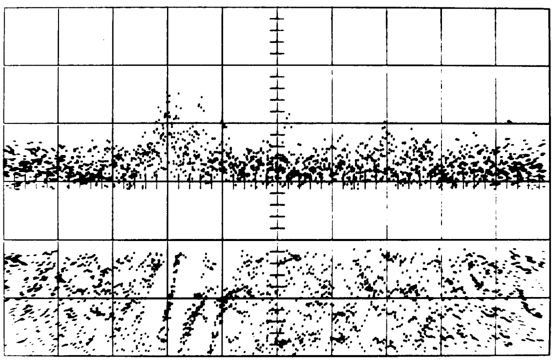

3-12

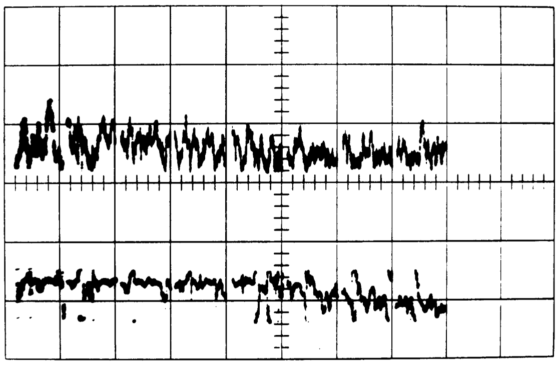

10-20


13-22


21-31


23-32

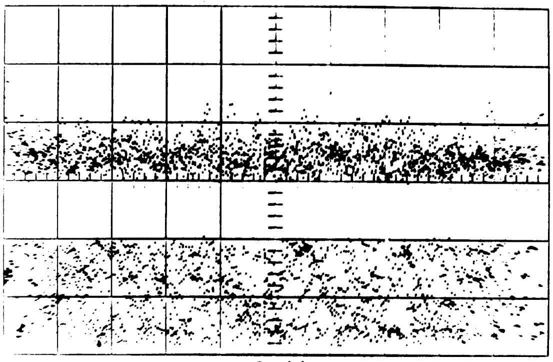

32-39


33-40

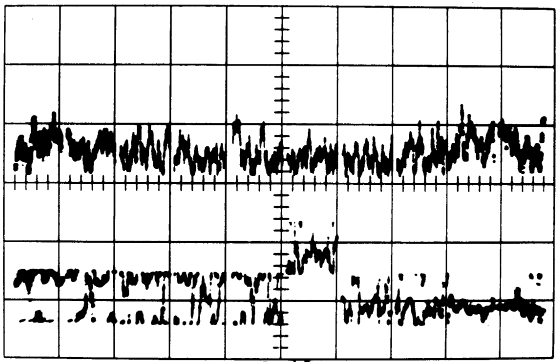
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

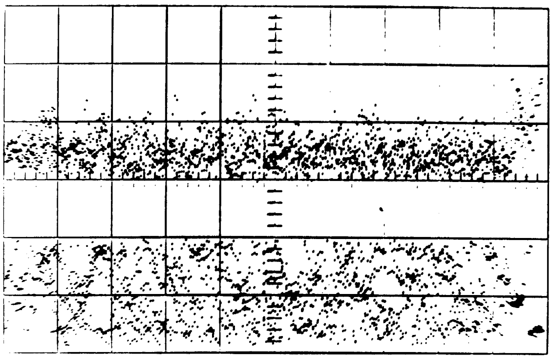
AMSEQ 11 August 1966 1948 - 2000 hours



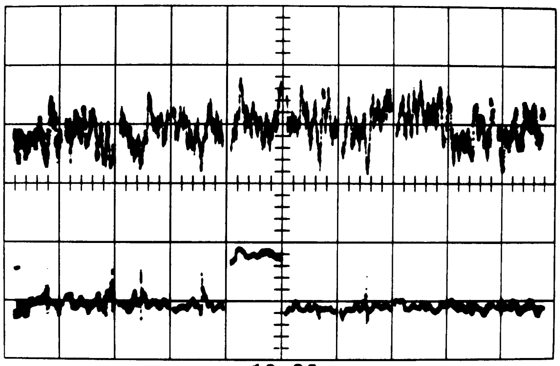
3-11



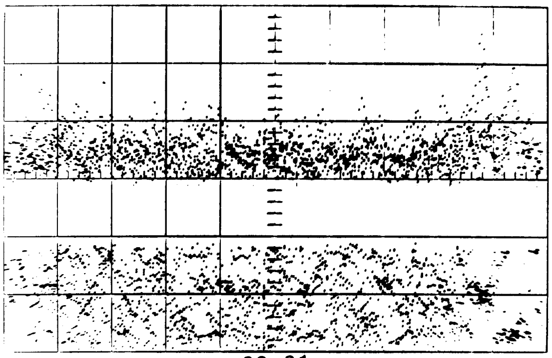
3-12



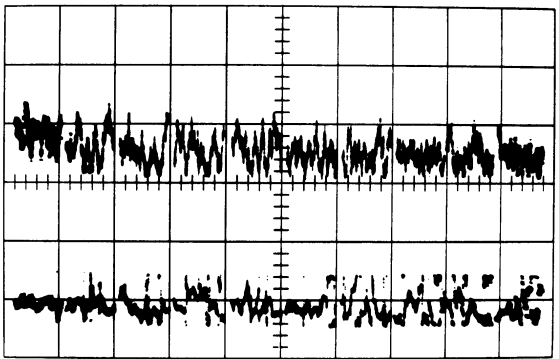
13-20



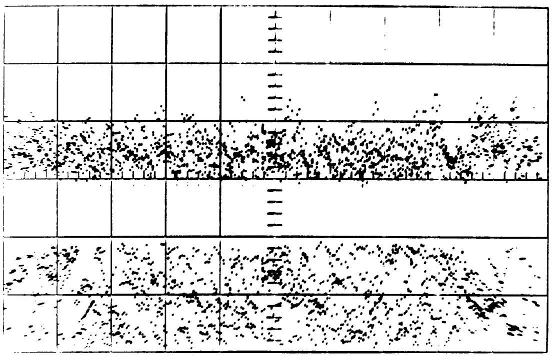
13-22



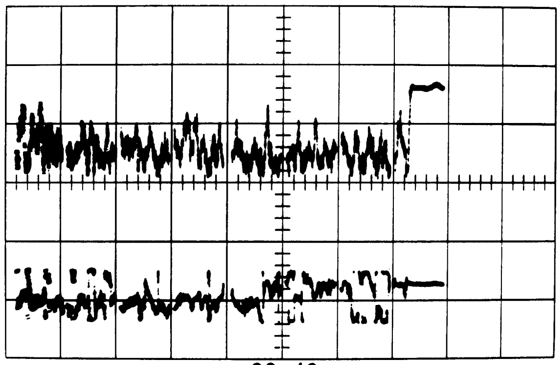
23-31



23-32



32-39

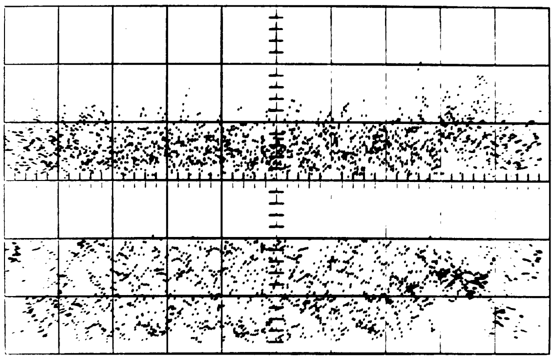


33-40

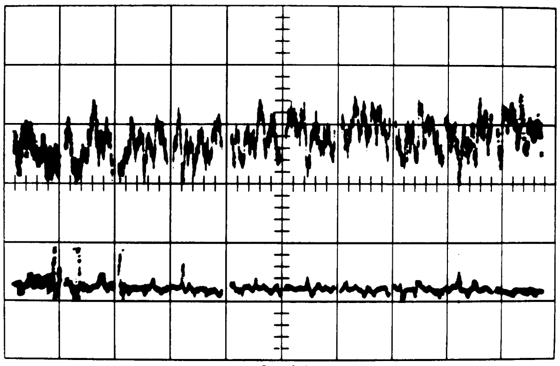
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

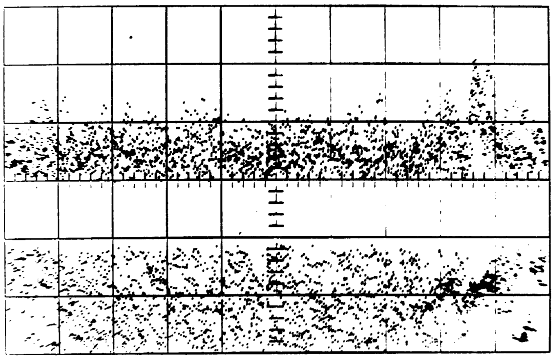
AMSEQ 11 August 1966 2015 - 2027 hours



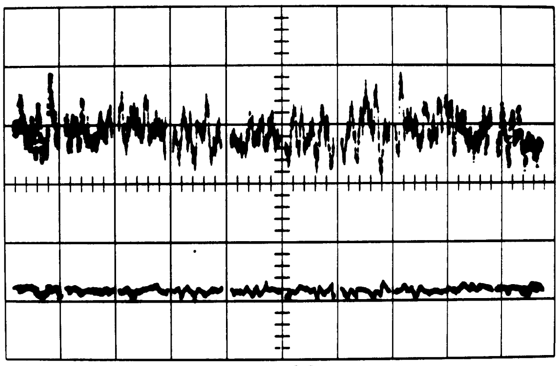
3-10



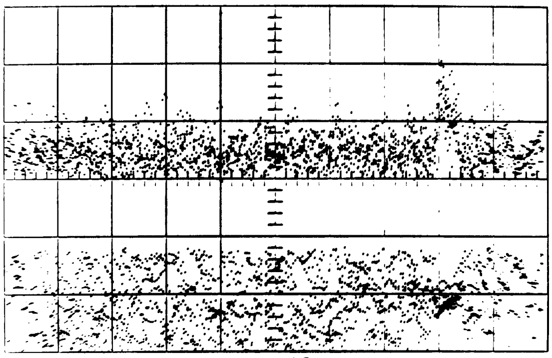
3-12



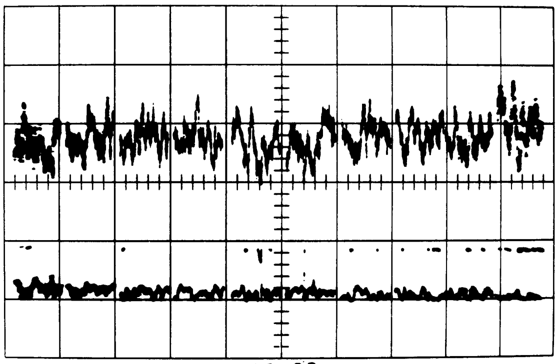
13-22



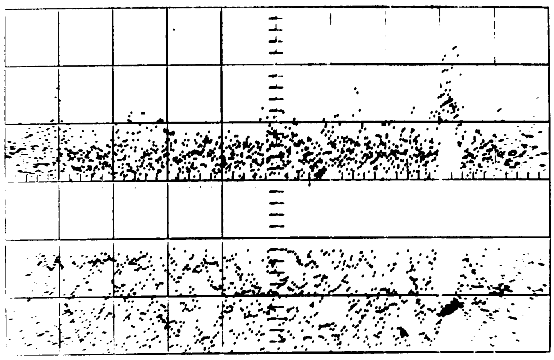
13-22



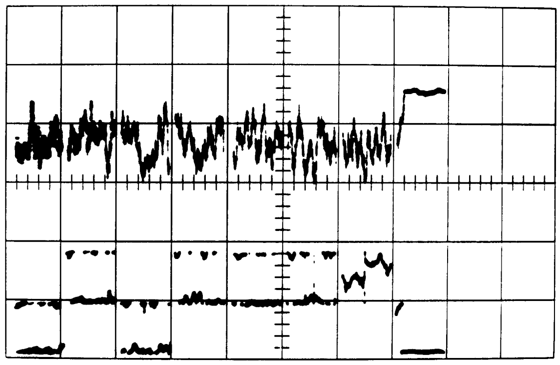
24-32



23-32



33-38

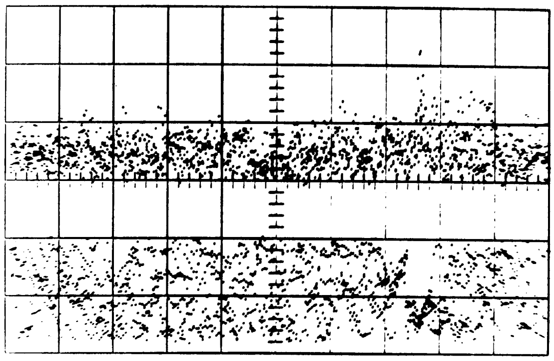


33-40

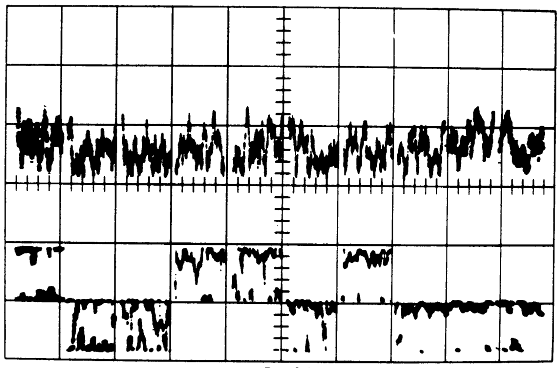
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

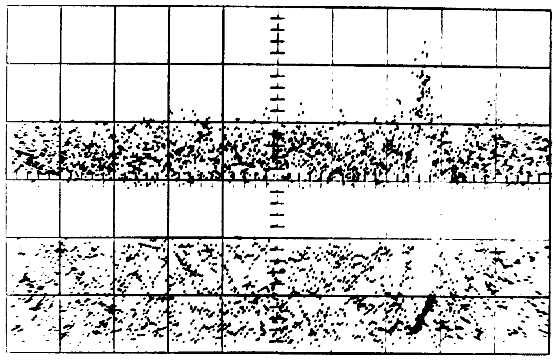
AMSEQ 11 August 1966 2027 - 2039 hours



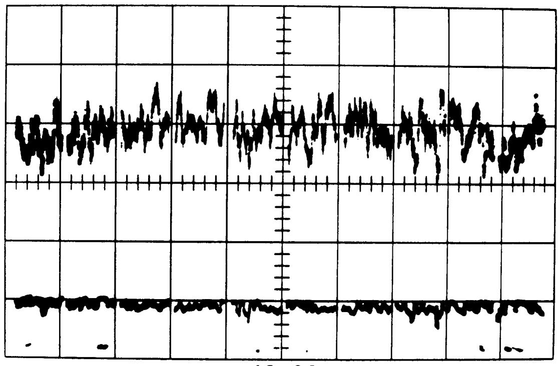
4-10



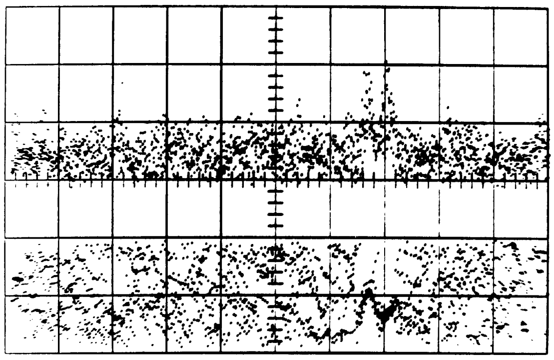
3-12



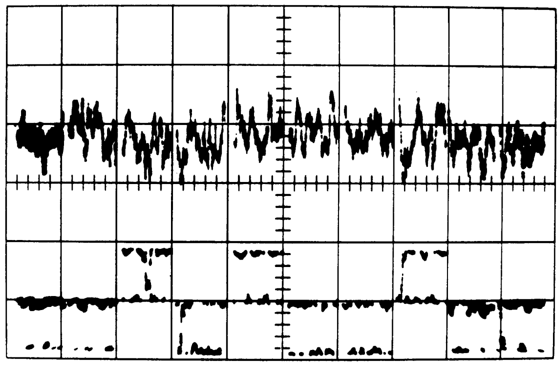
11-19



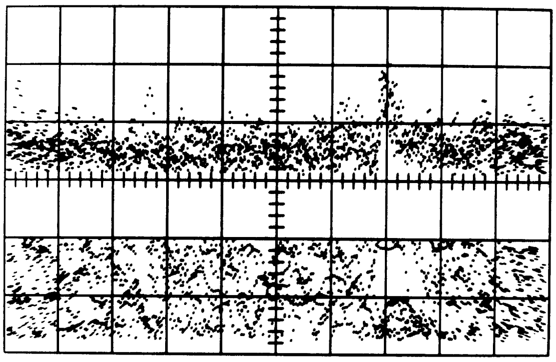
13-22



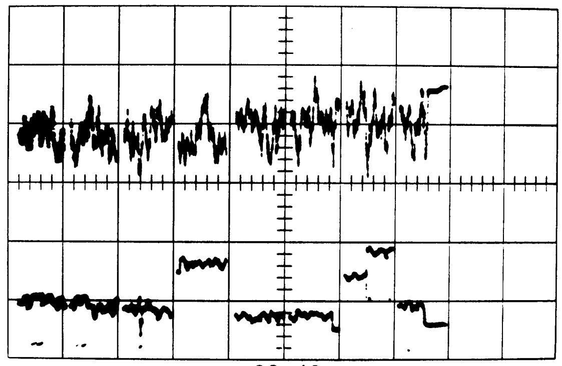
23-30



23-32



31-38

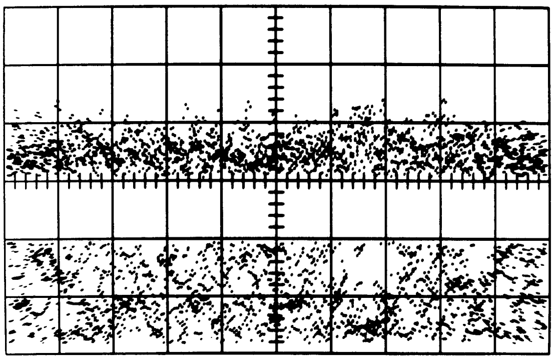


33-40

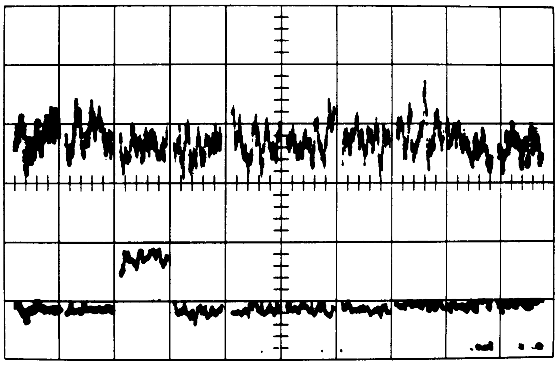
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

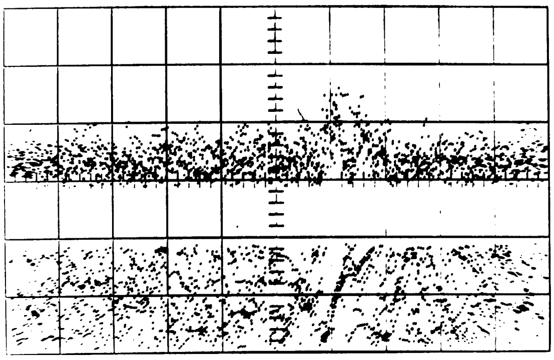
AMSEQ 11 August 1966 2039-2051 hours



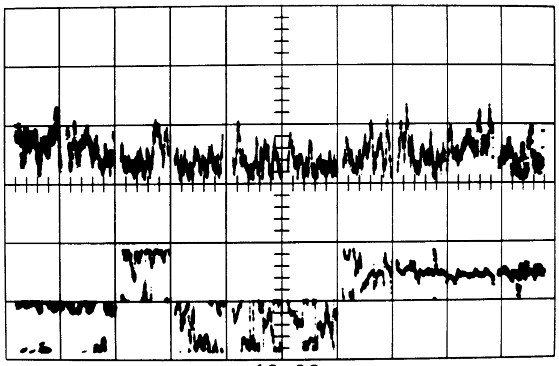
4-11



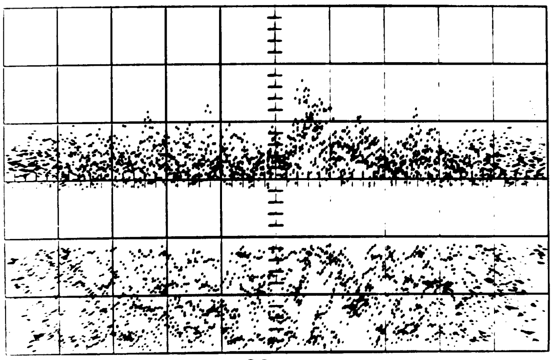
3-12



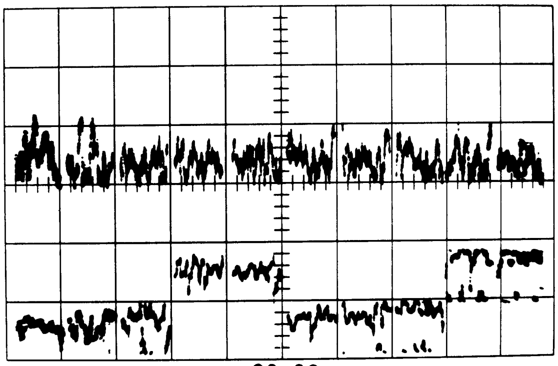
13-20



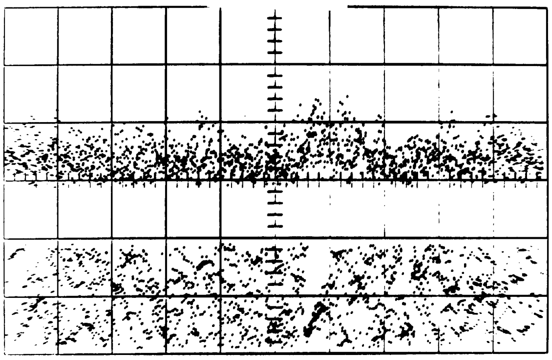
13-22



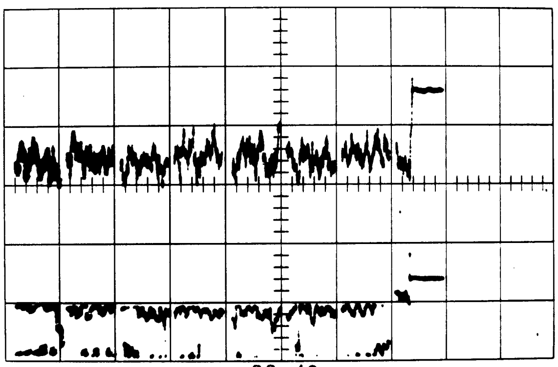
23-31



23-32



32-39

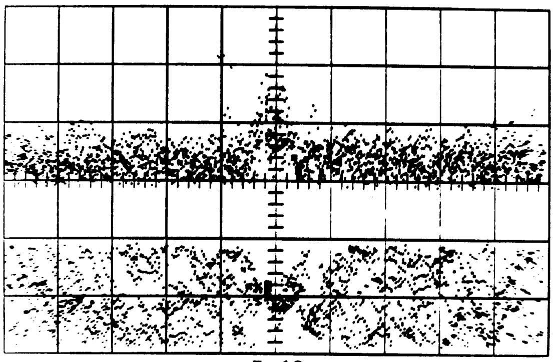


33-40

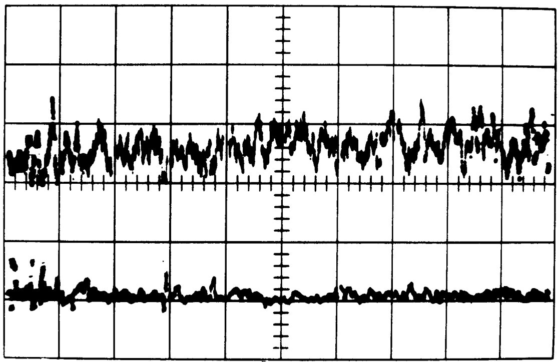
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

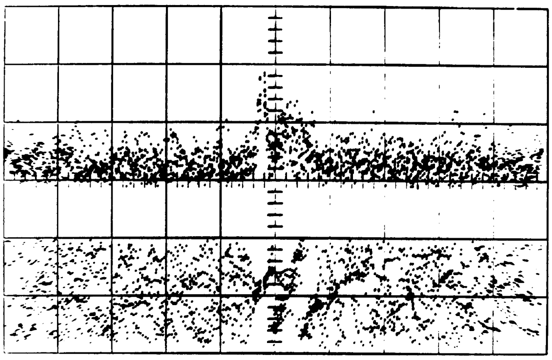
AMSEQ 11 August 1966 2051-2103 hours



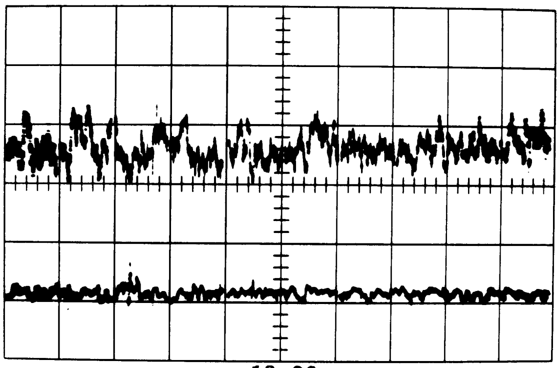
5-13



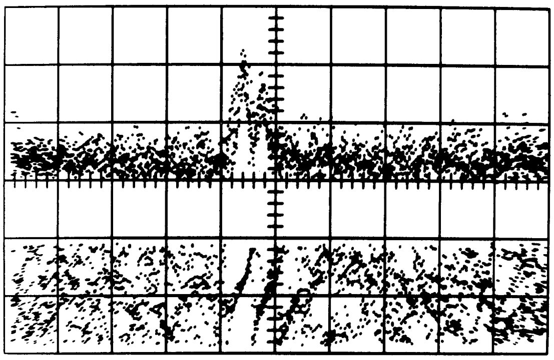
3-12



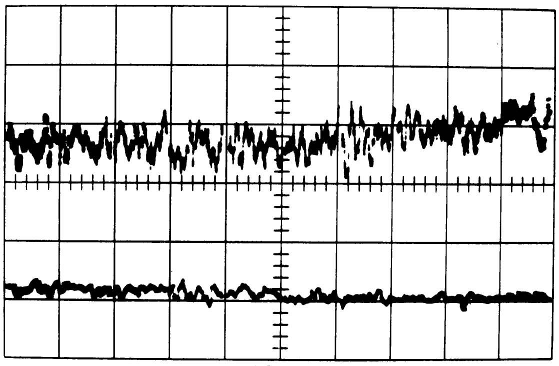
14-22



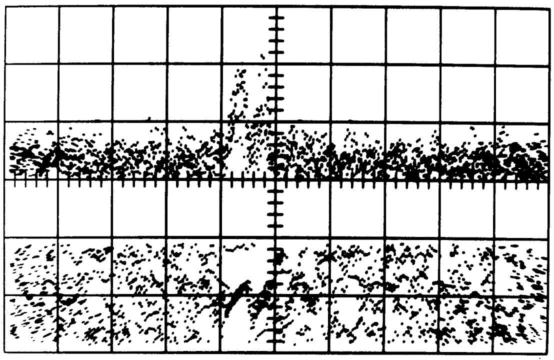
13-22



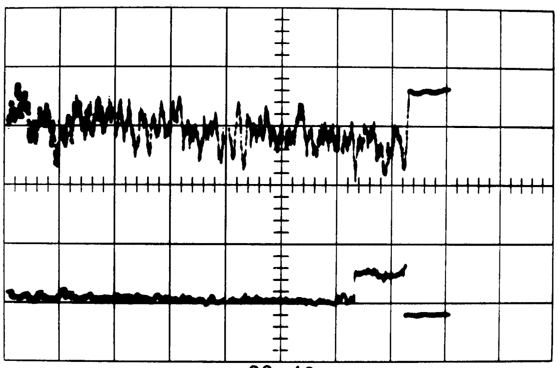
23-31



23-32



32-39

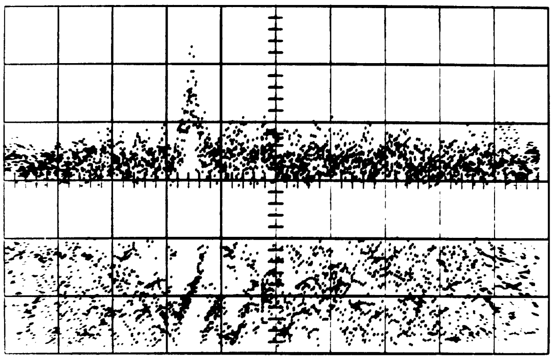


33-40

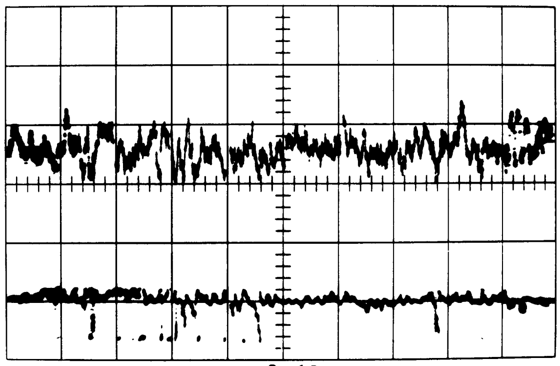
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

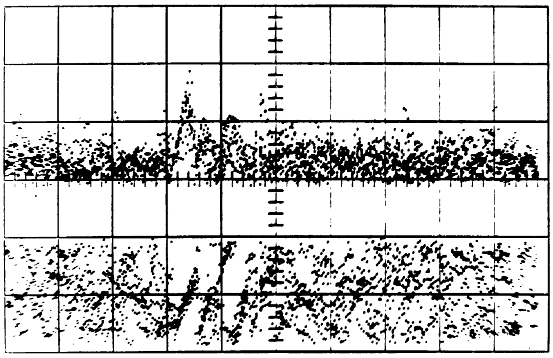
AMSEQ 11 August 1966 2103 - 2115 hours



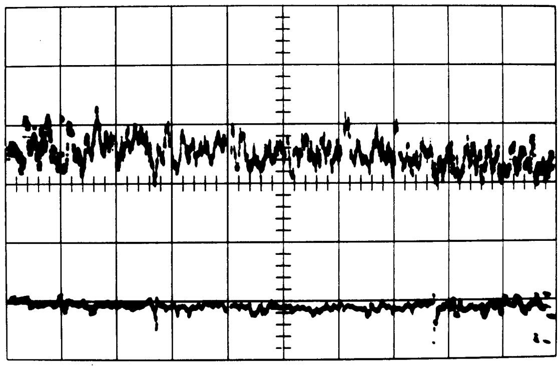
3-12



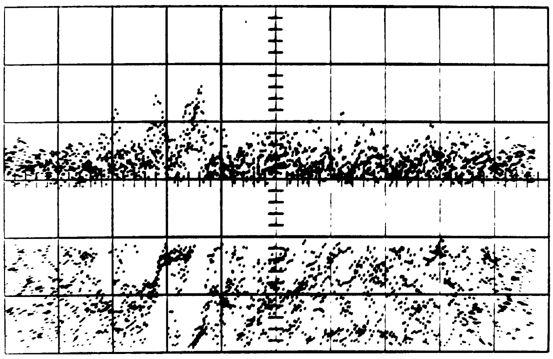
3-12



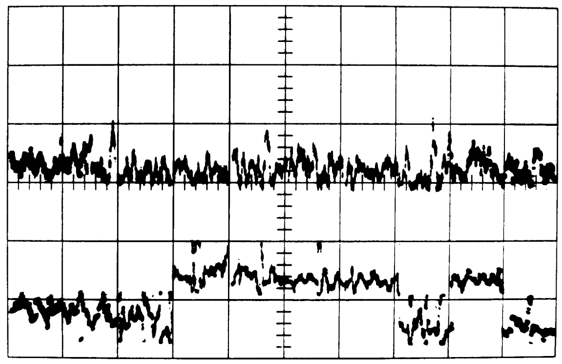
13-22



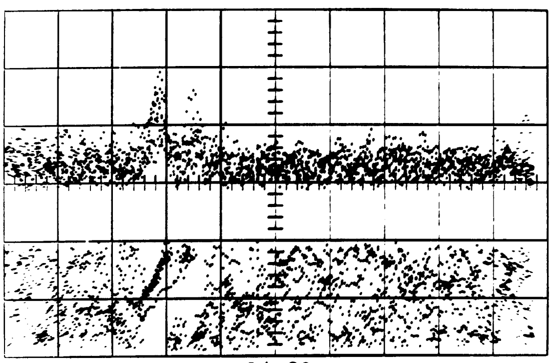
13-22



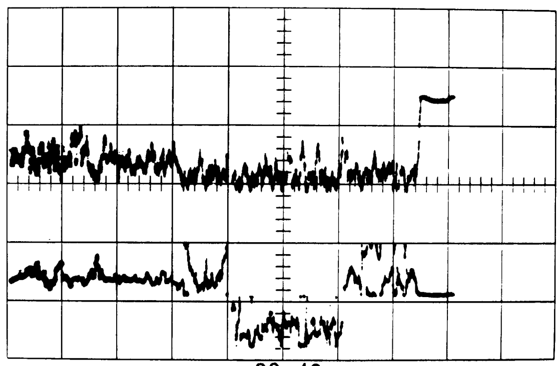
23-30



23-32



31-39

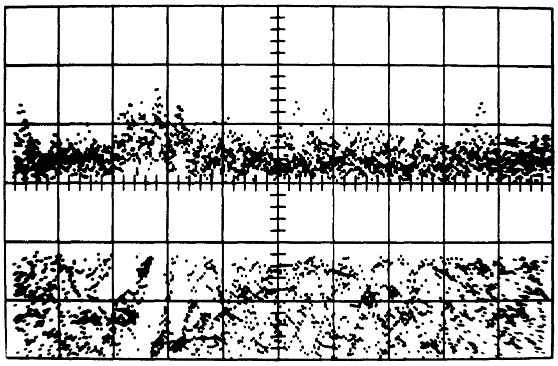


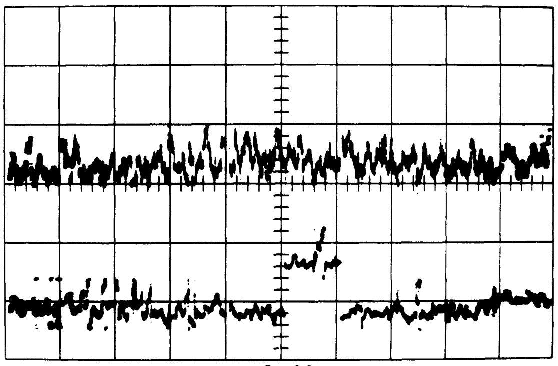
33-40

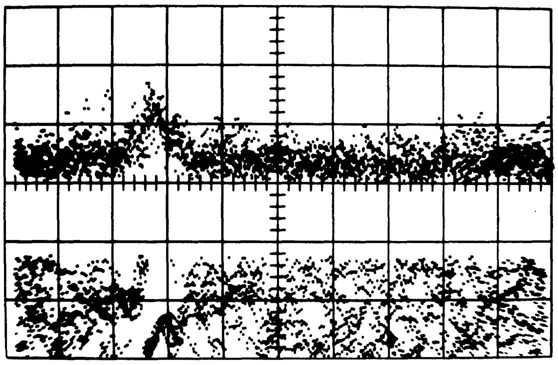
SEQ, R = 0.5 V/cm

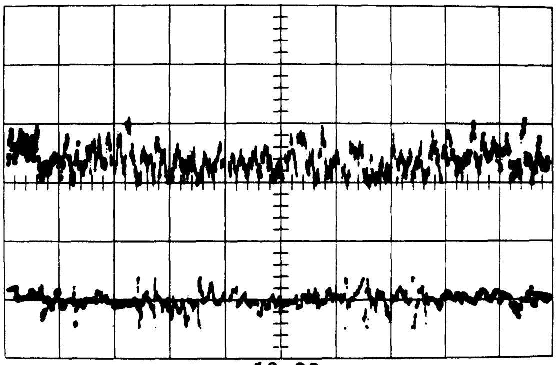
CW, R = 0.2 V/cm

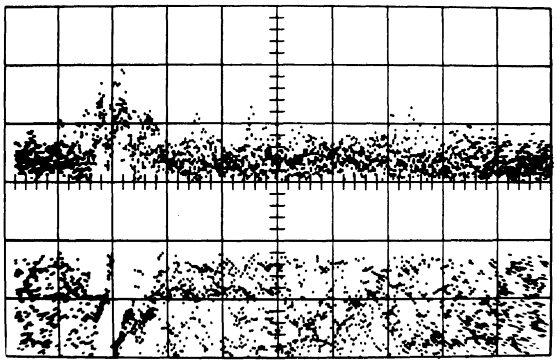
AMSEQ 11 August 1966 2115 - 2127 hours

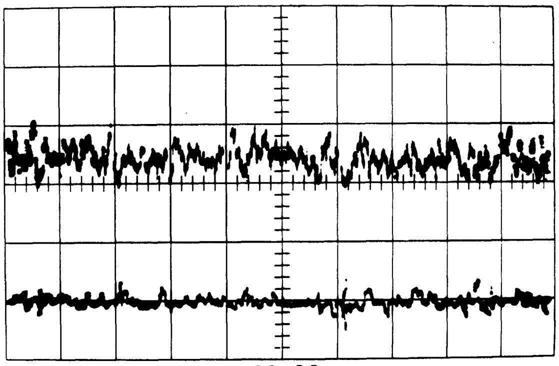

3-11

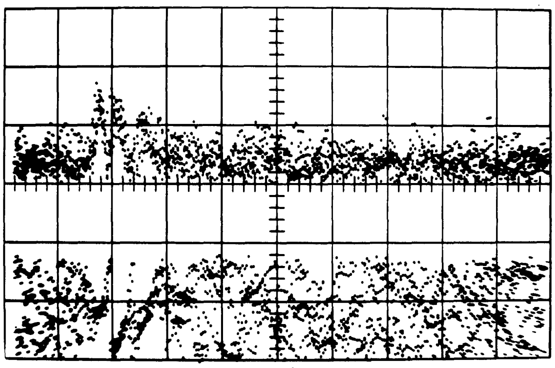

3-12

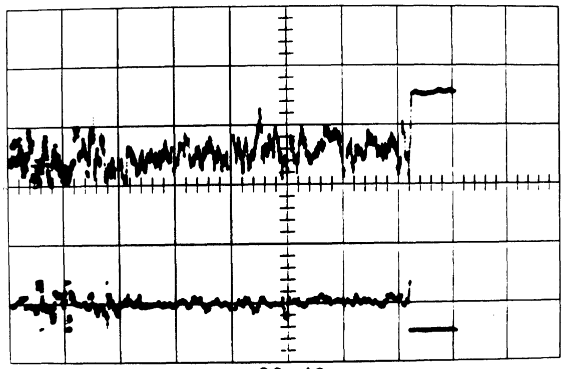

12-22


13-22


23-31


23-32

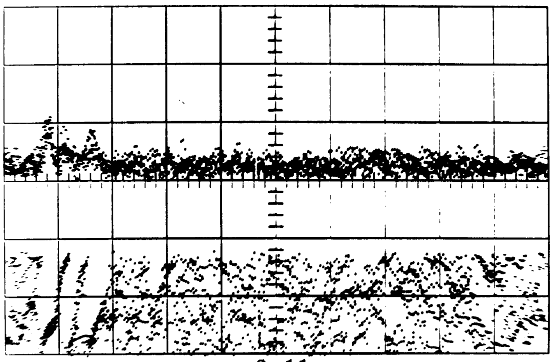

32-39


33-40

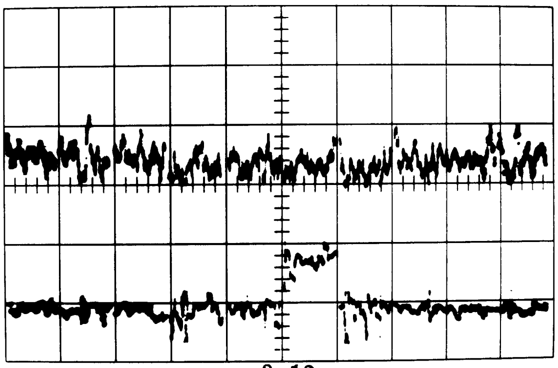
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

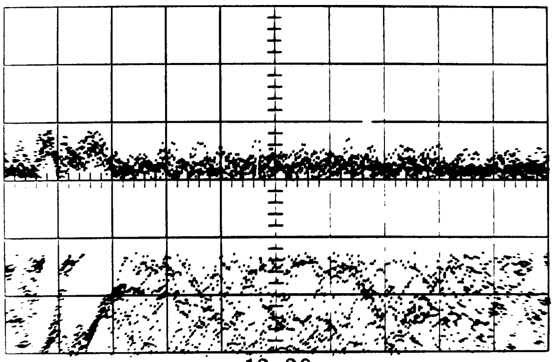
AMSEQ 11 August 1966 2127 - 2139 hours



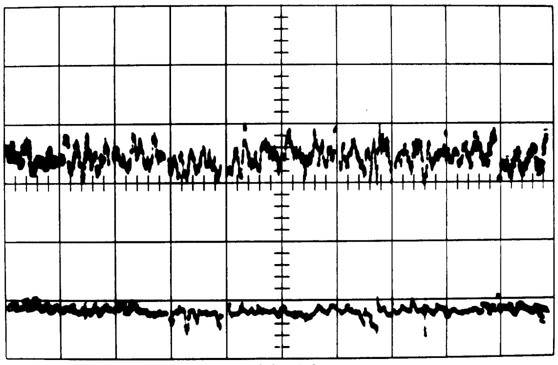
3-11



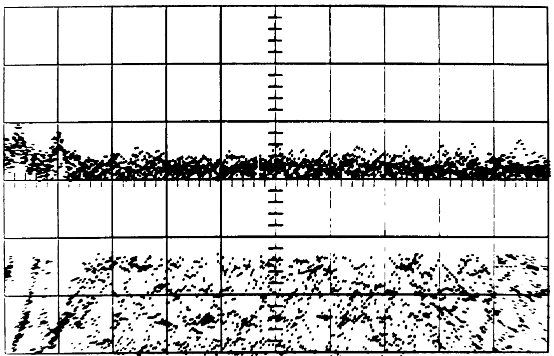
3-12



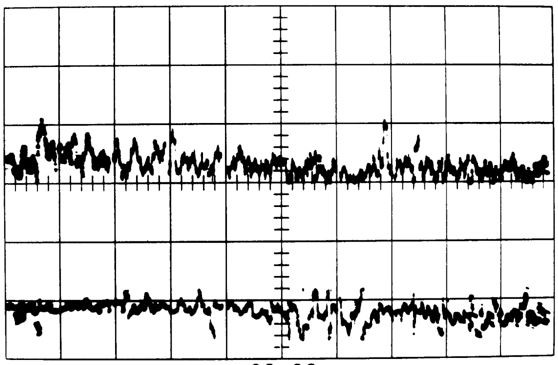
12-20



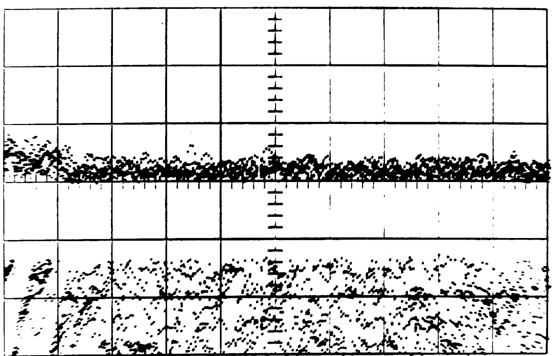
13-22



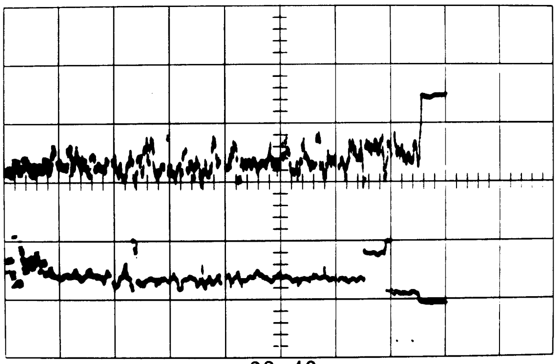
23-31



23-32



32-39

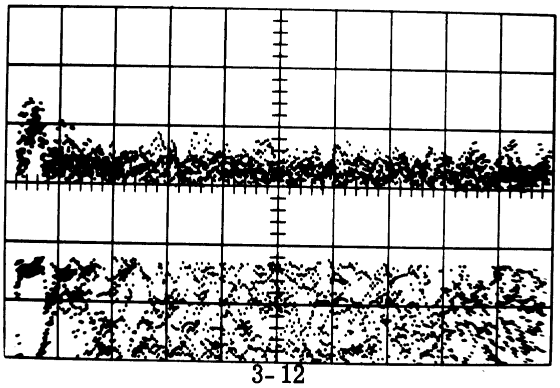


33-40

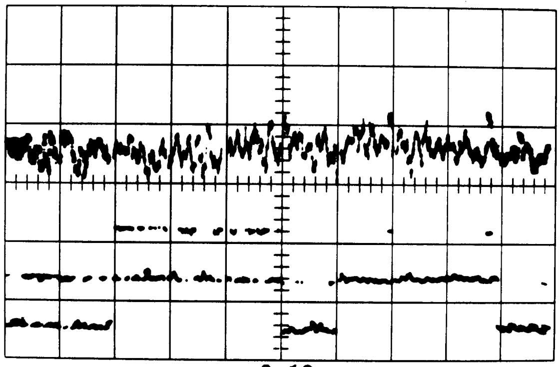
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

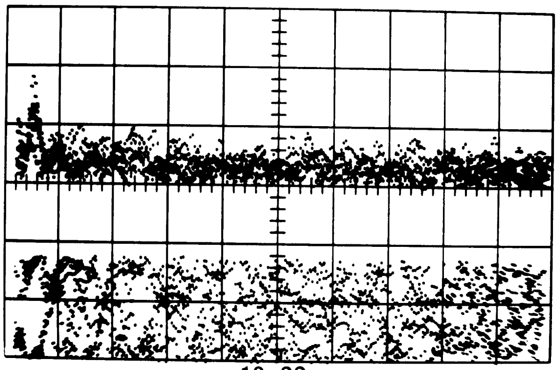
AMSEQ 11 August 1966 2139 - 2151 hours



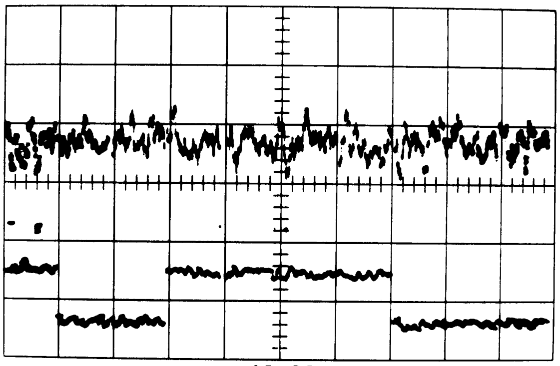
3-12



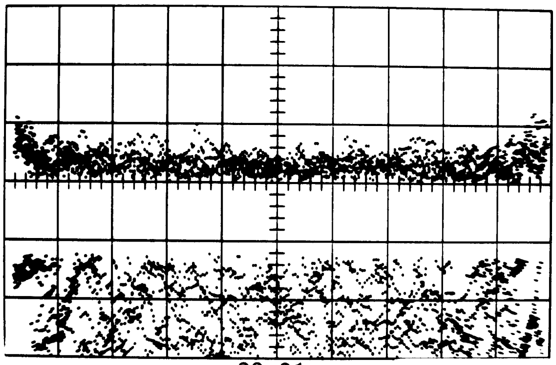
3-12



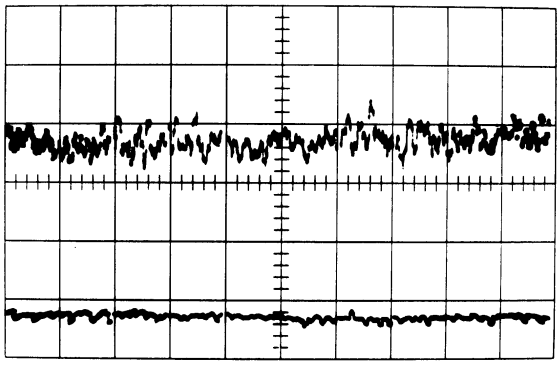
13-22



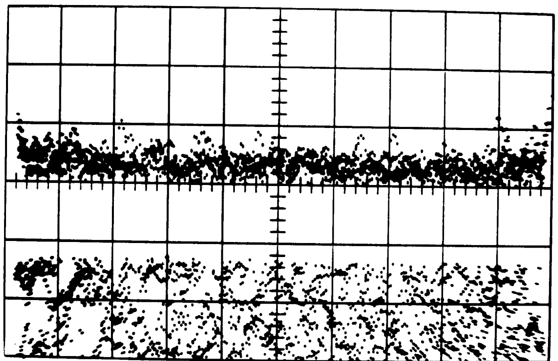
13-22



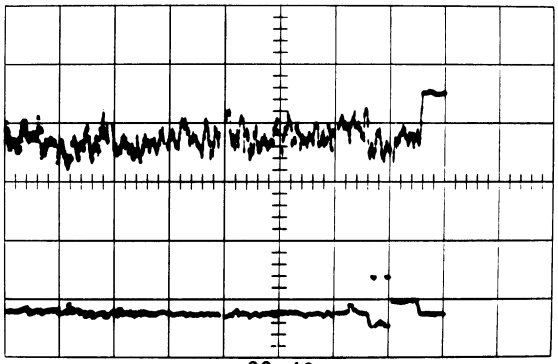
23-31



23-32



32-39

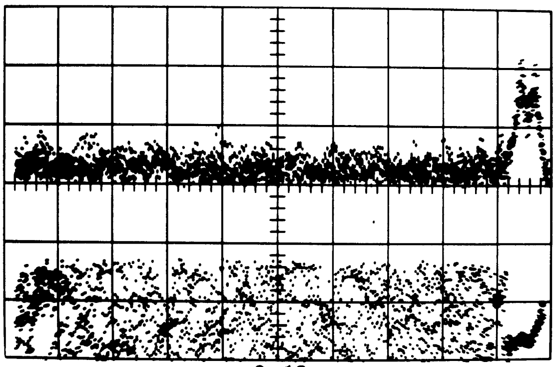


33-40

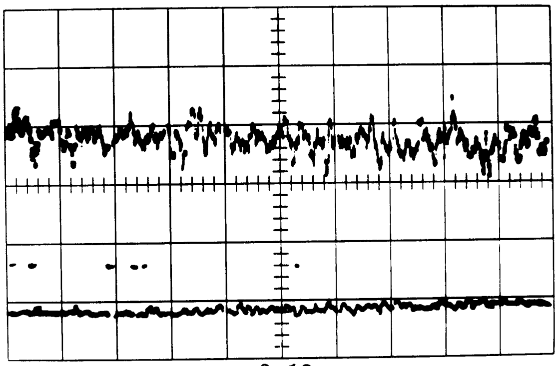
SEQ, R = 0.5 V/cm

CW, R = 0.2V/cm

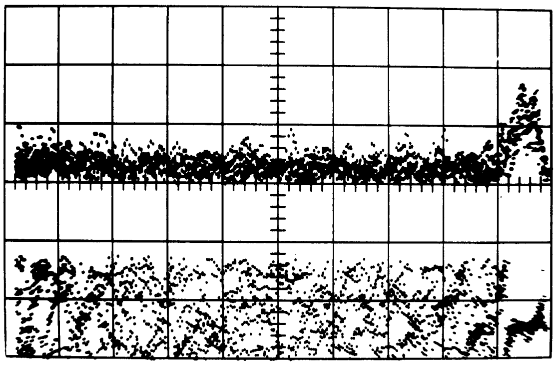
AMSEQ 11 August 1966 2151 - 2203 hours



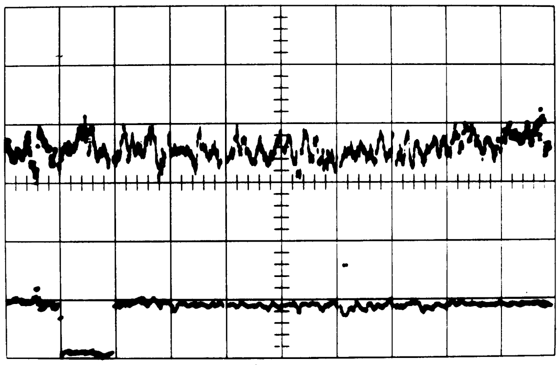
3-12



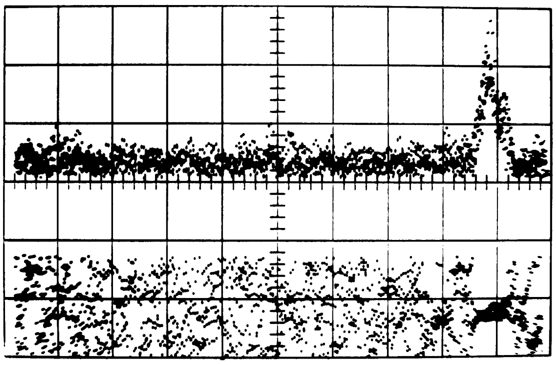
3-12



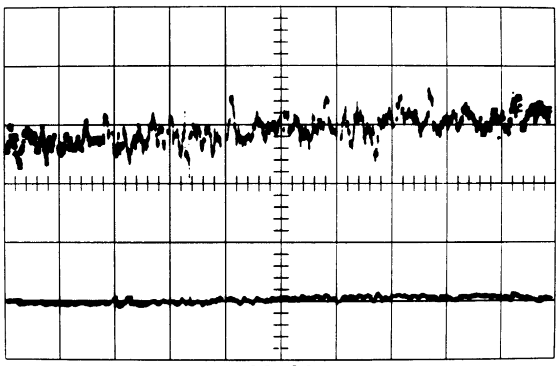
13-22



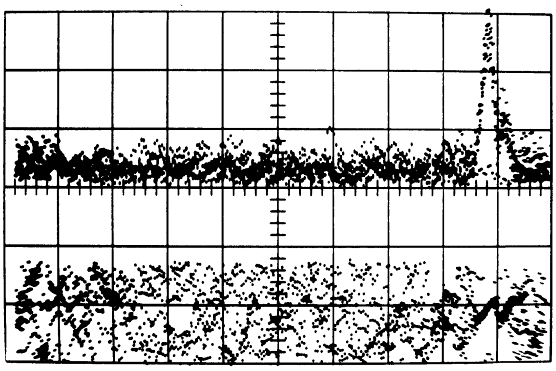
13-22



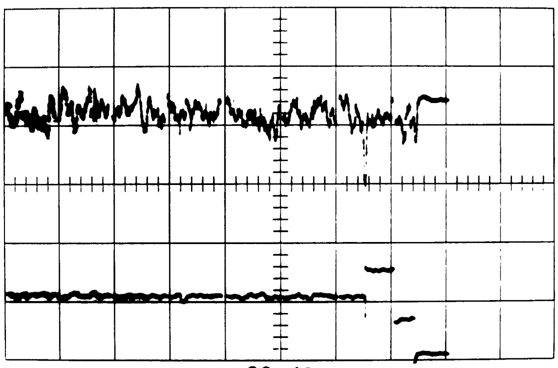
23-31



23-32



32-39

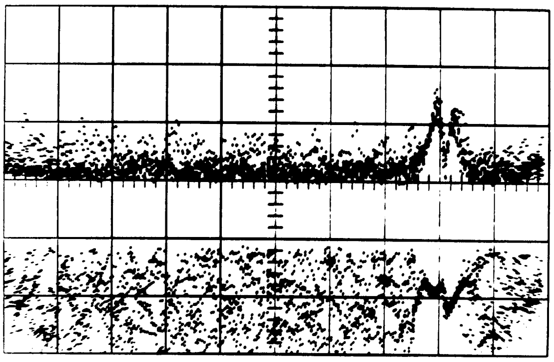


33-40

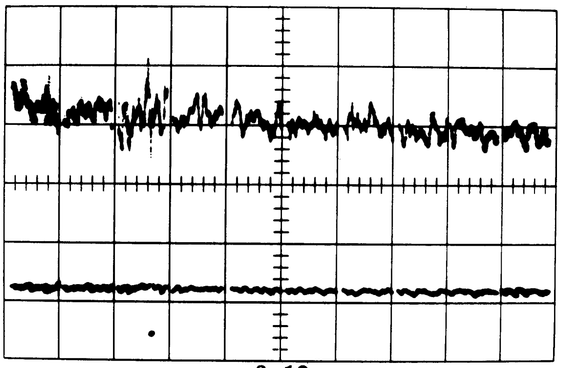
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

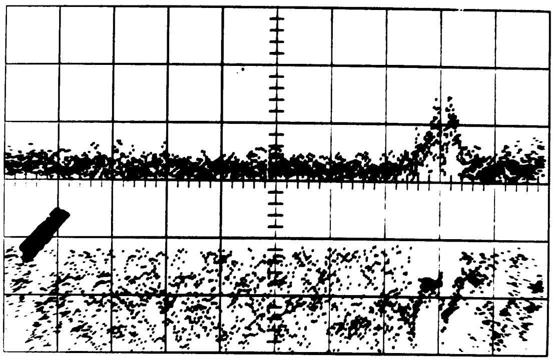
AMSEQ 11 August 1966 2203 - 2215 hours



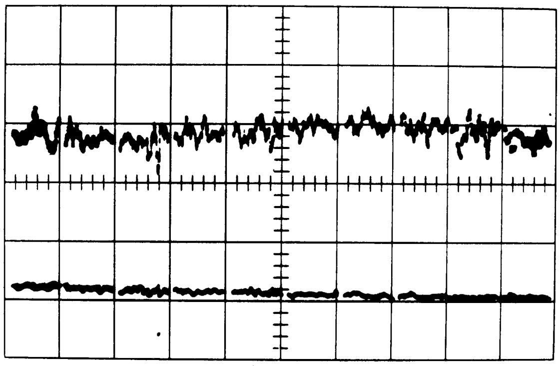
3-12



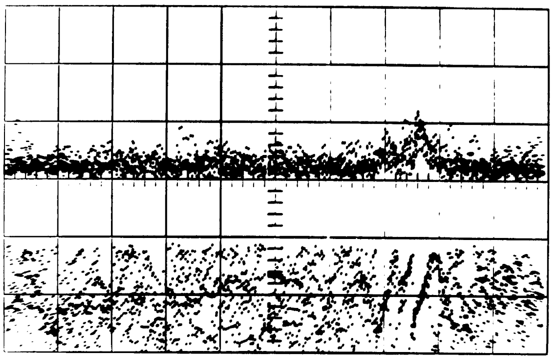
3-12



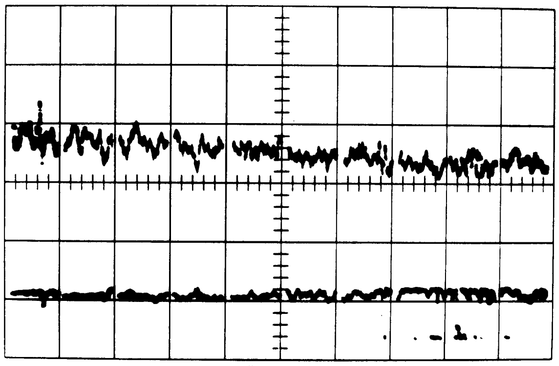
13-22



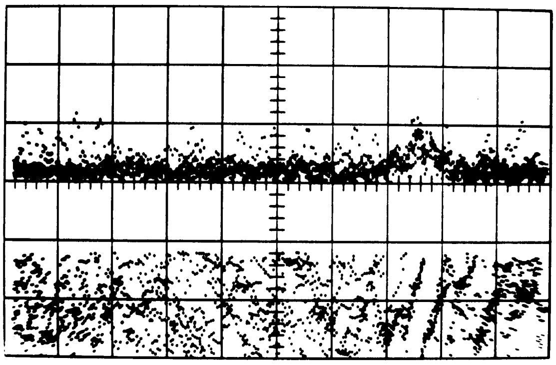
13-22



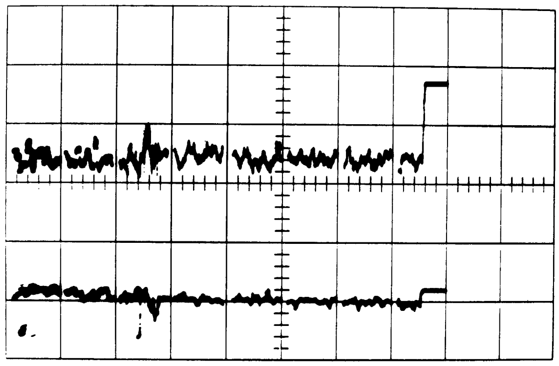
23-31



23-32



32-39

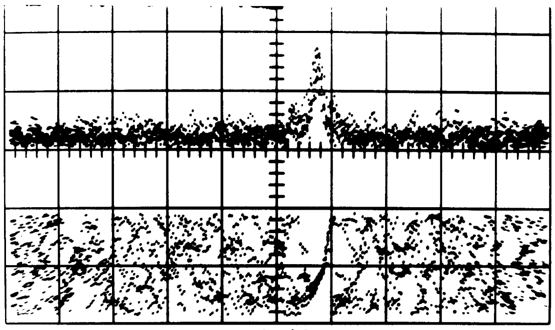


33-40

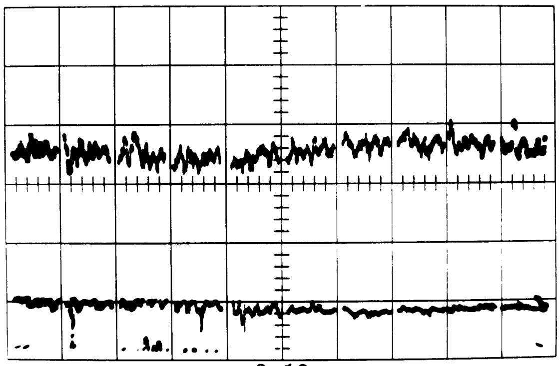
SEQ, R = 0.5 V/cm.

CW, R = 0.2 V/cm

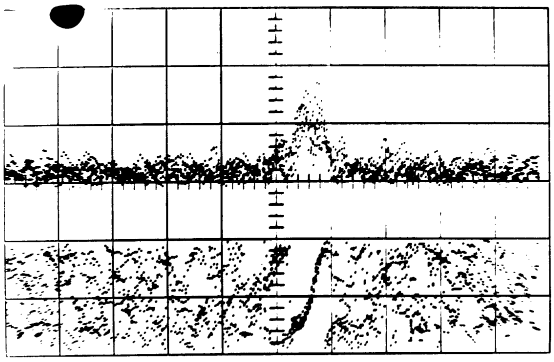
AMSEQ 11 August 1966 2215 - 2227 hours



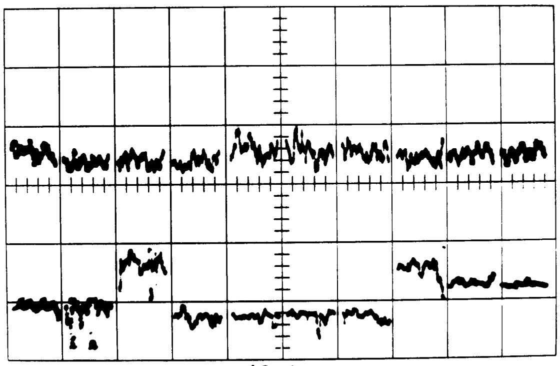
3-12



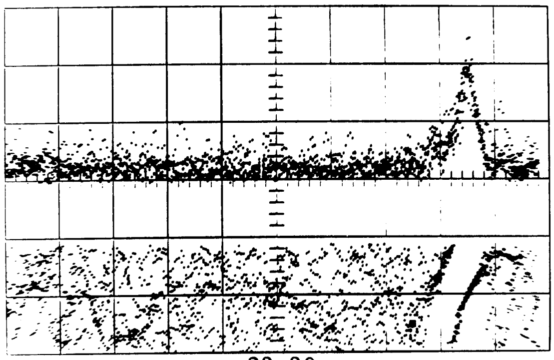
3-12



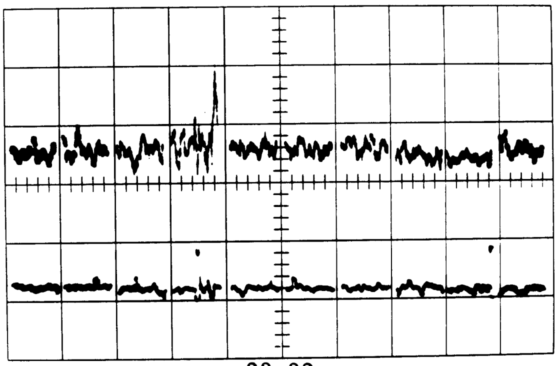
13-20



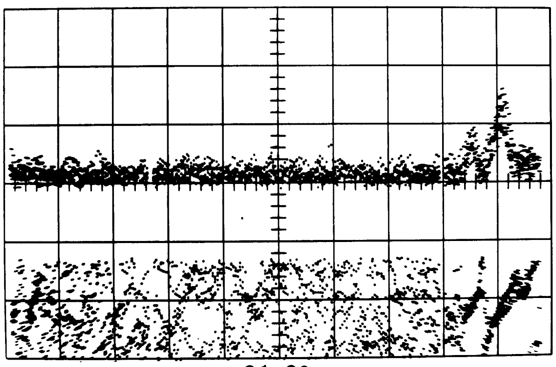
13-22



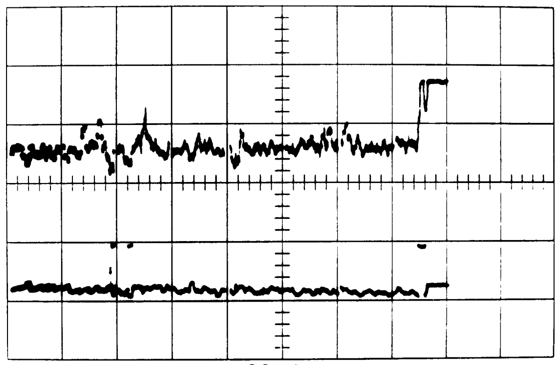
23-30



23-32



31-39

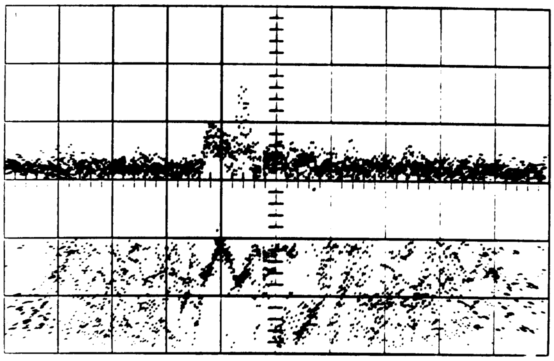


33-40

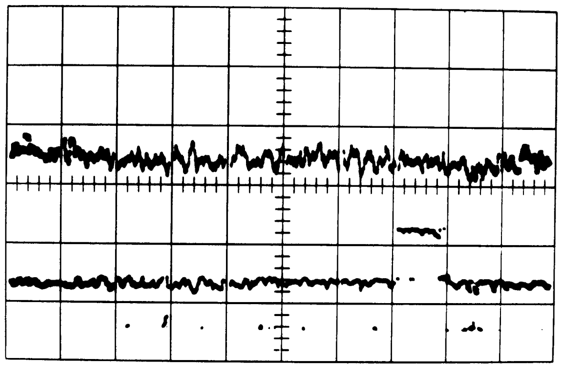
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

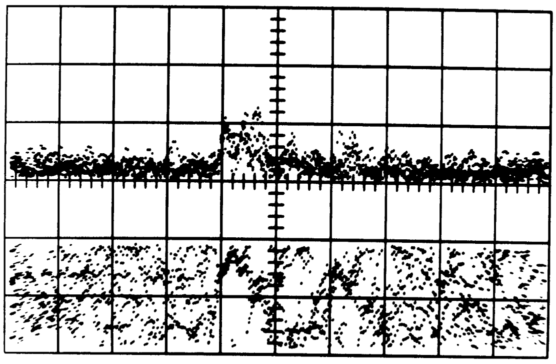
AMSEQ 11 August 1966 2239-2251 hours



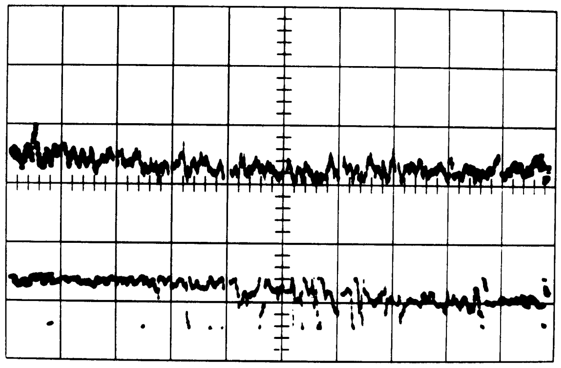
3-12



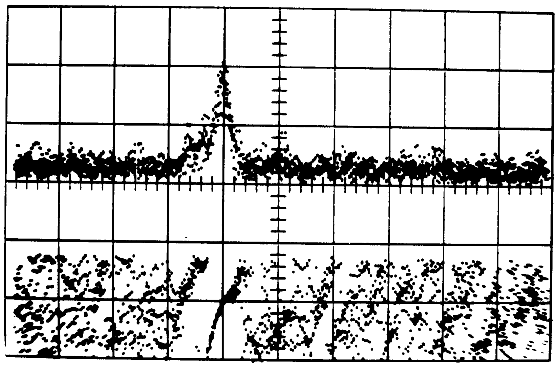
3-12



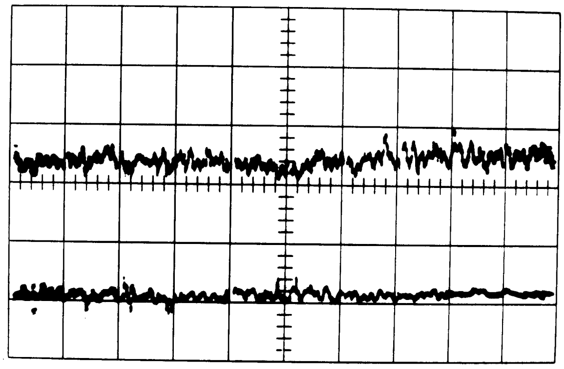
13-20



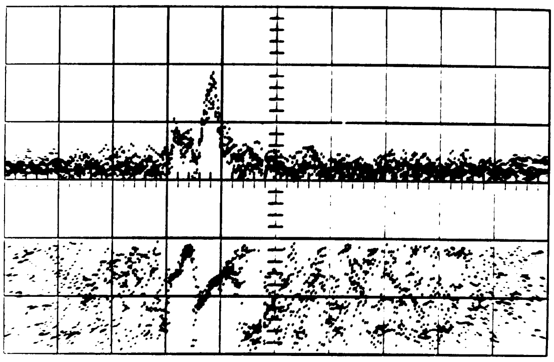
13-22



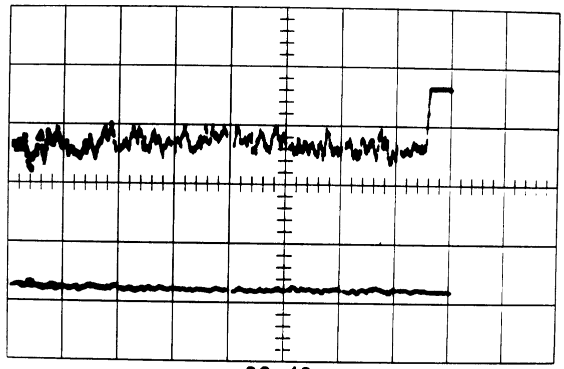
23-30



23-32



31-39

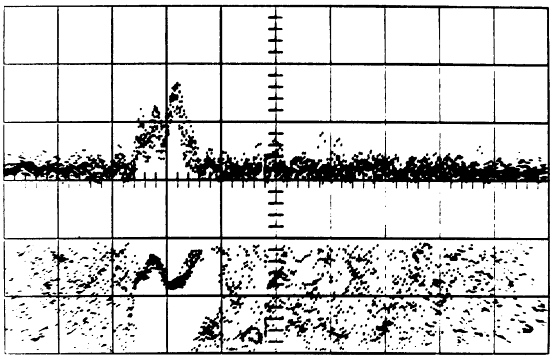


33-40

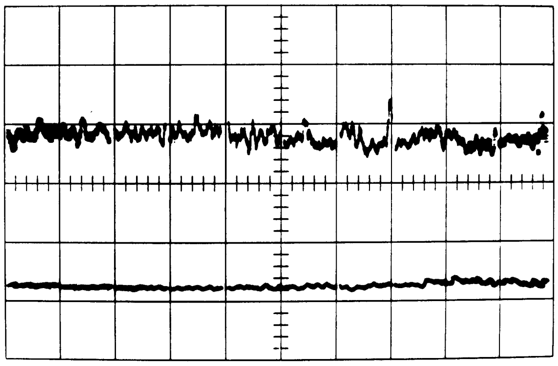
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

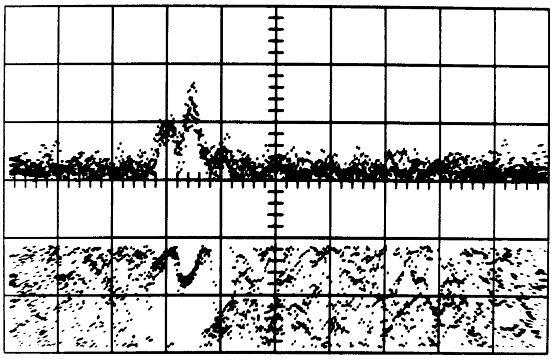
AMSEQ 11 August 1966 2251 - 2303 hours



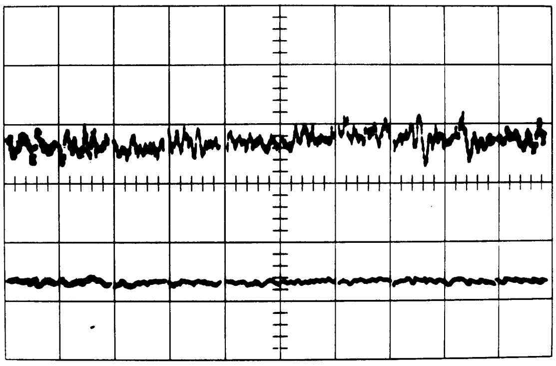
3-12



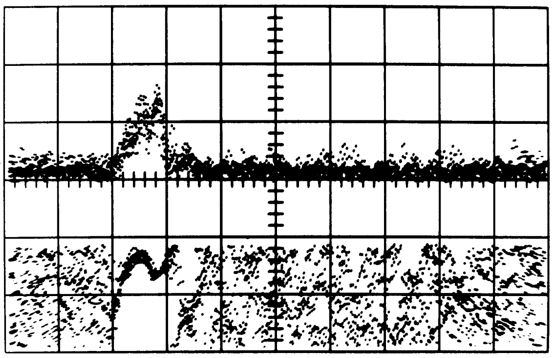
3-12



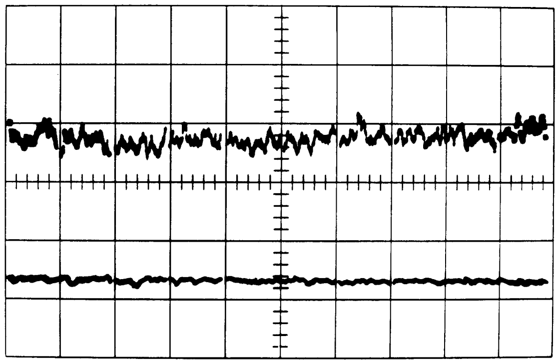
13-20



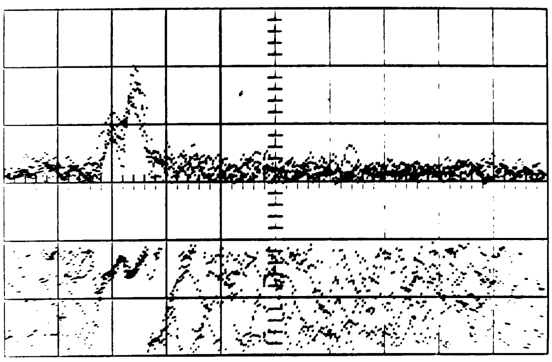
13-22



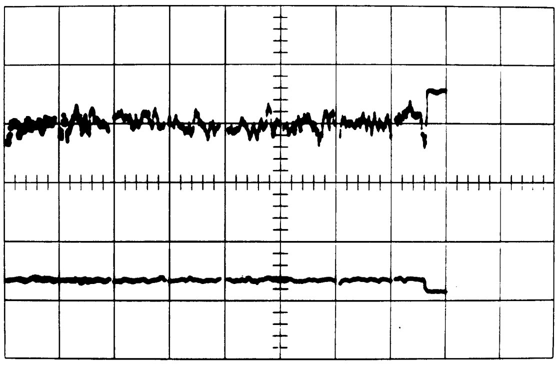
23-32



23-32



33-38

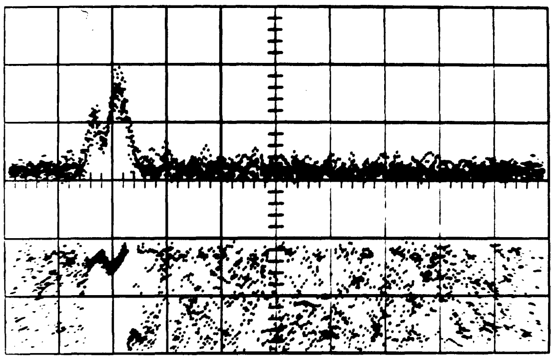


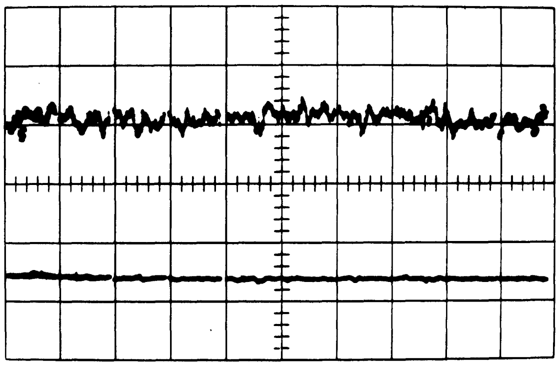
33-40

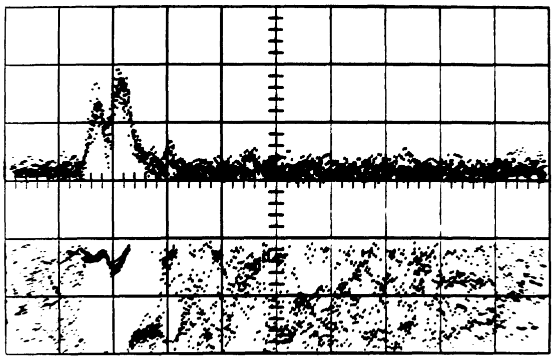
SEQ, R = 0.5 V/cm

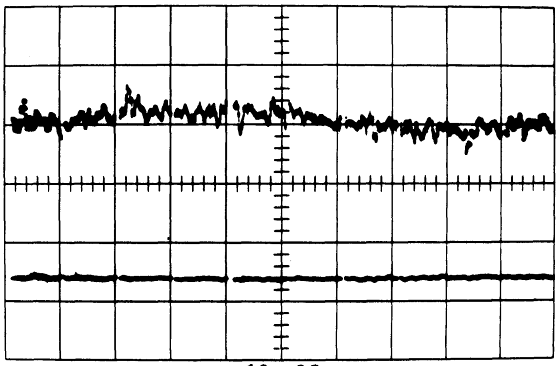
CW, R = 0.2 V/cm

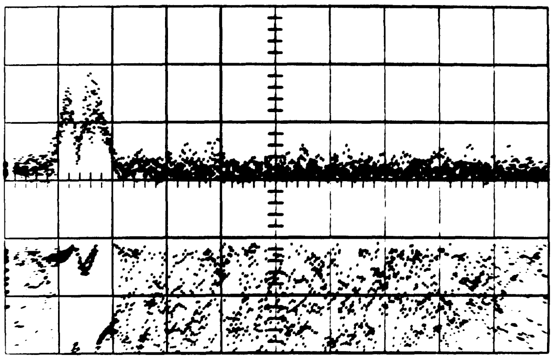
AMSEQ 11 August 1966 2303 - 2315 hours

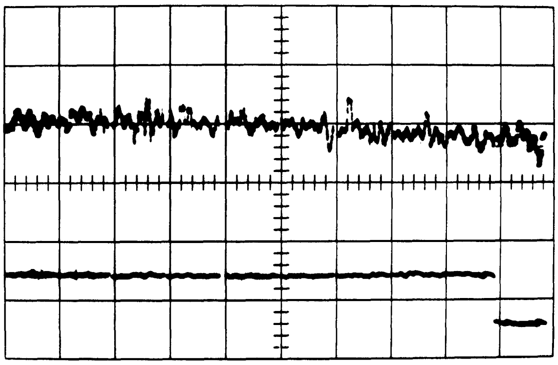

3-12

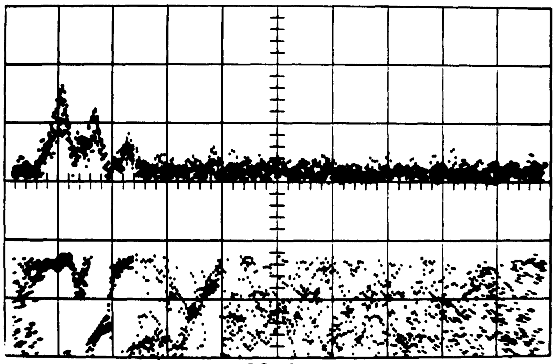

3-12

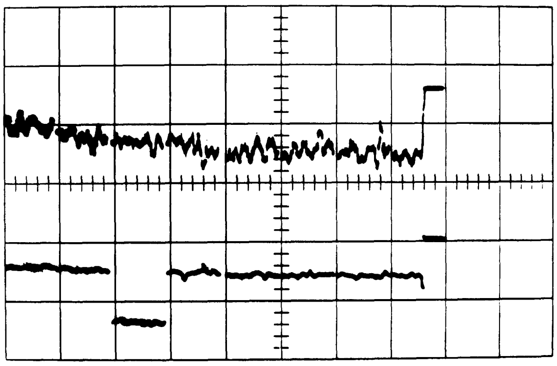

13-22


13 - 22


23-31


23-32

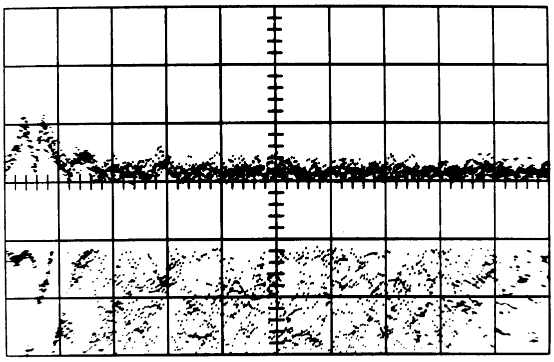

32-39

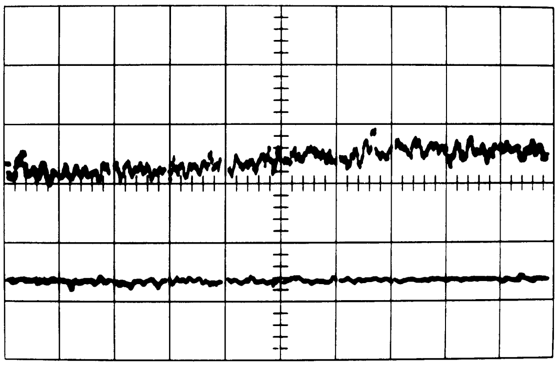

33-40

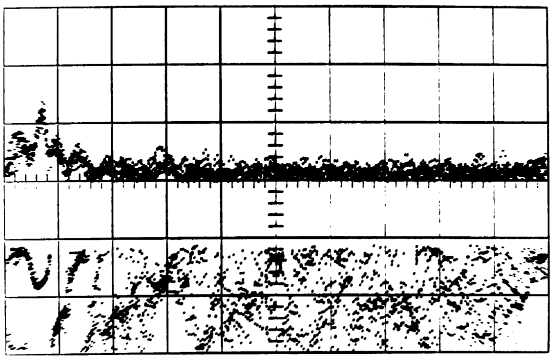
SEQ, R = 0.5 V/cm

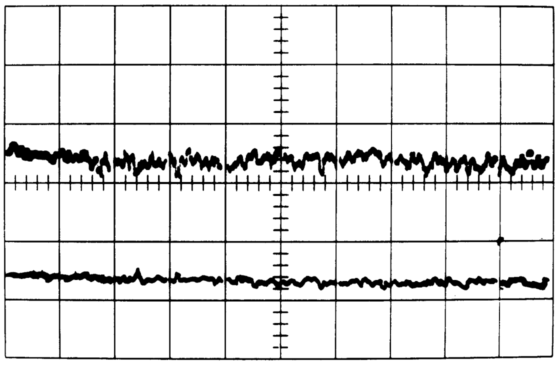
CW, R = 0.2 V/cm

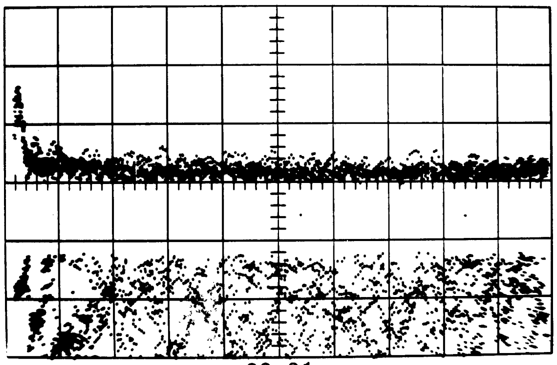
AMSEQ 11 August 1966 2315 - 2327 hours

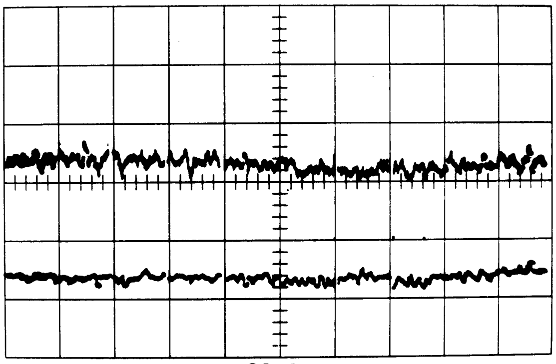

3-12

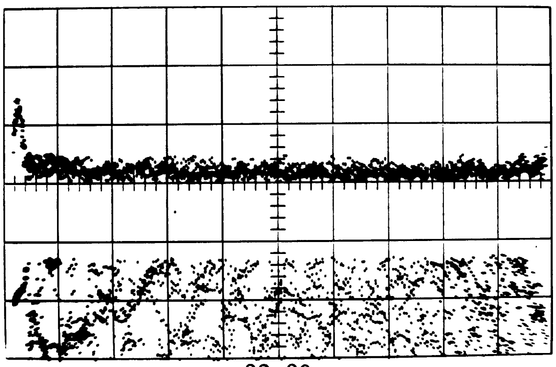

3-12

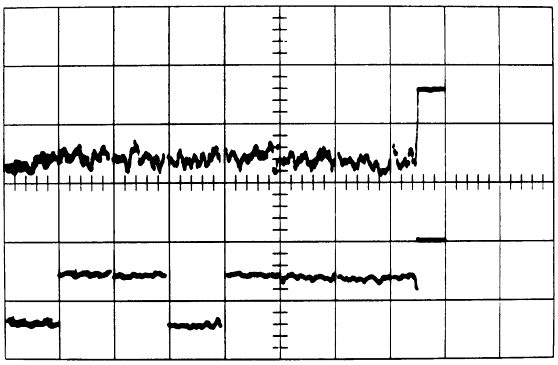

14-22


13-22


23-31


23-32

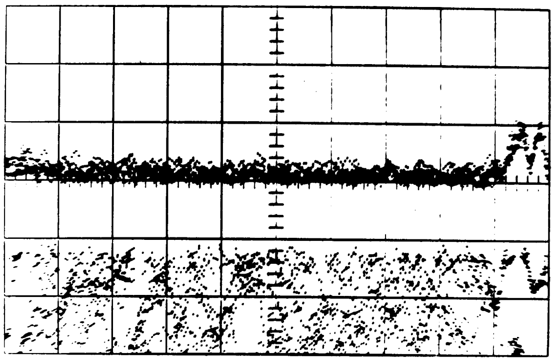

32-39


33-40

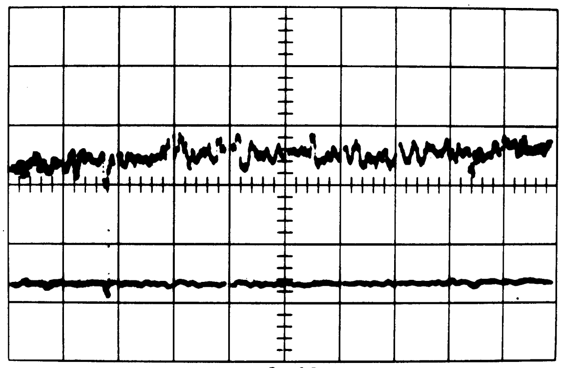
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

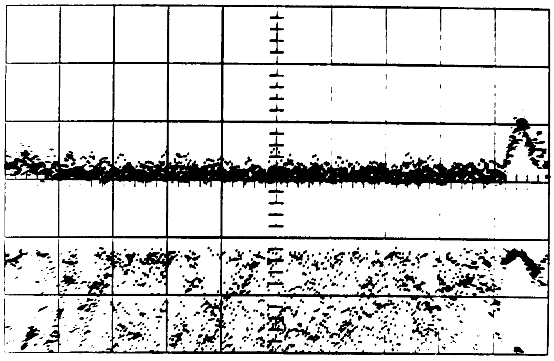
AMSEQ 11 August 1966 2327 - 2339 hours



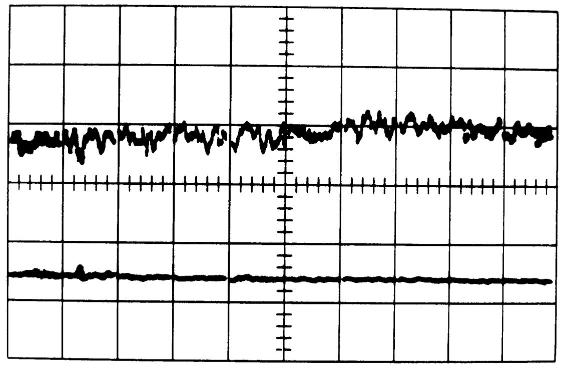
3-12



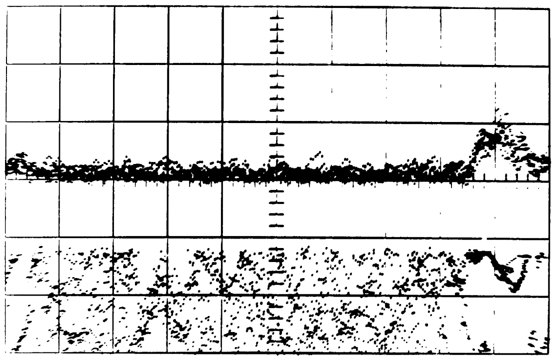
3-12



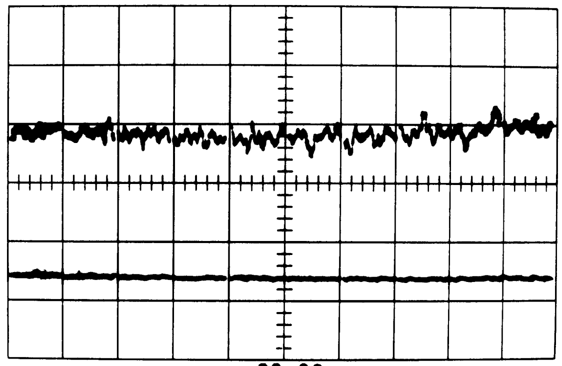
13-22



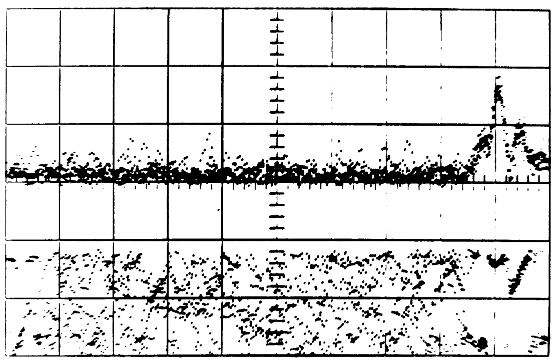
13-22



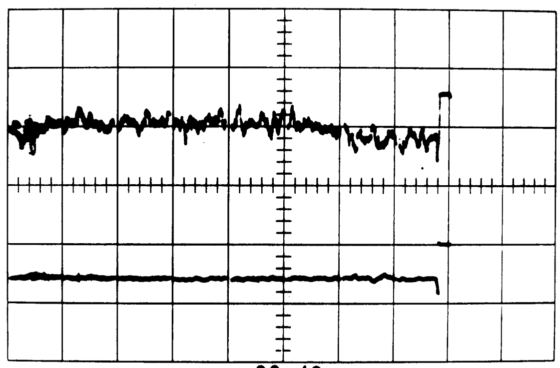
23-31



23-32



32-39

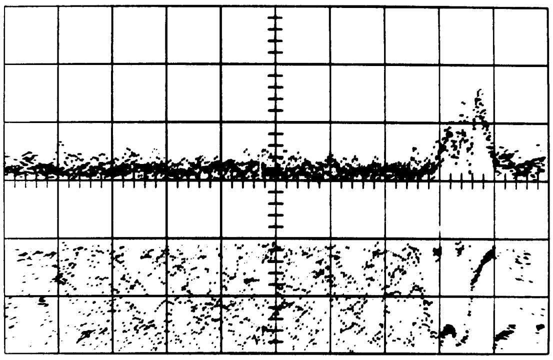


33-40

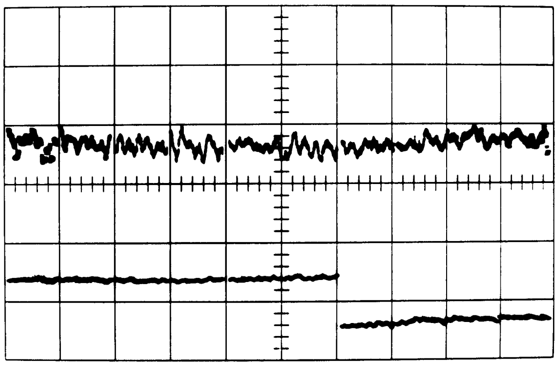
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

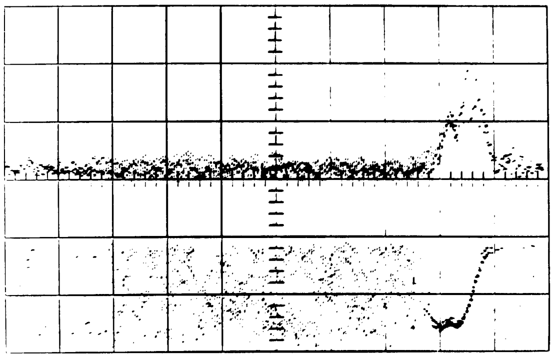
AMSEQ 11 August 1966 2339 - 2351 hours



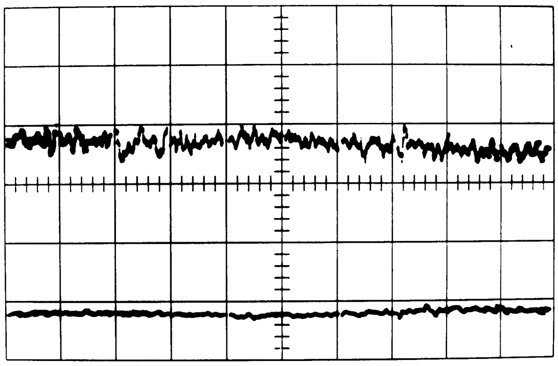
3-12



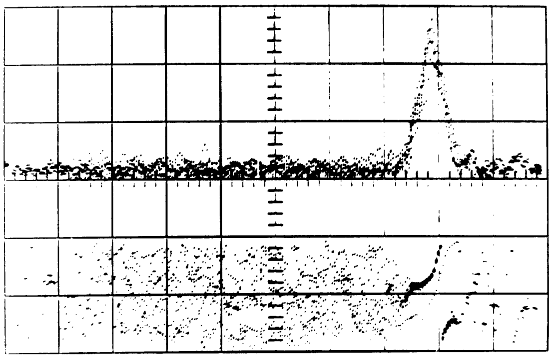
3-12



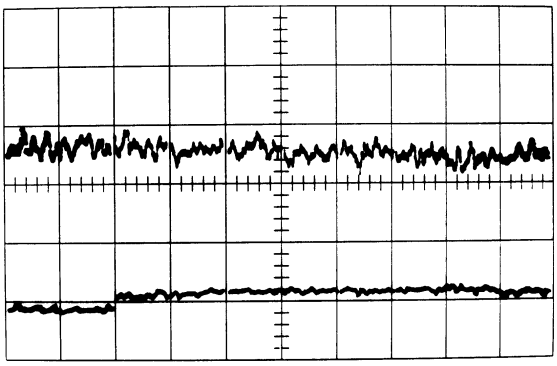
14-22



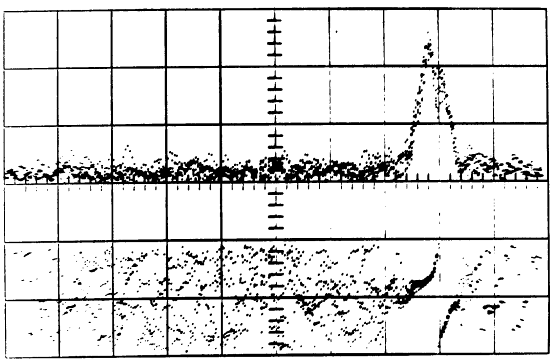
13-22



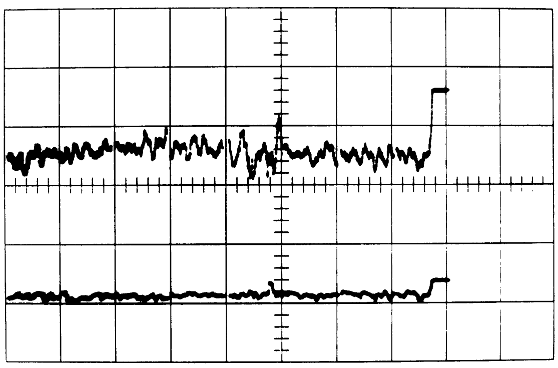
24-32



23-32



33-39

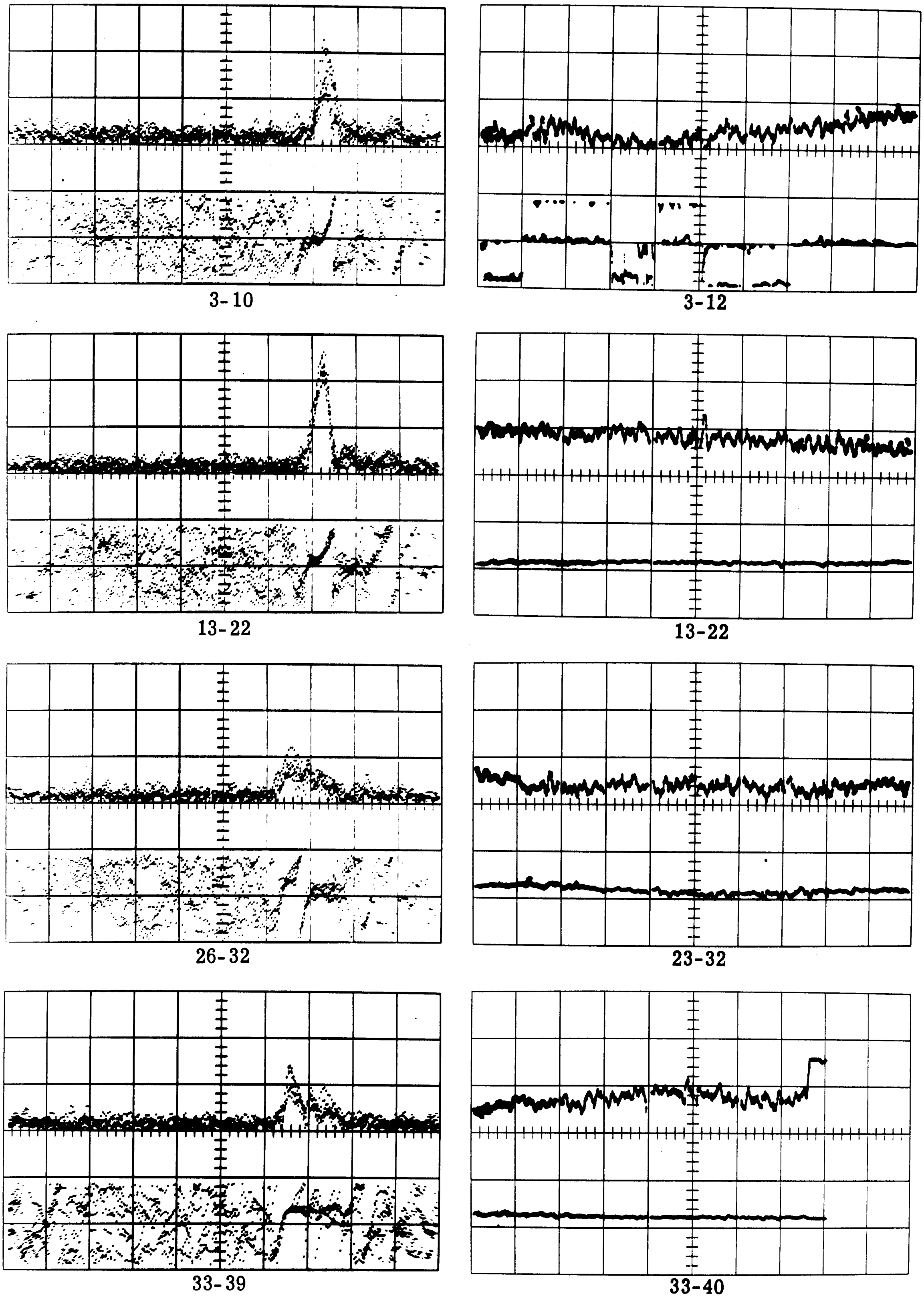


33-40

SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

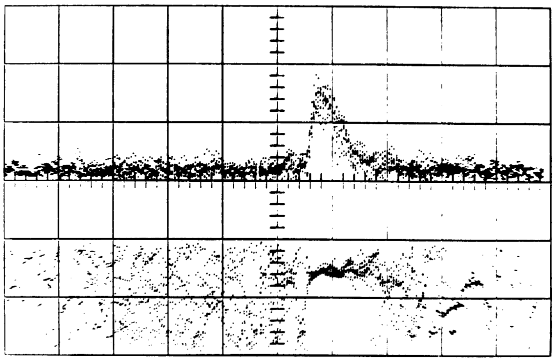
AMSEQ 11, 12 August 1966 2351 - 0003 hours



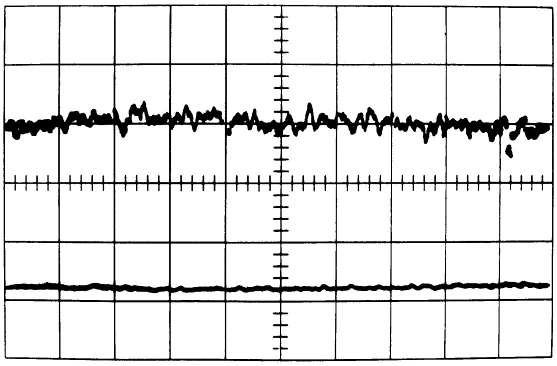
SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

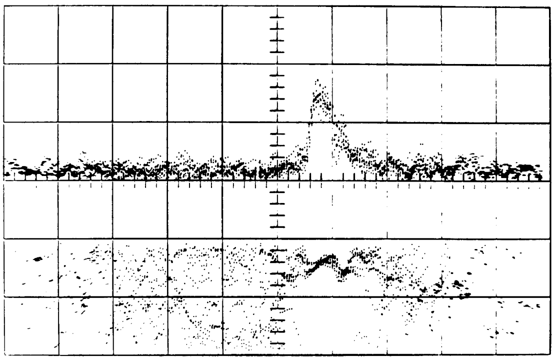
AMSEQ 12 August 1966 0003 - 0015 hours



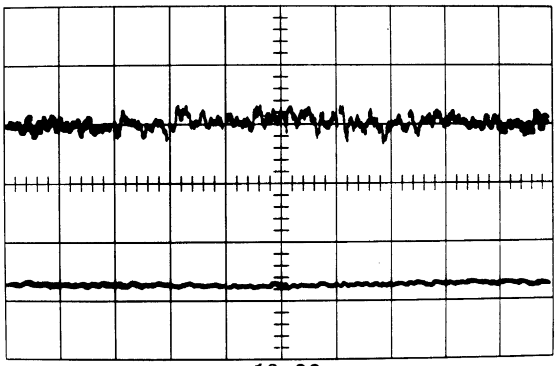
3-12



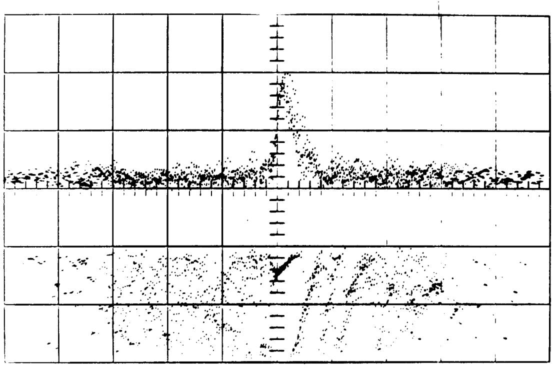
3-12



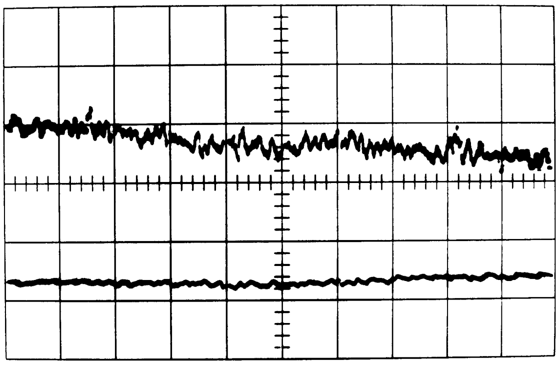
13-22



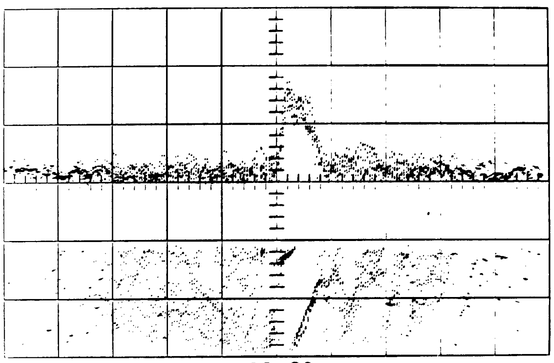
13-22



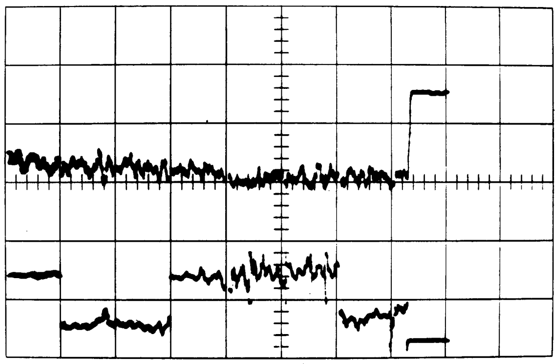
23-31



23-32



32-39

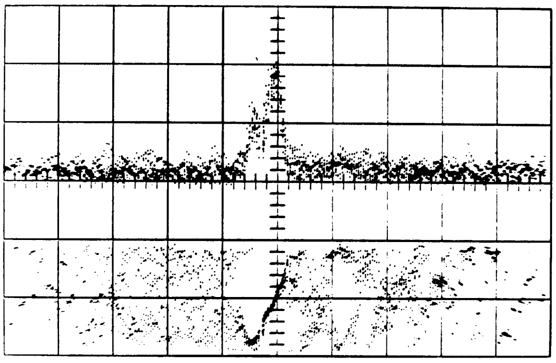


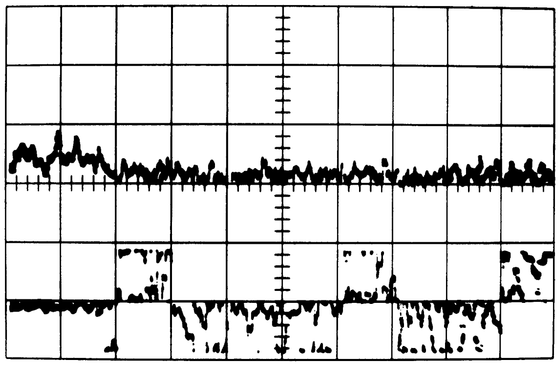
33-40

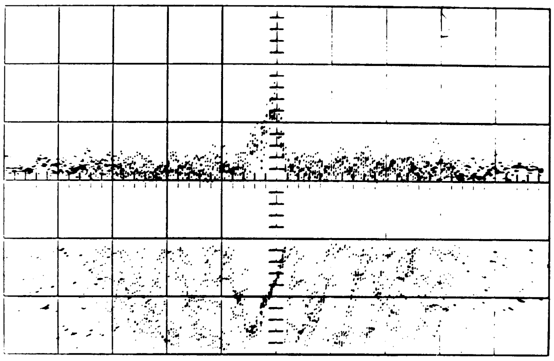
SEQ, R = 0.5 V/cm

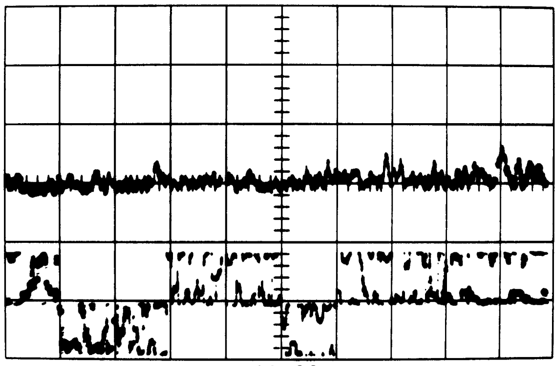
CW, R = 0.2 V/cm

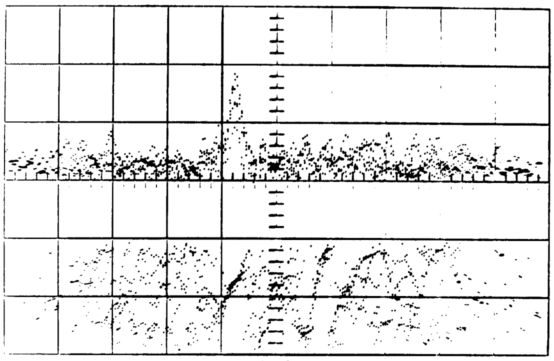
AMSEQ 12 August 1966 0015 - 0027 hours

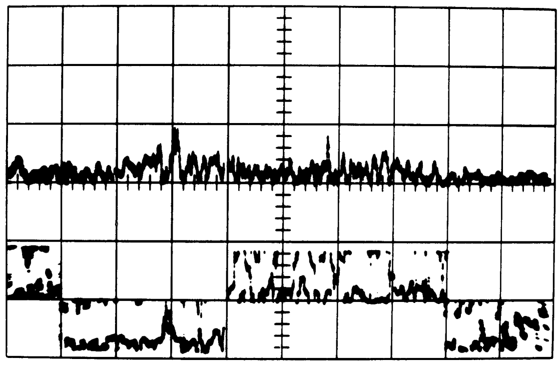

3-10

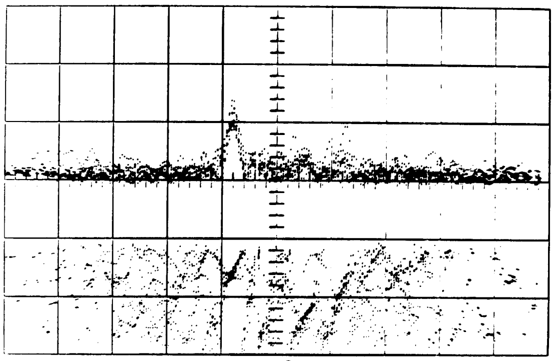

3-12

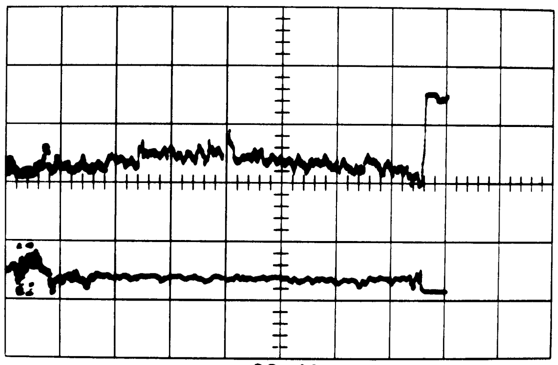

14-21


13-22


24-29


23-32

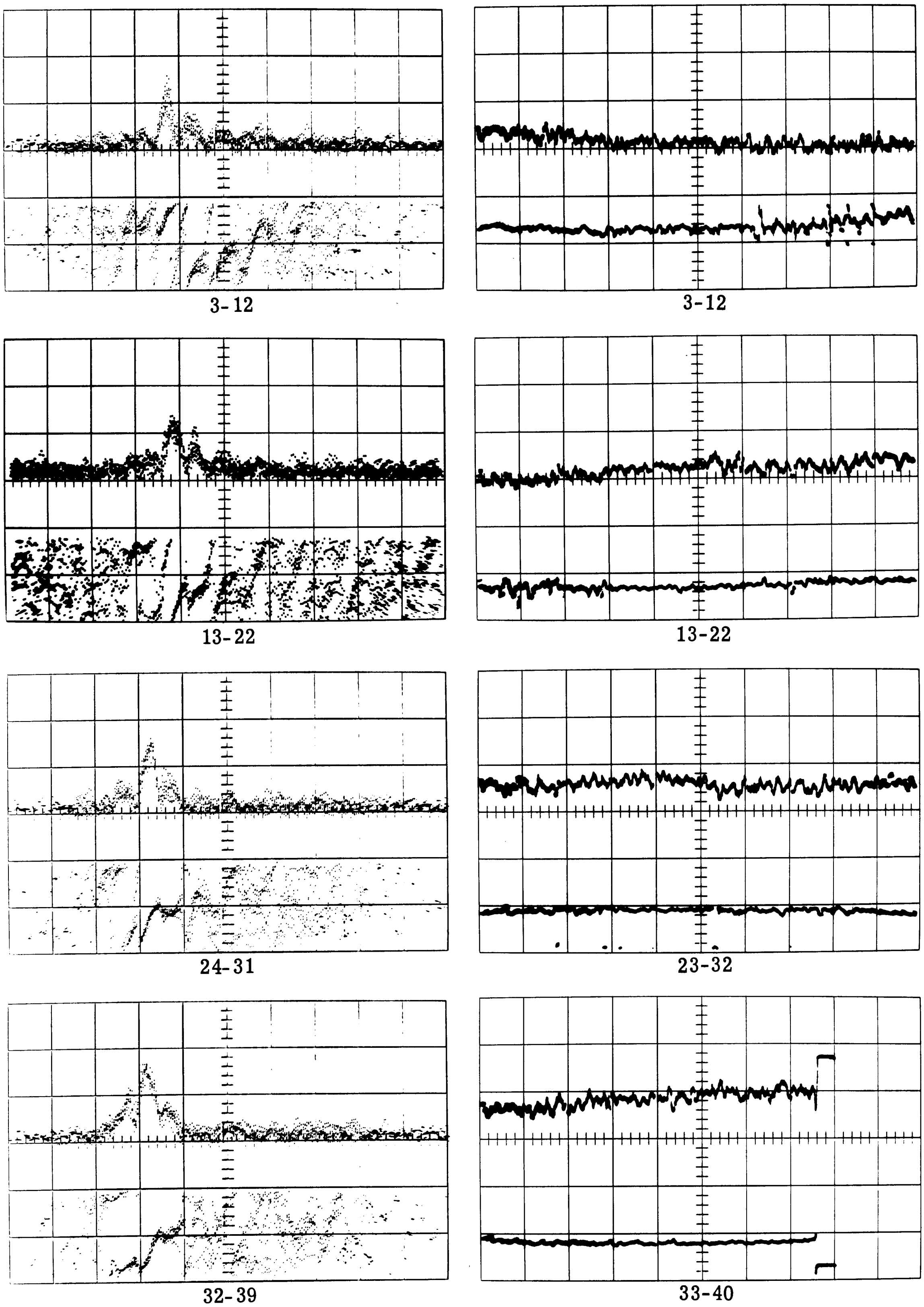

30-39


33-40

SEQ, R = 0.5 V/cm

CW, R = 0.2 V/cm

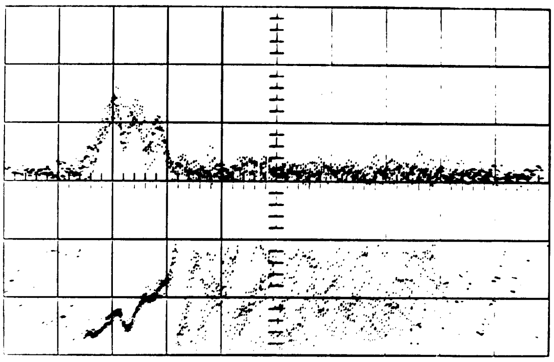
AMSEQ 12 August 1966 0027 - 0039 hours



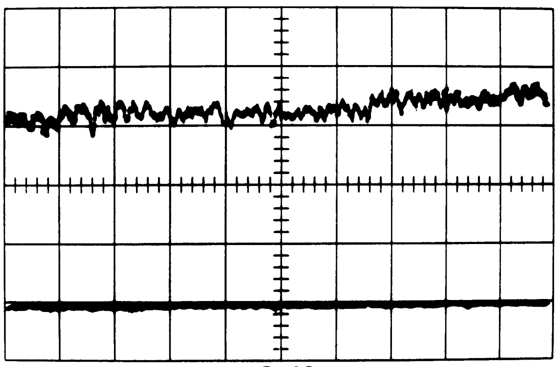
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

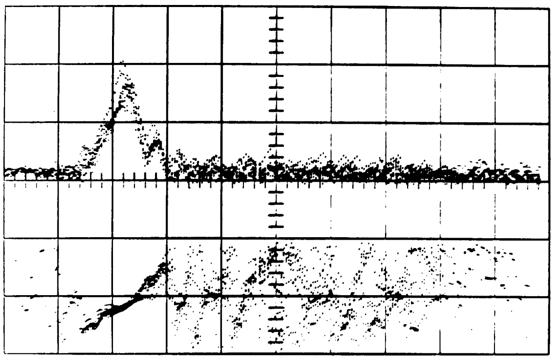
AMSEQ 12 August 1966 0039-0051 hours



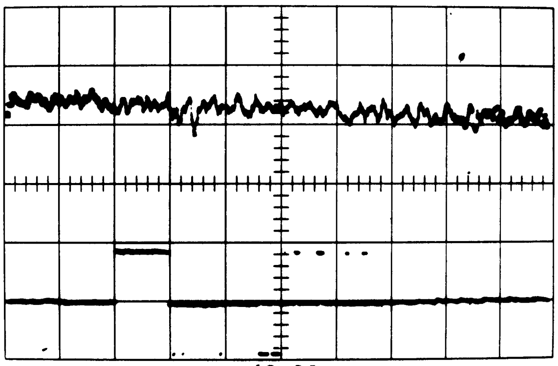
3-10



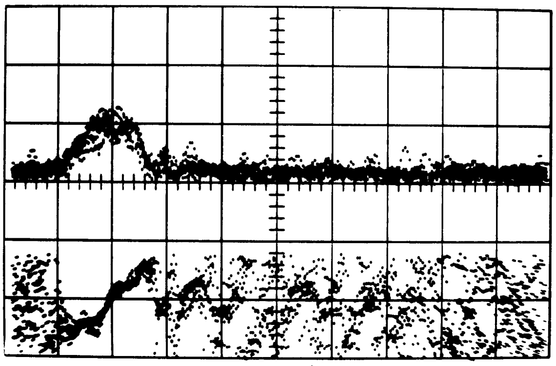
3-12



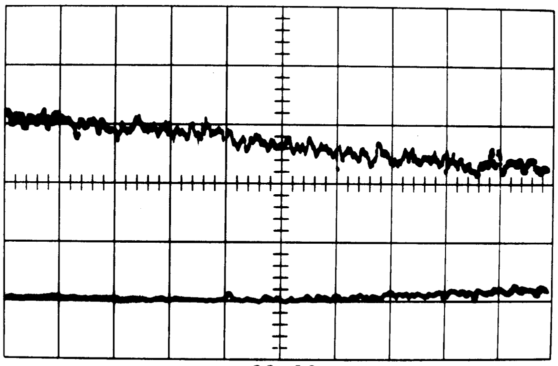
13-22



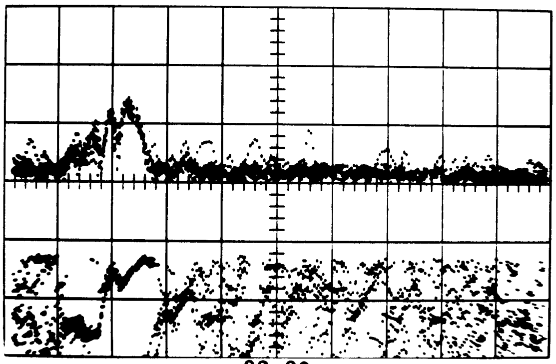
13-22



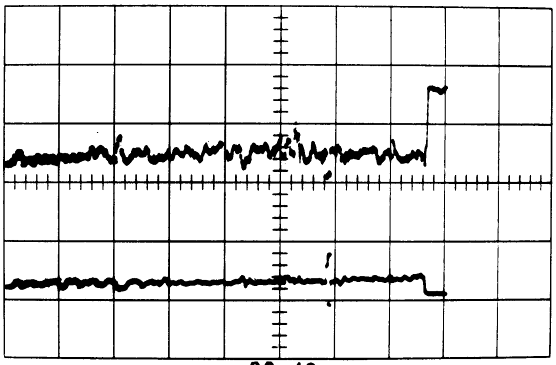
23-31



23-32



32-39

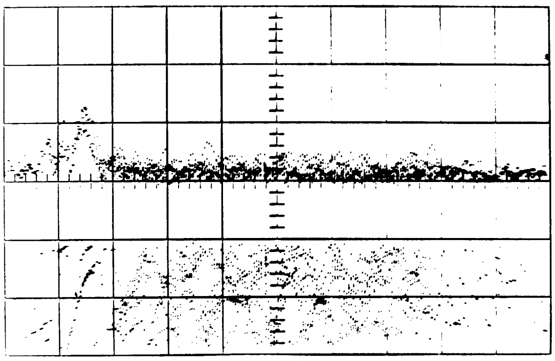


33-40

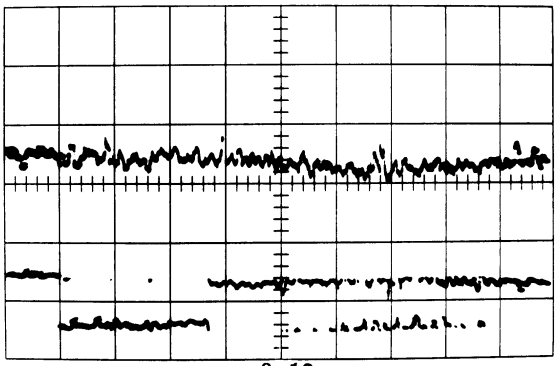
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

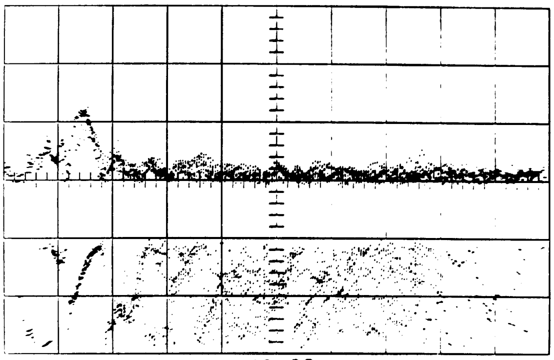
AMSEQ 12 August 1966 0051-0103 hours



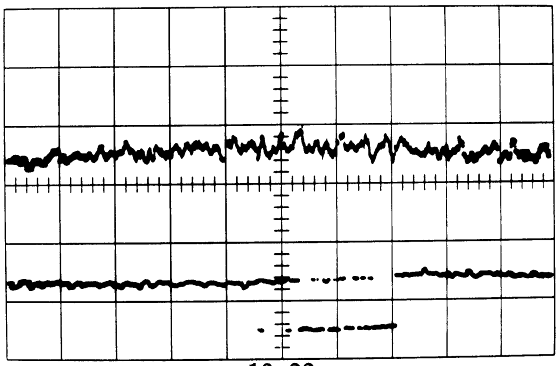
3-12



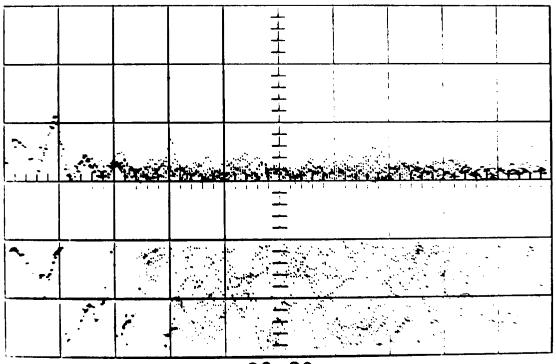
3-12



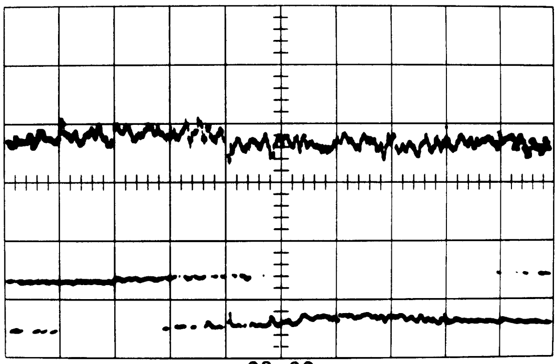
13-22



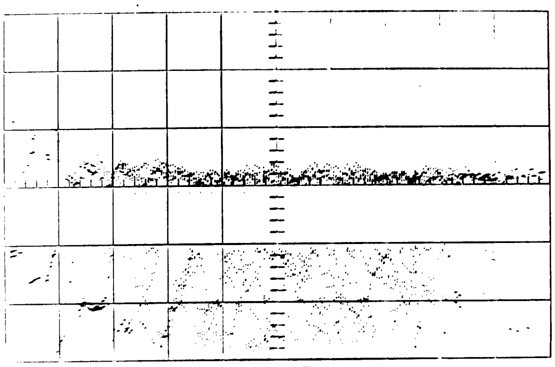
13-22



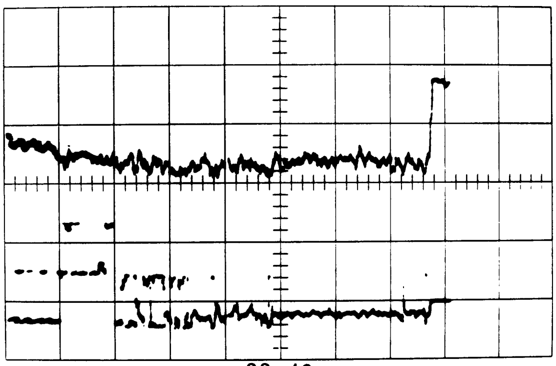
23-29



23-32



30-35

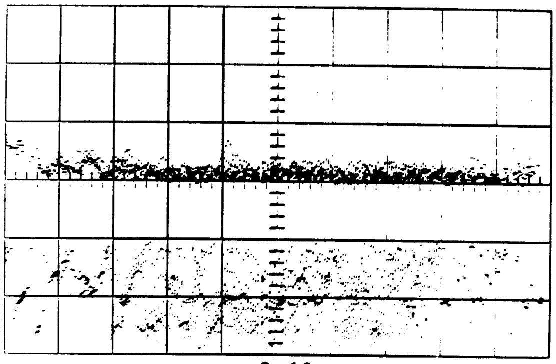


33-40

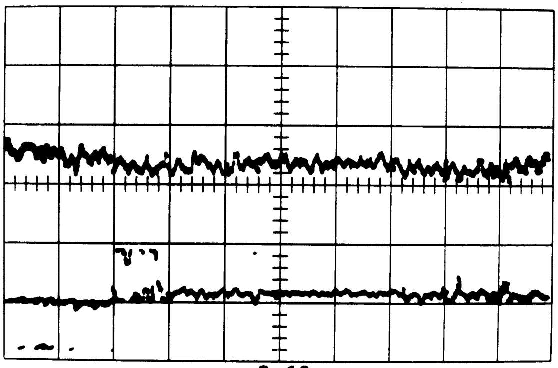
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

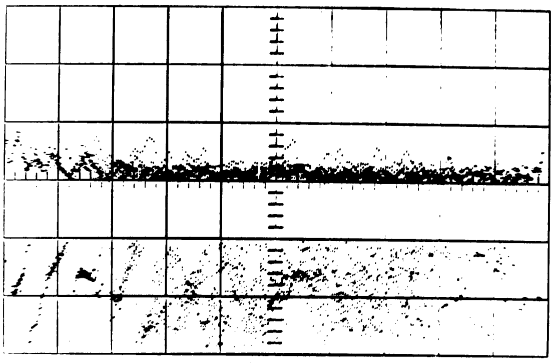
AMSEQ 12 August 1966 0103-0115 hours



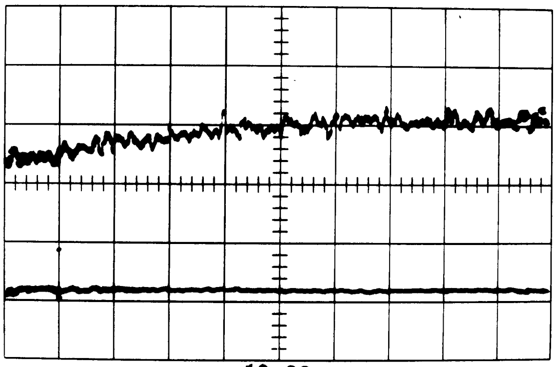
3-10



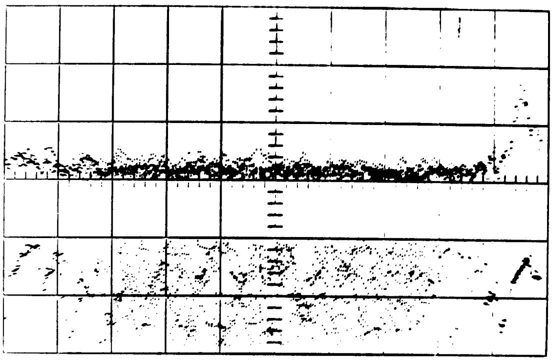
3-12



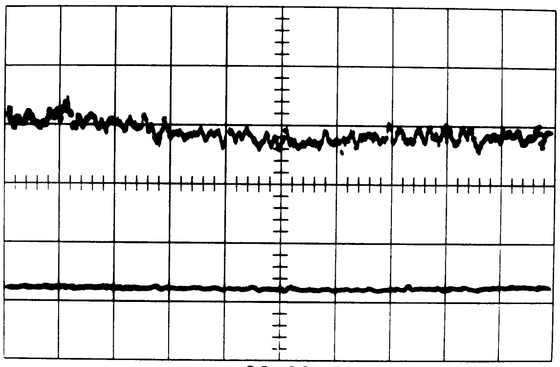
13-22



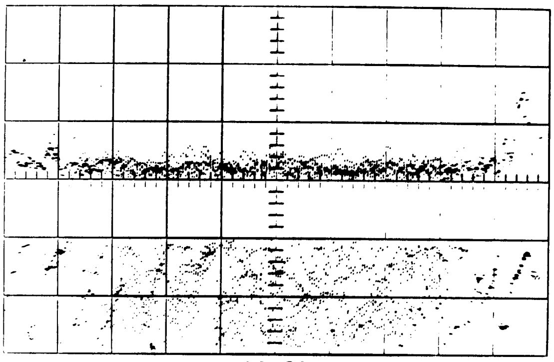
13-22



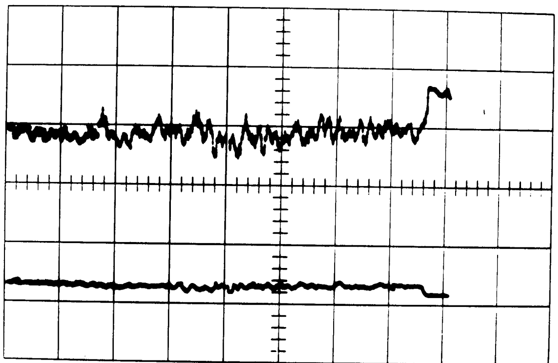
23-31



23-32



32-39

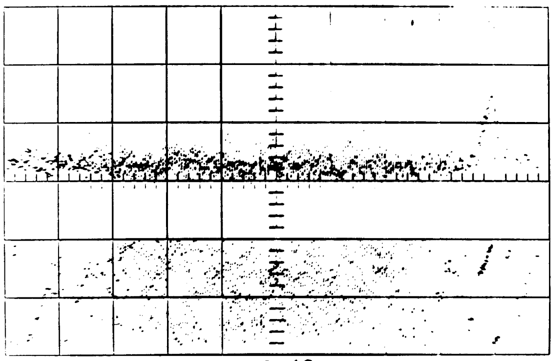


33-40

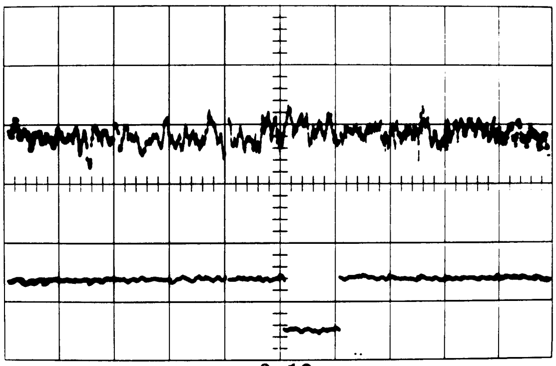
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

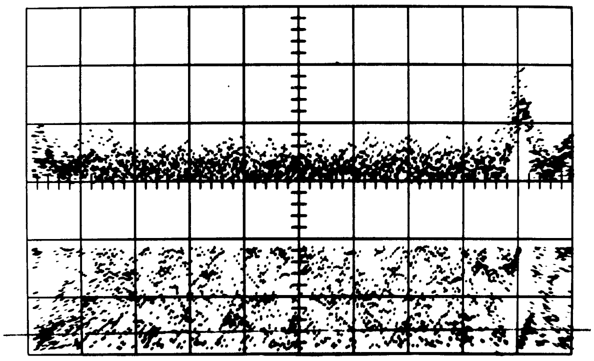
AMSEQ 12 August 1966 0115-0127 hours



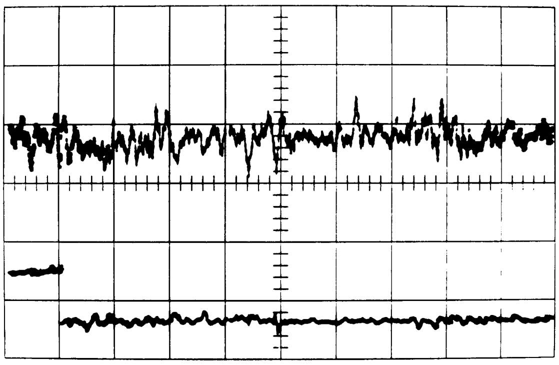
3-12



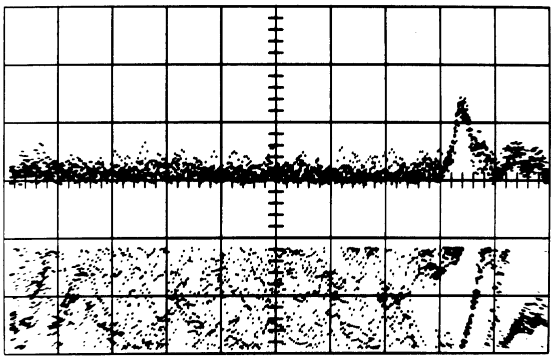
3-12



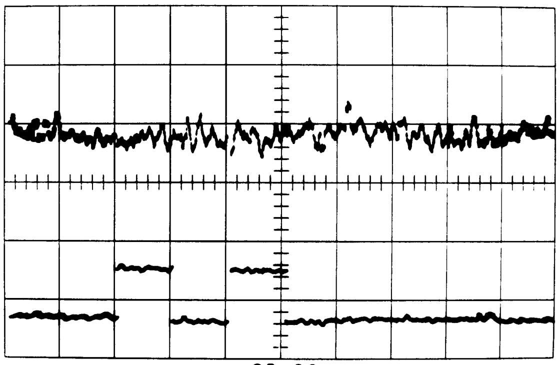
13-22



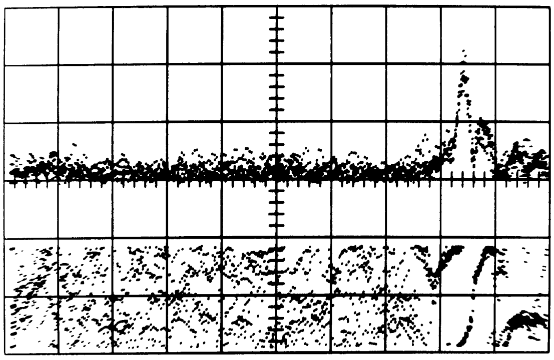
13-22



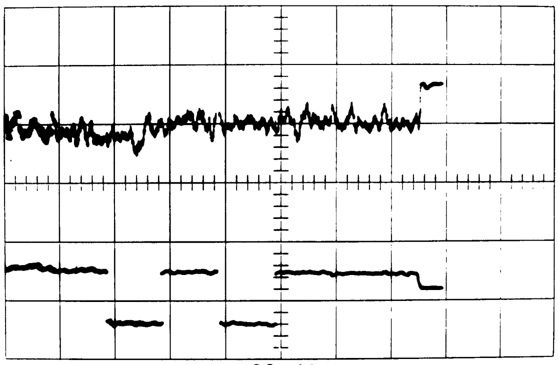
23-31



23-32



32-39

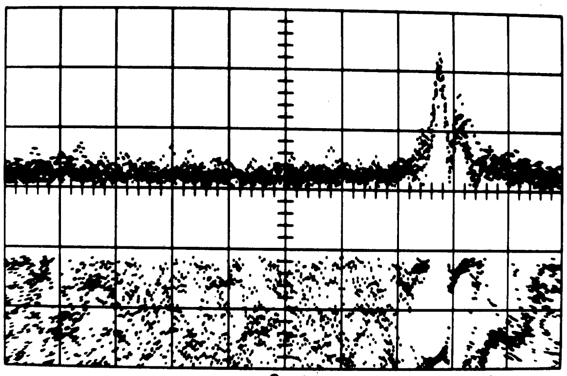


33-40

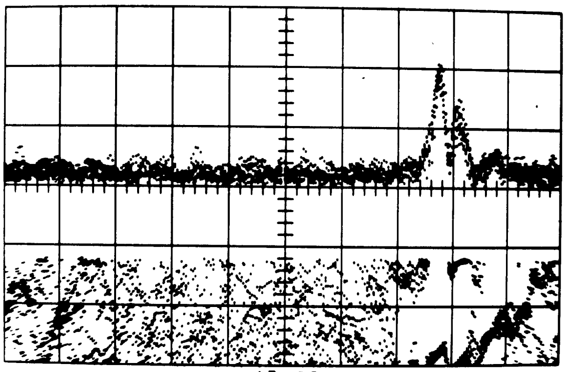
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

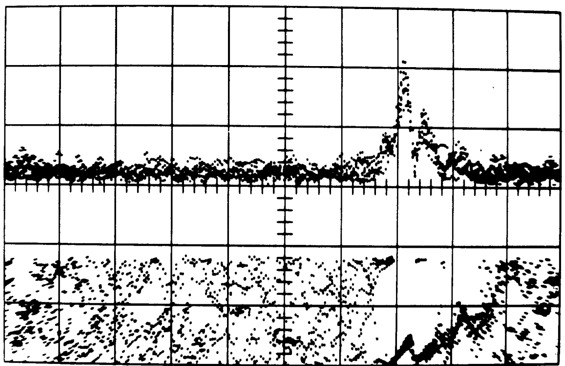
AMSEQ 12 August 1966 0127-0139 hours



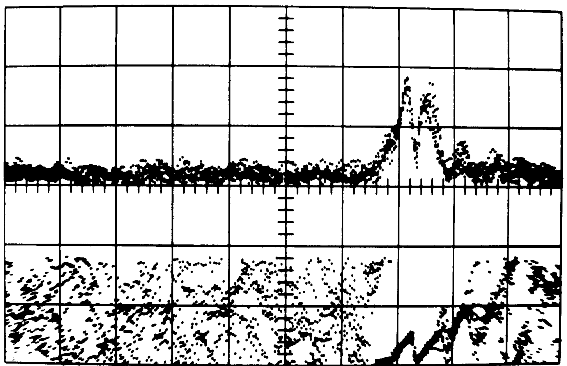
3-12



13-22

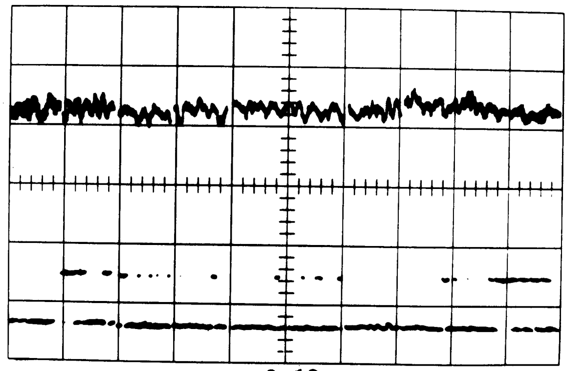


23-30

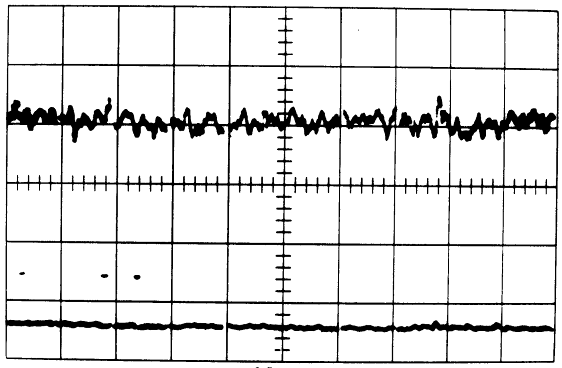


31-39

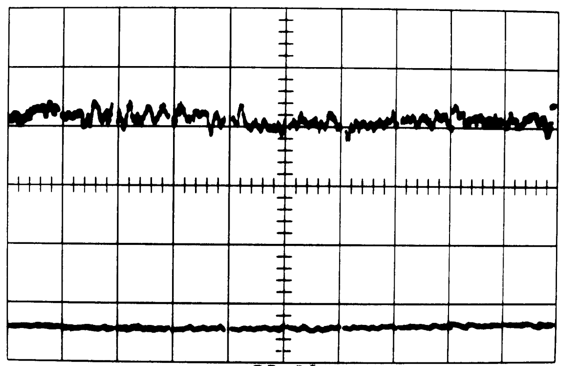
SEQ, R = 0.5V/cm



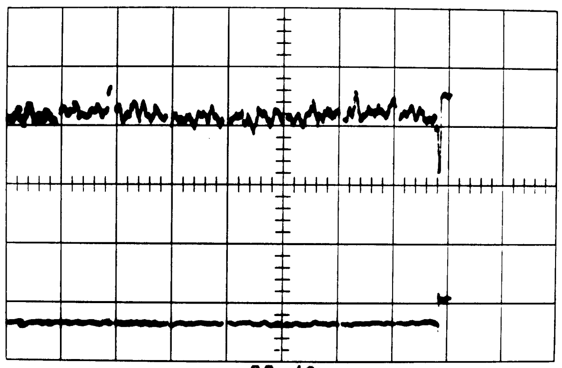
3-12



13-22



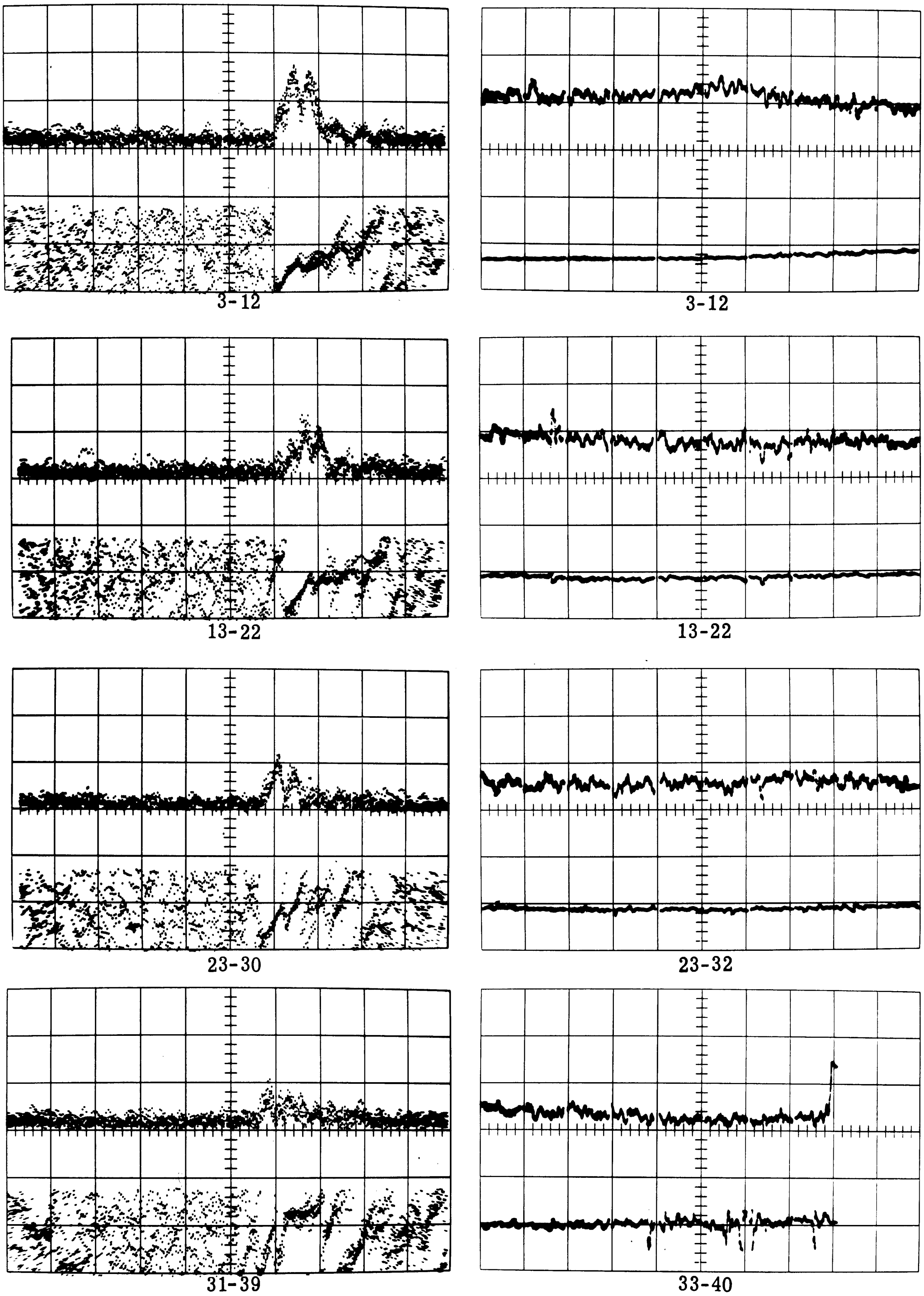
23-32



33-40

CW, R = 0.2V/cm

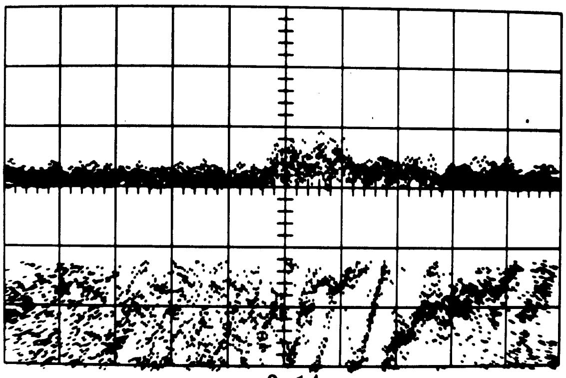
AMSEQ 12 August 1966 0139-0151 hours

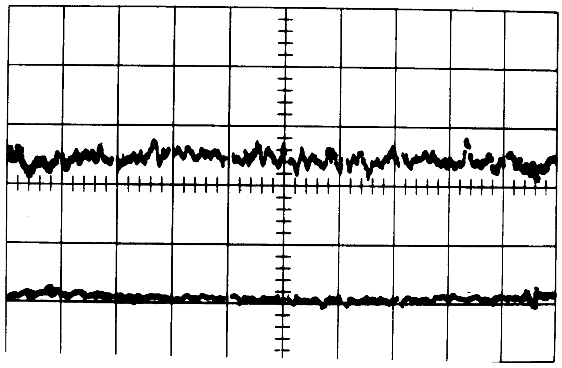


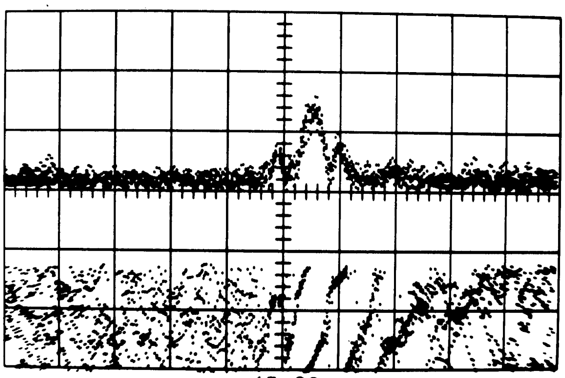
SEQ, R = 0.5V/cm

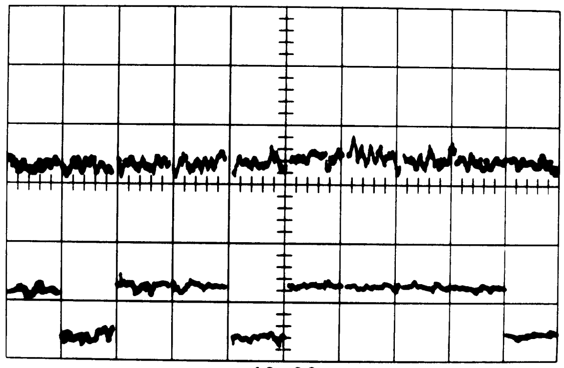
CW, R = 0.2V/cm

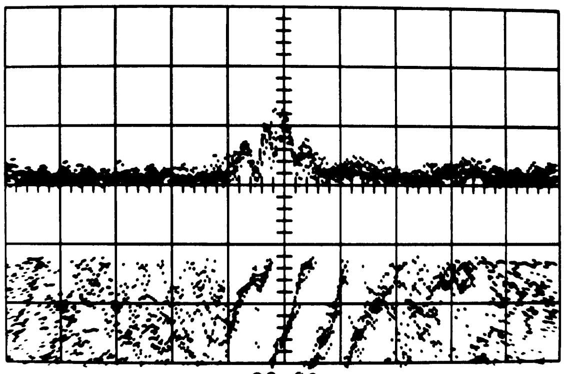
AMSEQ 12 August 1966 0151-0203 hours

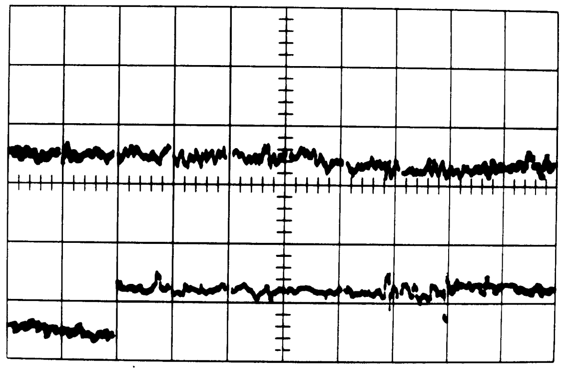

3-14

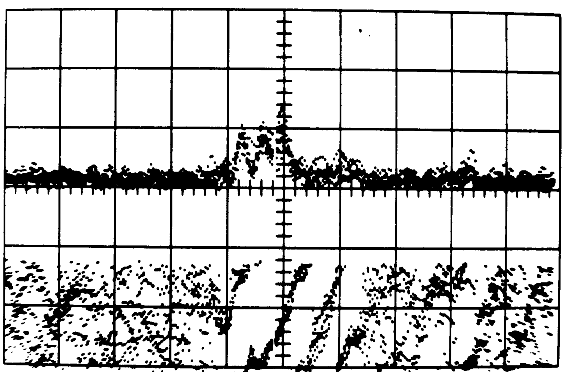

3-12

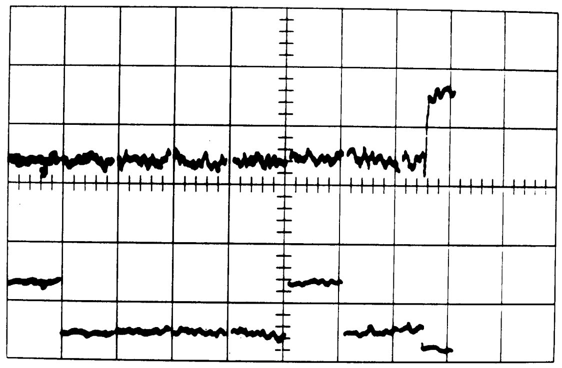

15-22


13-22


23-30


23-32

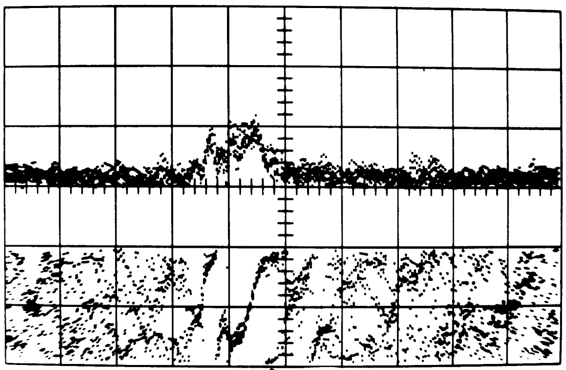

31-39

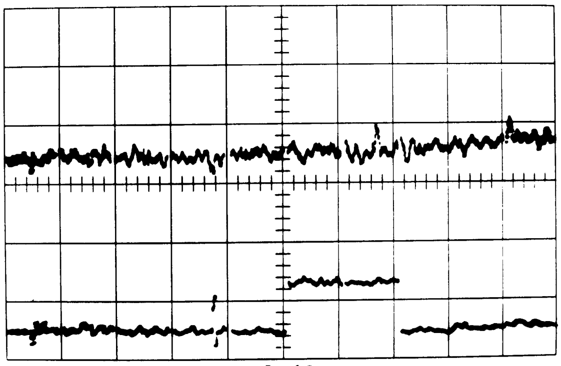

33-40

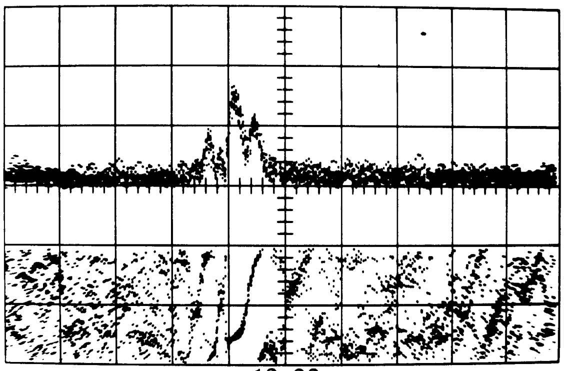
SEQ, R = 0.5V/cm

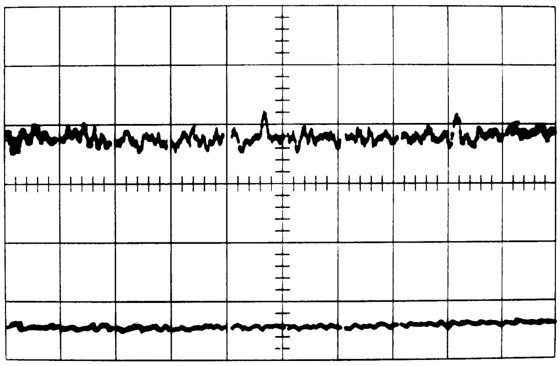
CW, R = 0.2V/cm

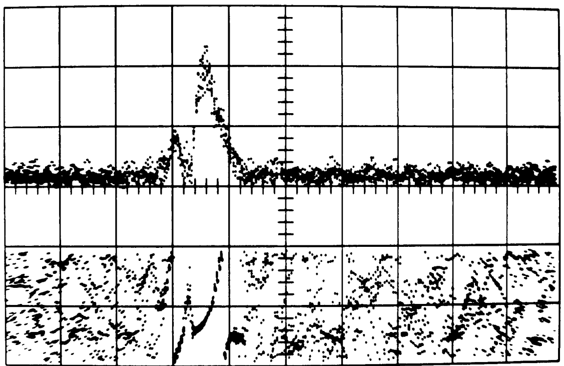
AMSEQ 12 August 1966 0203 - 0215 hours

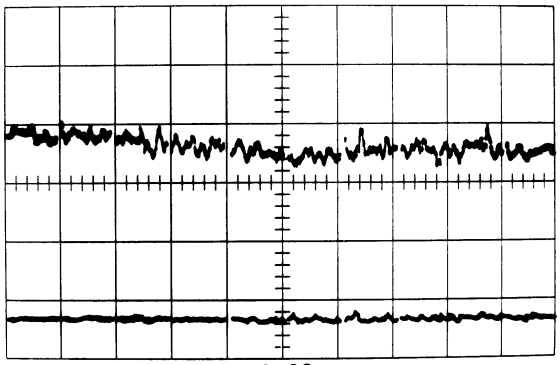

3-11

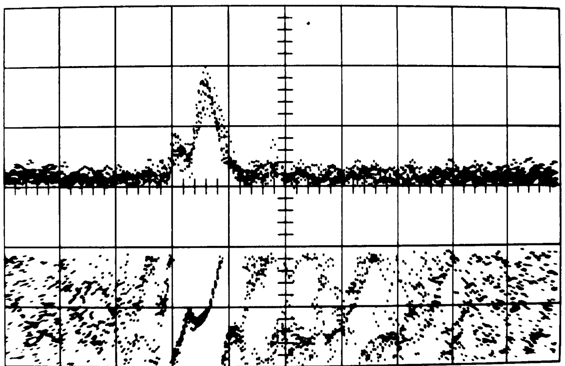

3-12

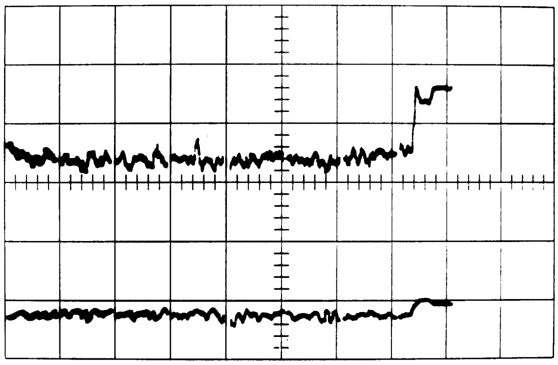

12-22


13-22


23-30


23-32

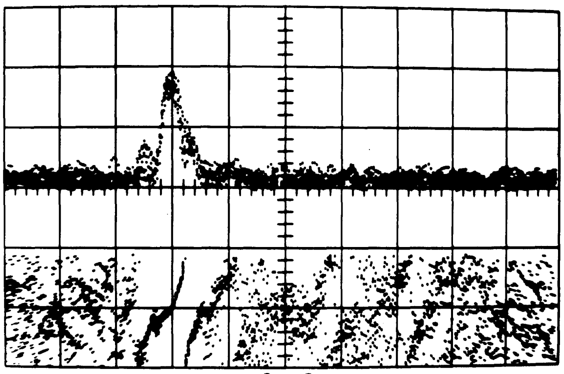

31-39


33-40

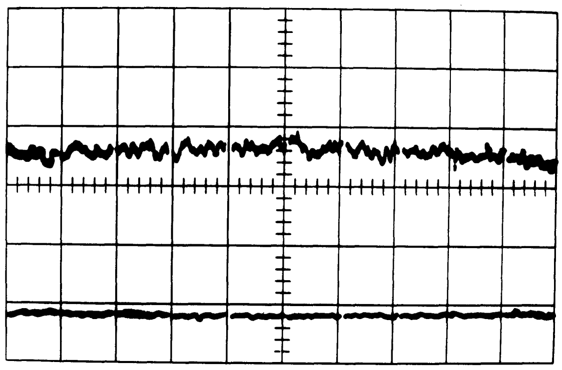
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

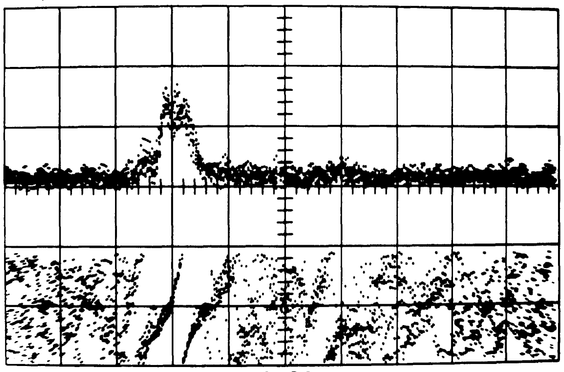
AMSEQ 12 August 1966 0215 - 0227 hours



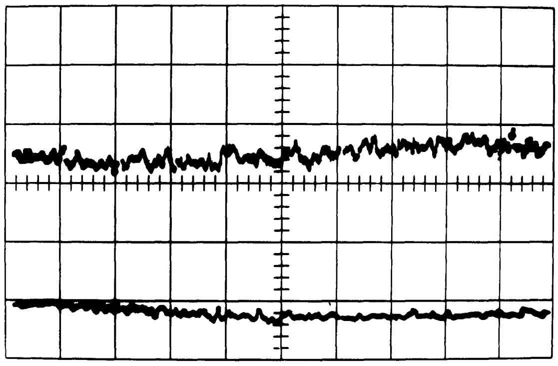
3-12



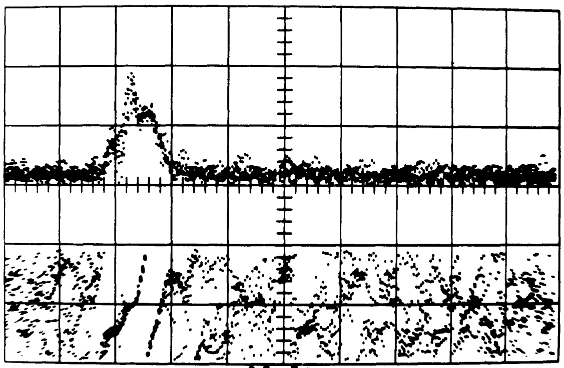
3-12



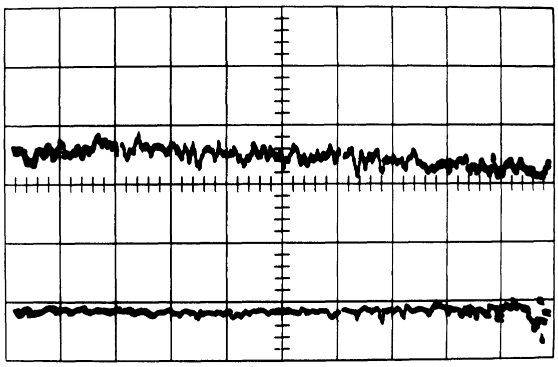
13-22



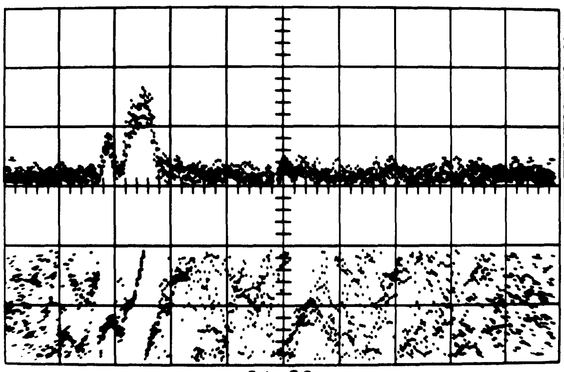
13-22



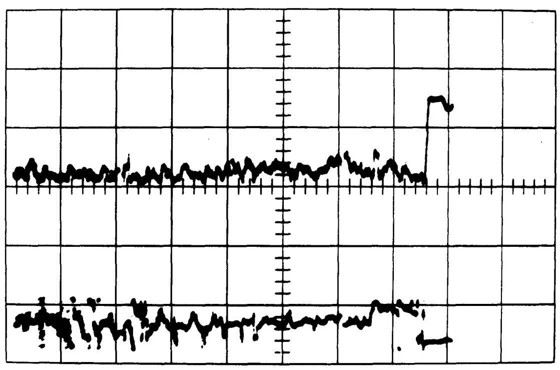
23-30



23-32



31-38

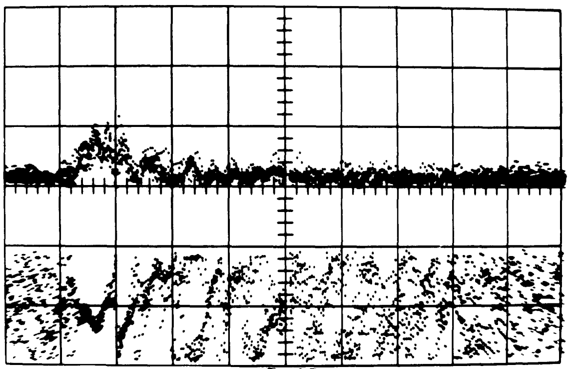


33-40

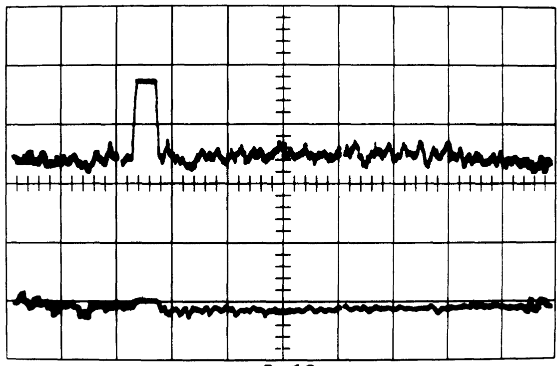
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

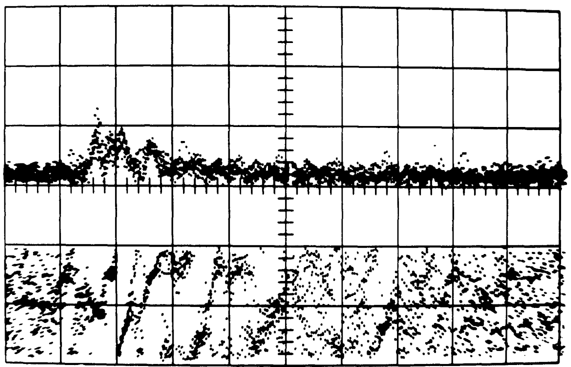
AMSEQ 12 August 1966 0227 - 0239 hours



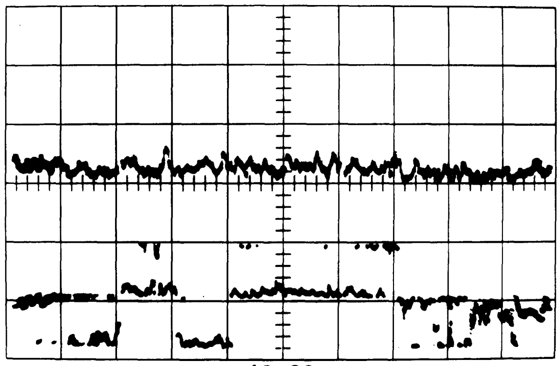
3-12



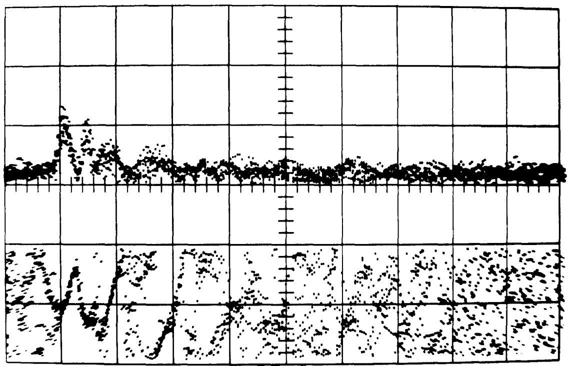
3-12



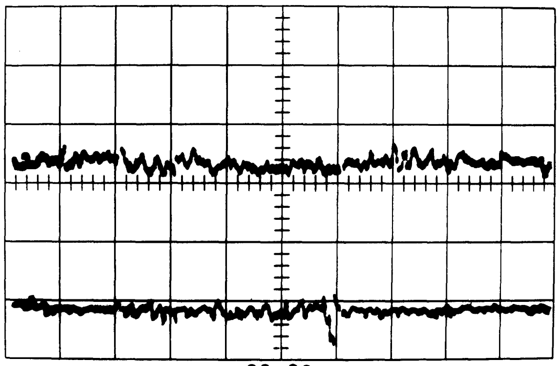
13-22



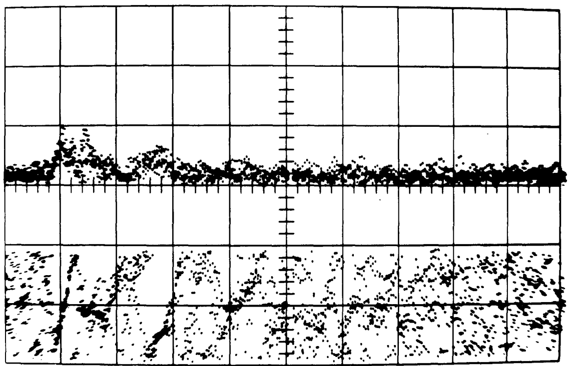
13-22



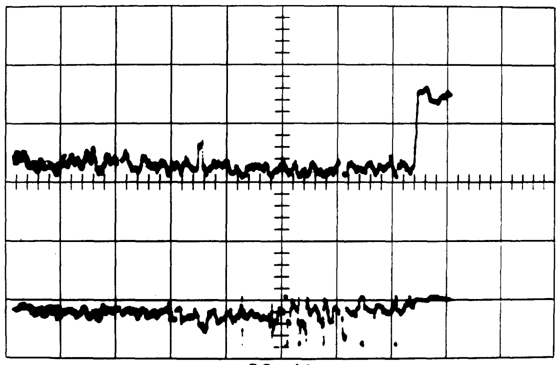
23-30



23-32



31-38

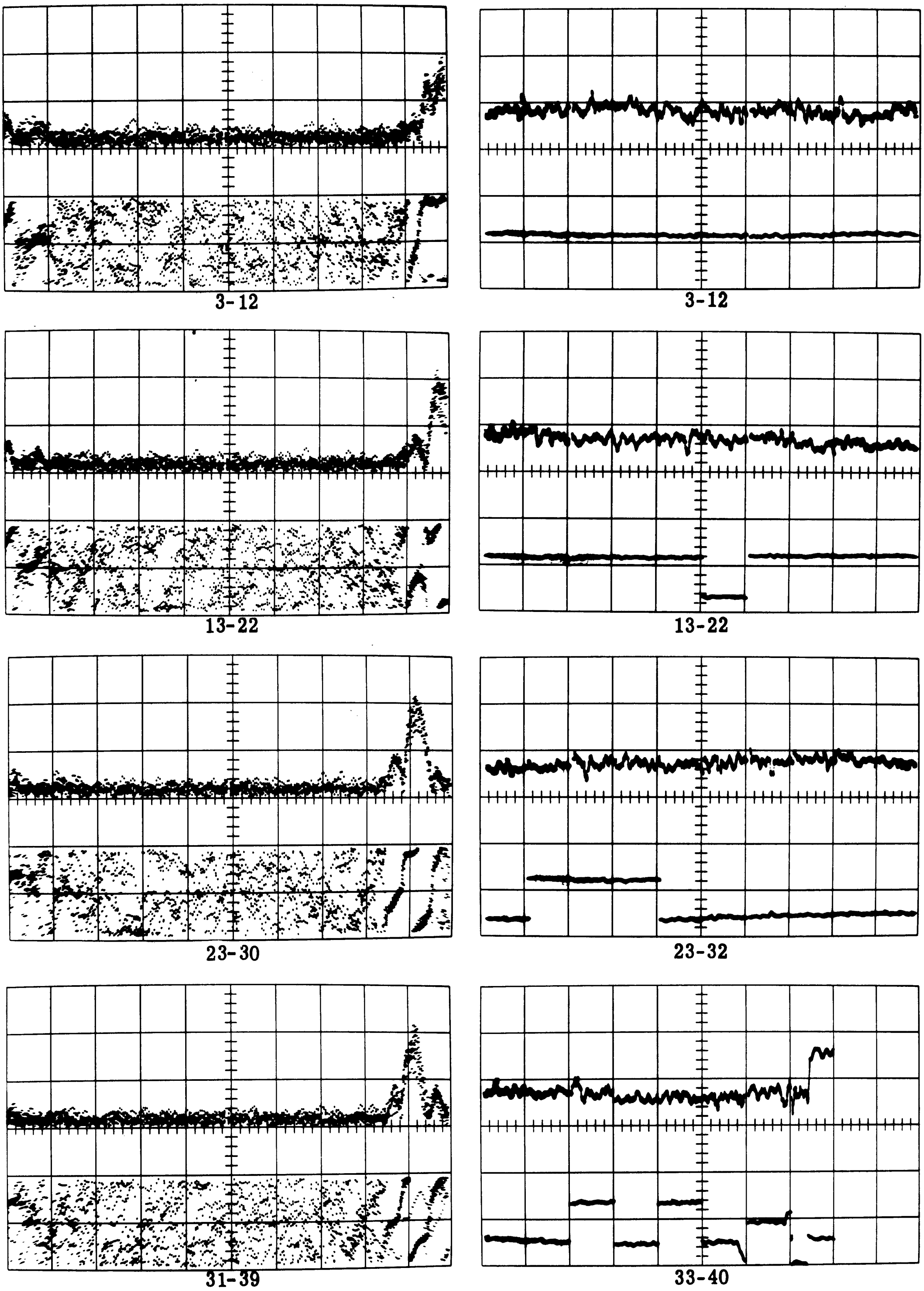


33-40

SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

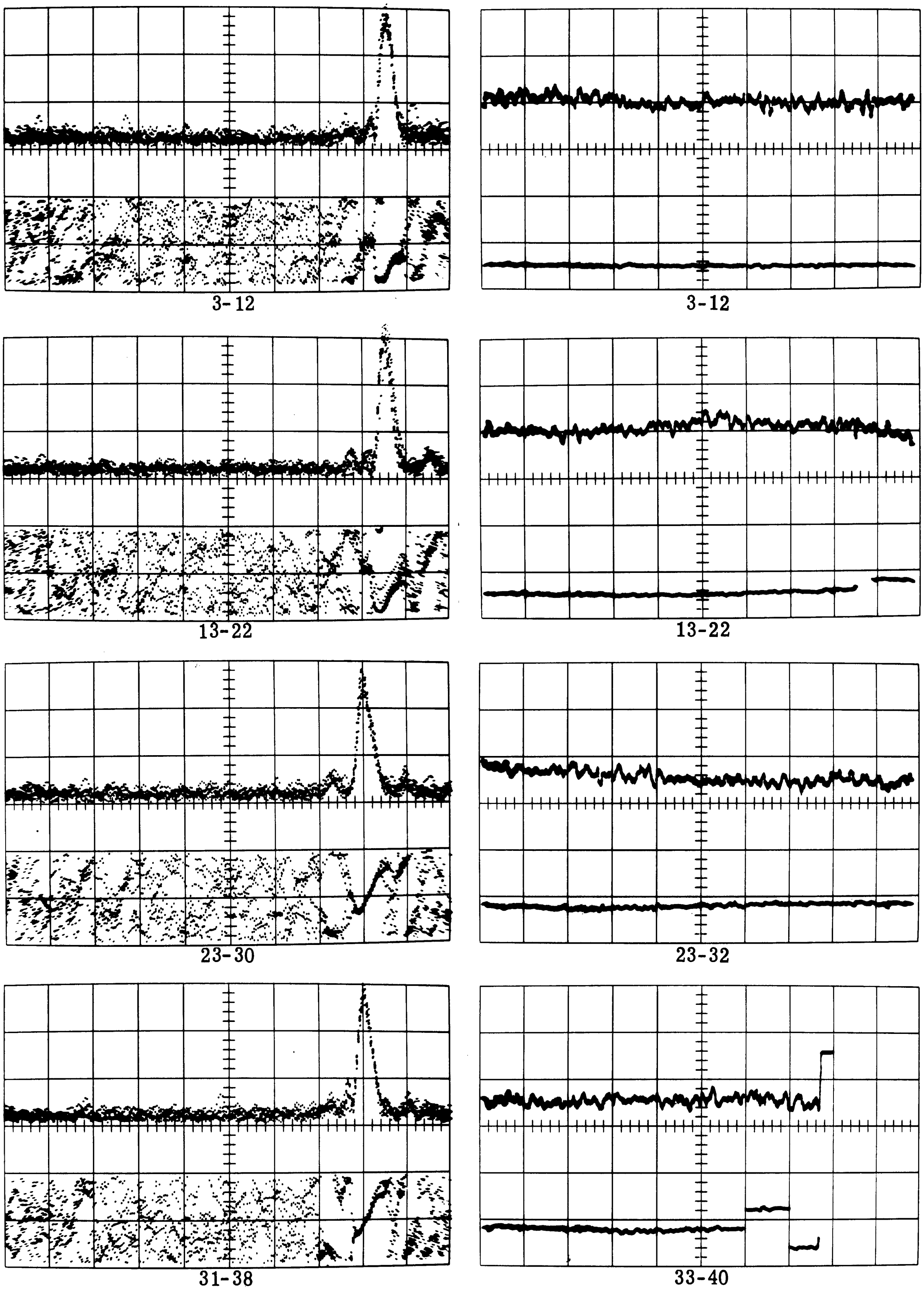
AMSEQ 12 August 1966 0239-0251 hours



SEQ, R = 0.5V/cm

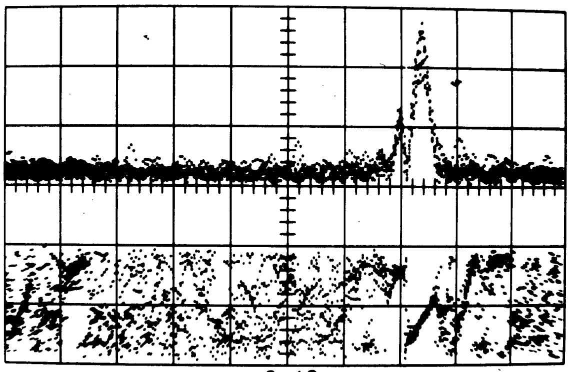
CW, R = 0.2V/cm

AMSEQ 12 August 1966 0303 - 0315 hours

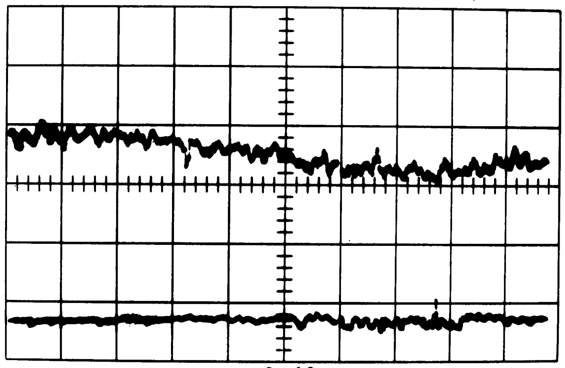


SEQ, R = 0.5V/cm CW, R = 0.2V/cm

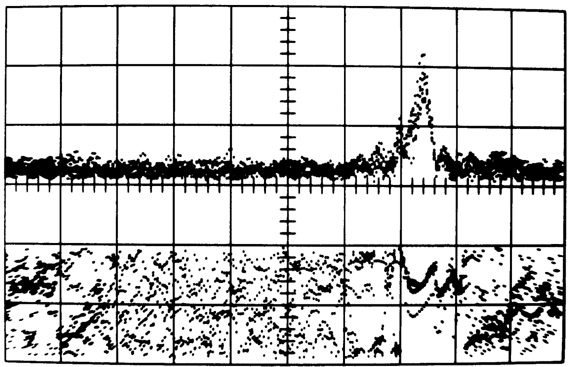
AMSEQ 12 August 1966 0315-0327 hours



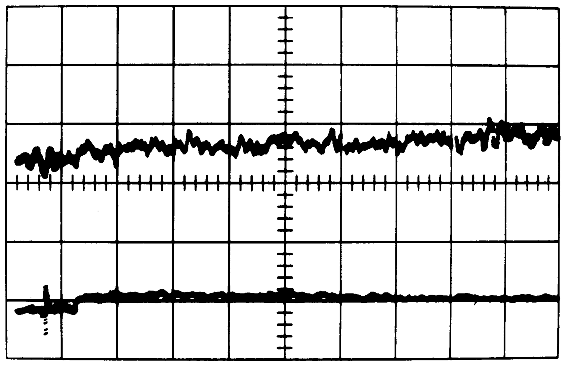
3-12



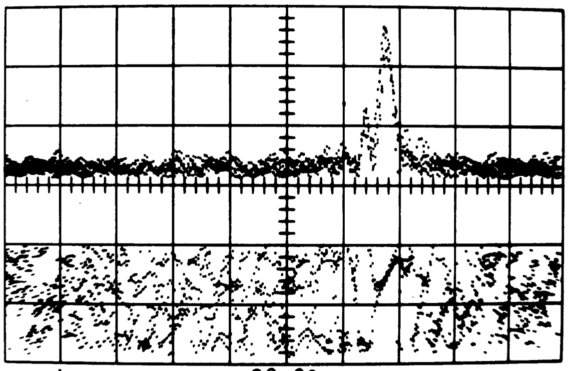
3-12



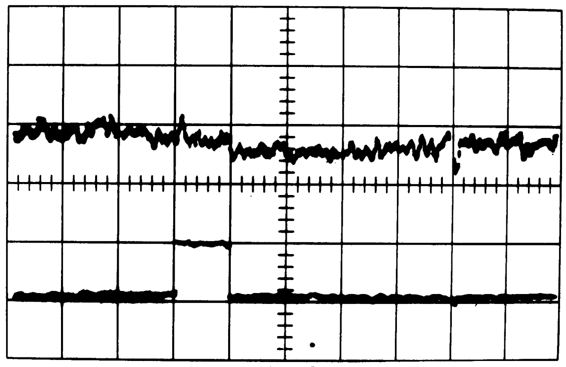
13-22



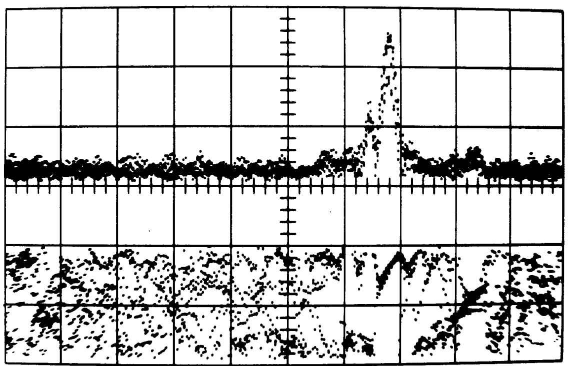
13-22



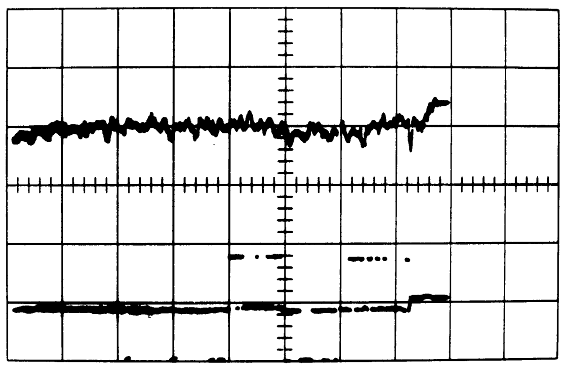
23-30



23-32



31-39

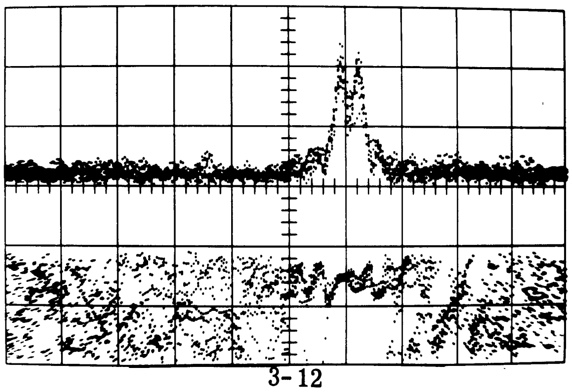


33-40

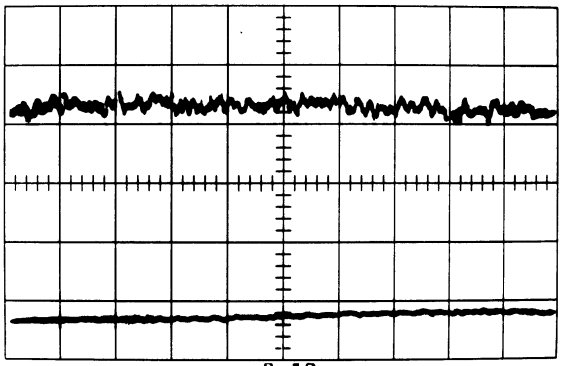
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

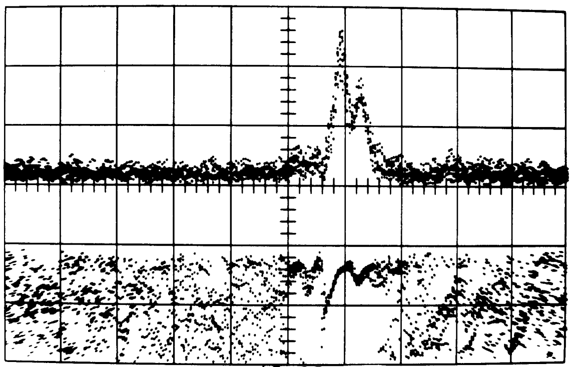
AMSEQ 12 August 1966 0327-0339 hours



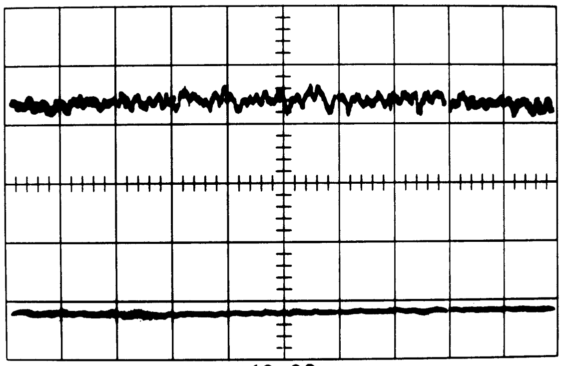
3-12



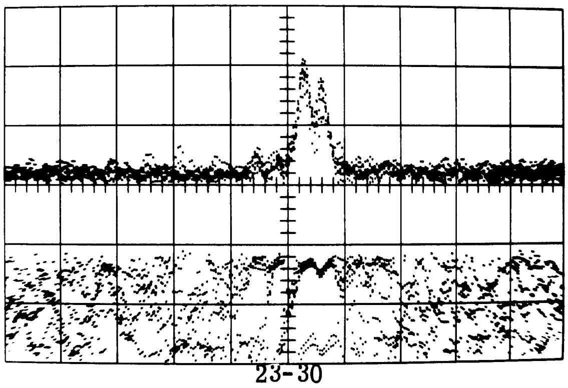
3-12



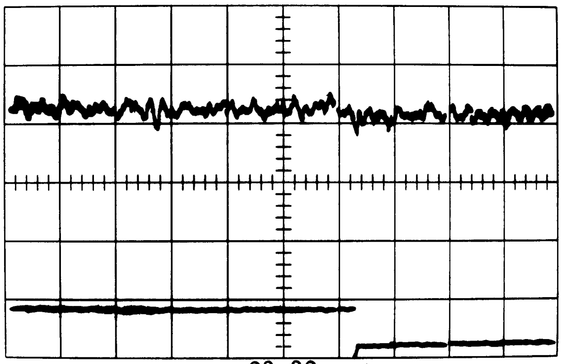
13-22



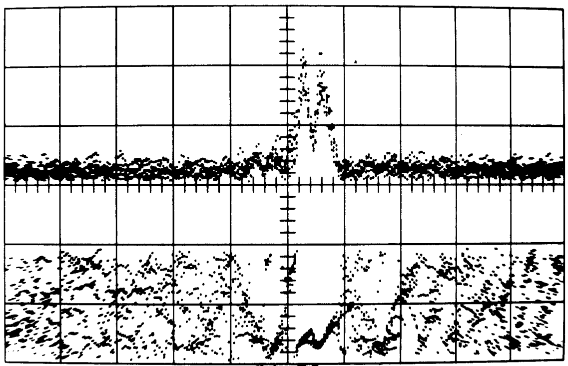
13-22



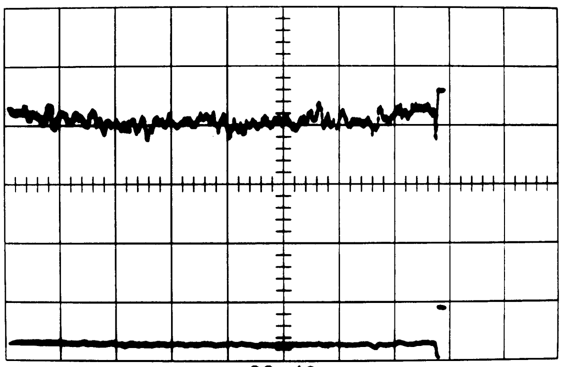
23-30



23-32



31-39

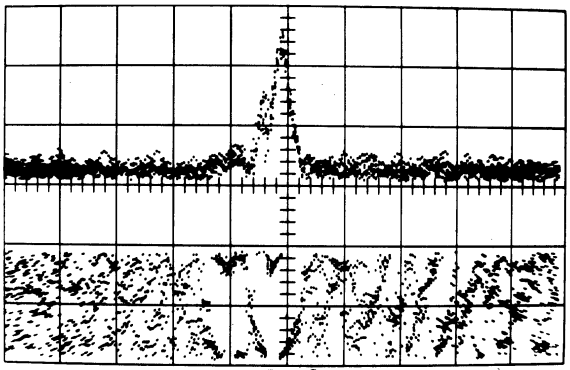


33-40

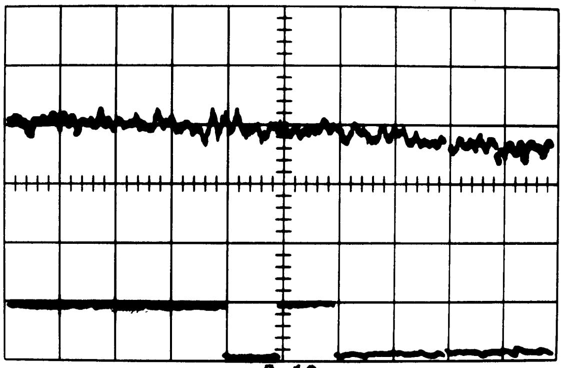
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

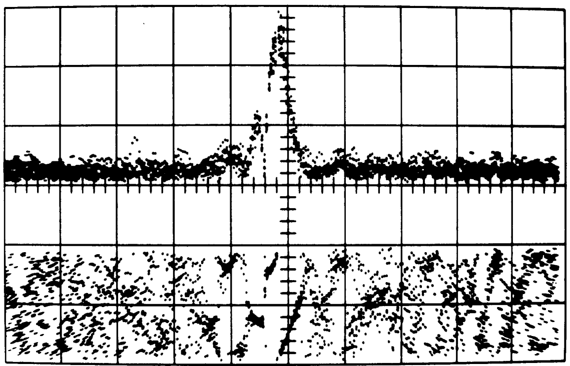
AMSEQ 12 August 1966 0339-0351 hours



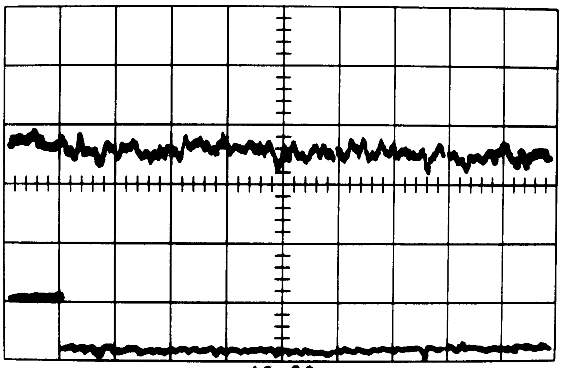
5-12



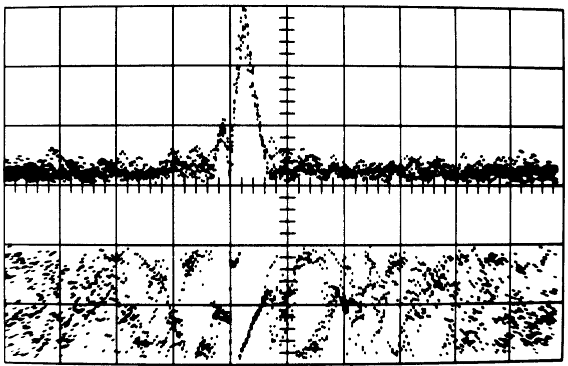
3-12



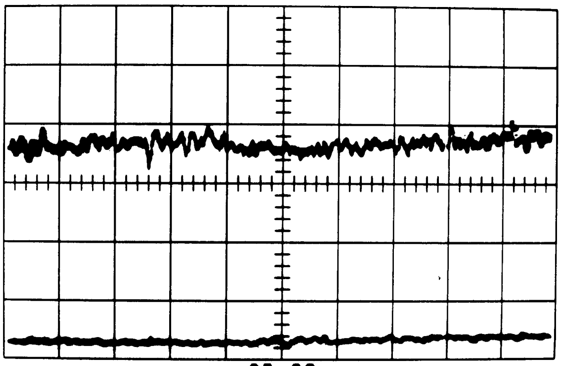
13-22



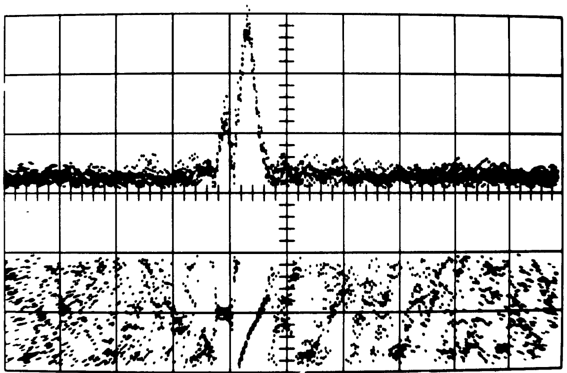
13-22



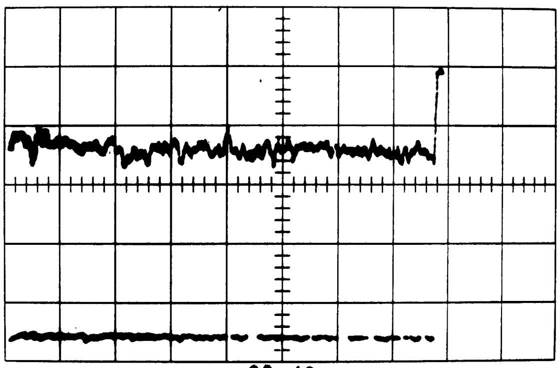
23-30



23-32



31-39

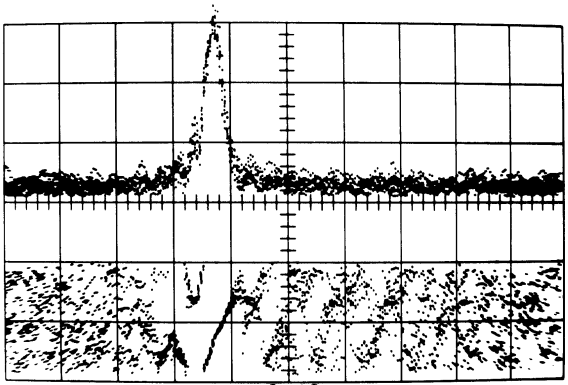


33-40

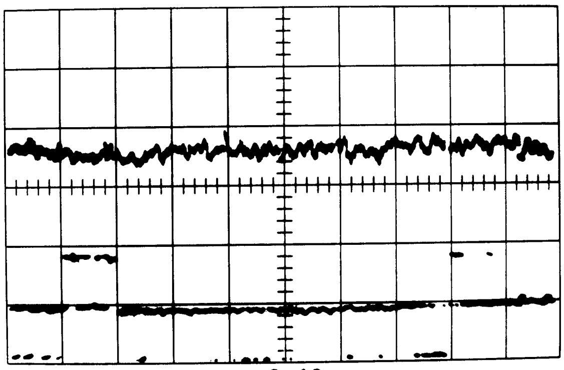
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

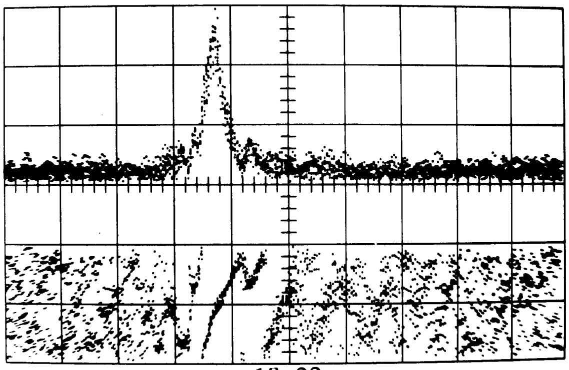
AMSEQ 12 August 1966 0351-0403 hours



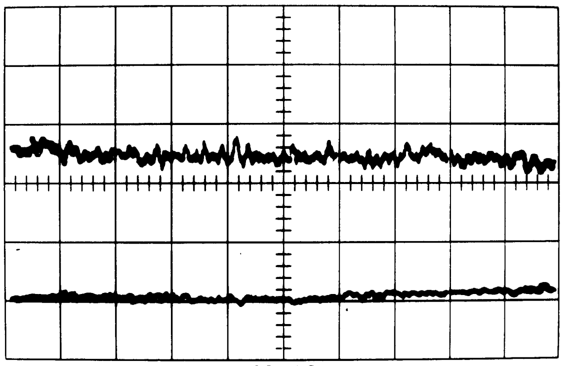
3-12



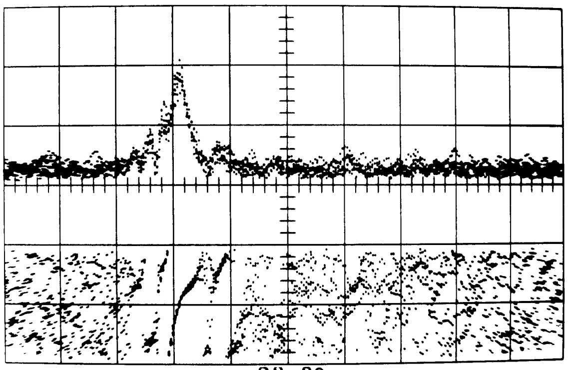
3-12



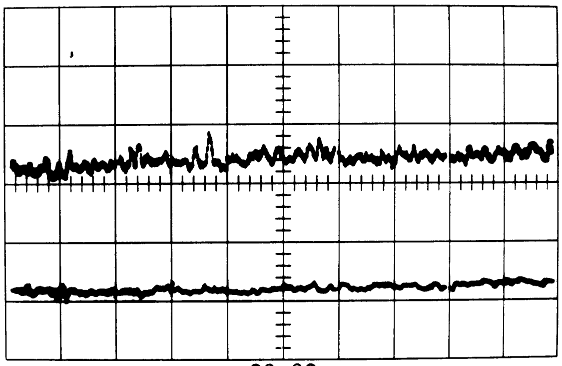
13-22



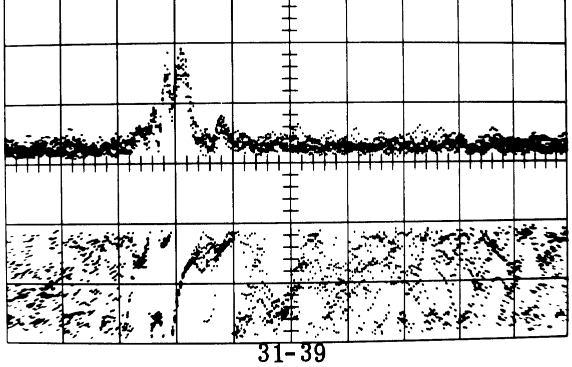
13-22



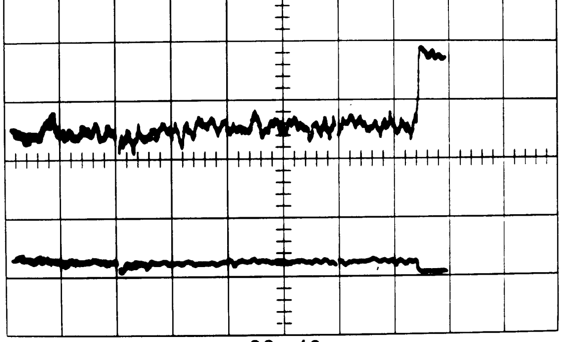
23-30



23-32



31-39

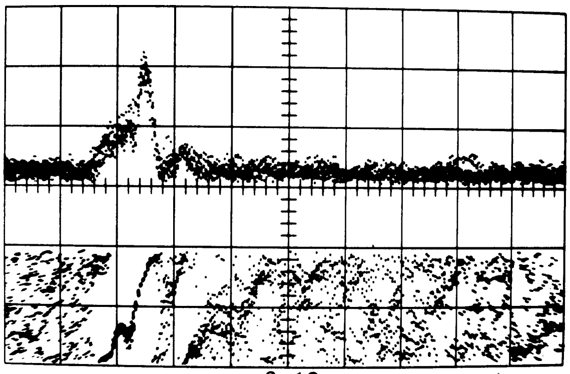


33-40

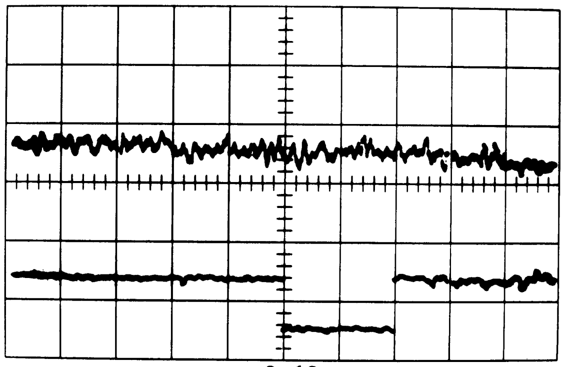
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

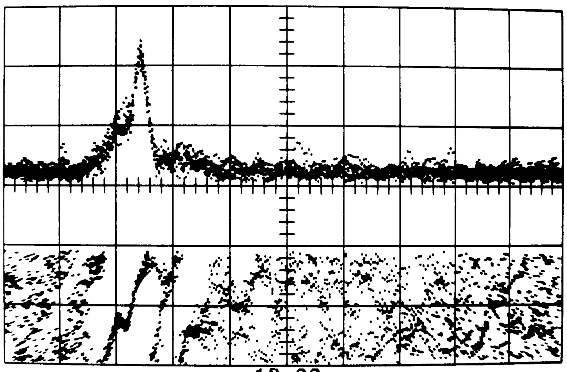
AMSEQ 12 August 1966 0403 - 0415 hours



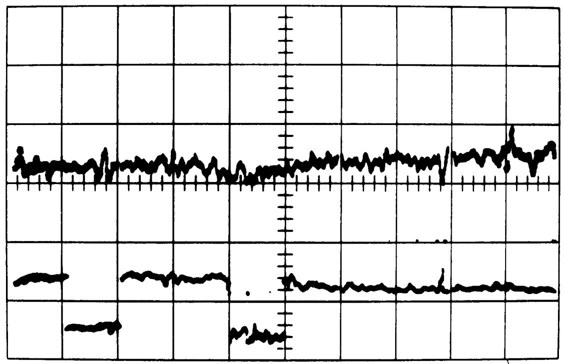
3-12



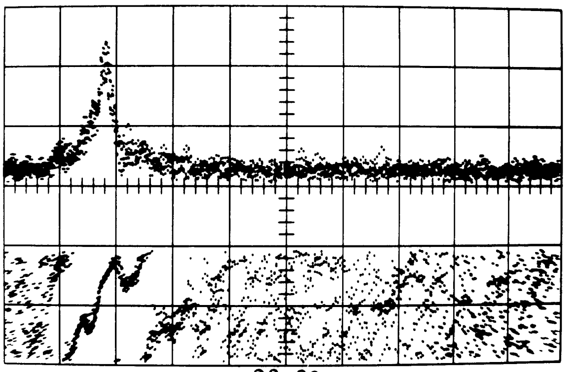
3-12



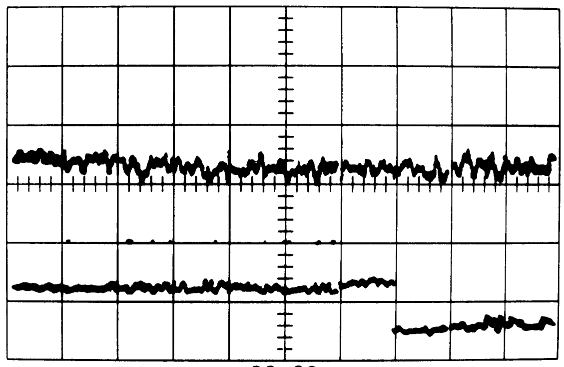
13-22



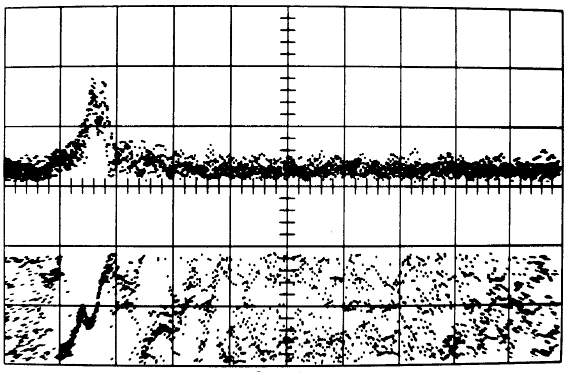
13-22



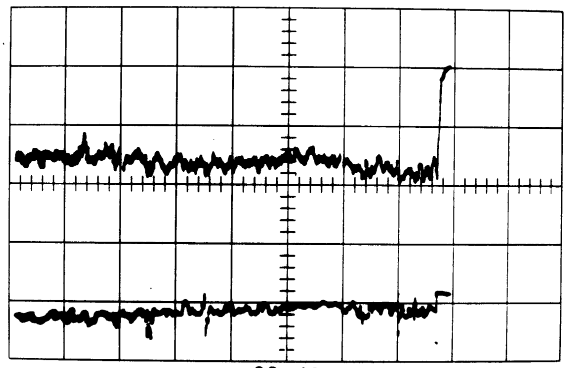
23-30



23-32



31-39

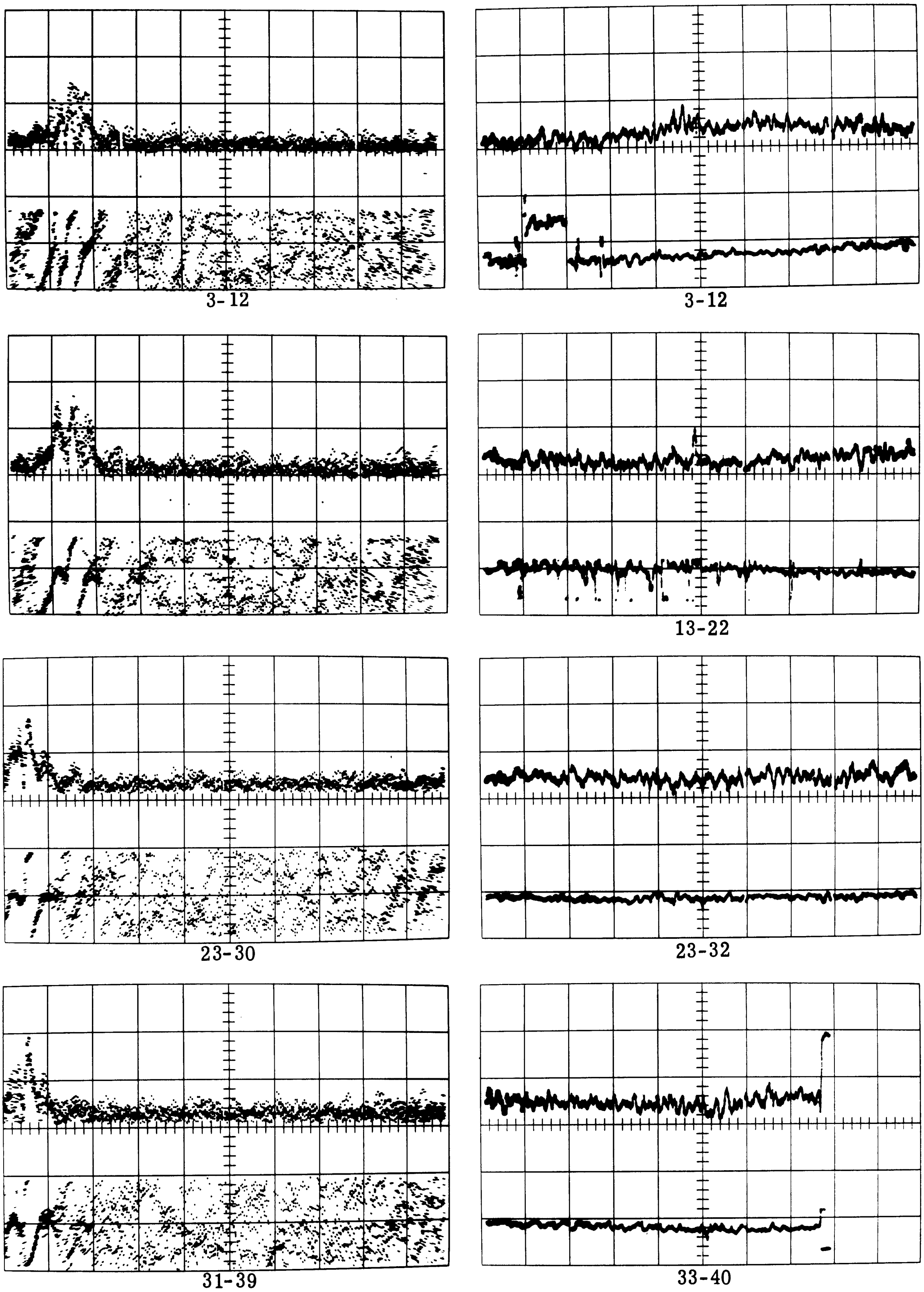


33-40

SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

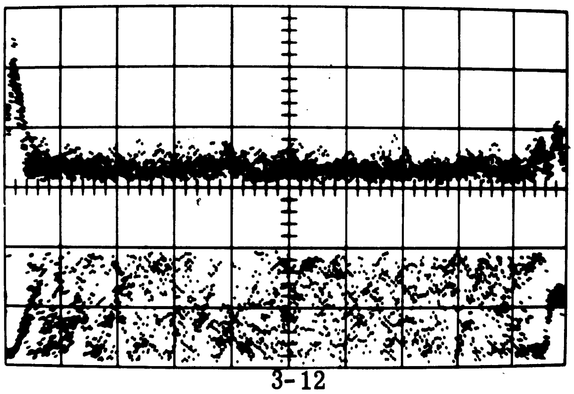
AMSEQ 12 August 1966 0415-0427 hours



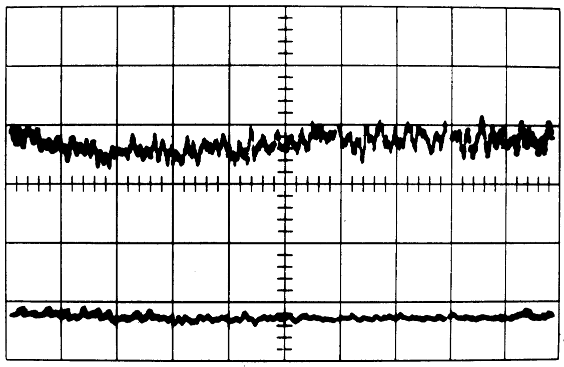
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

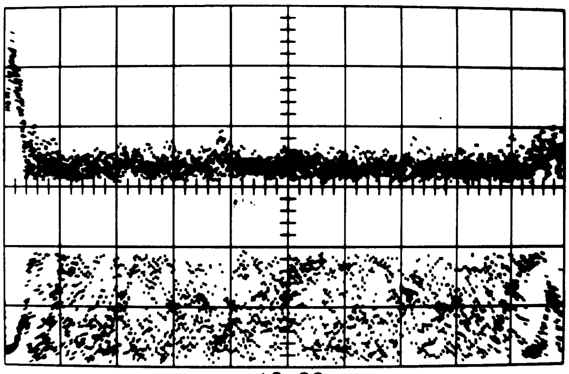
AMSEQ 12 August 1966 0427-0439 hours



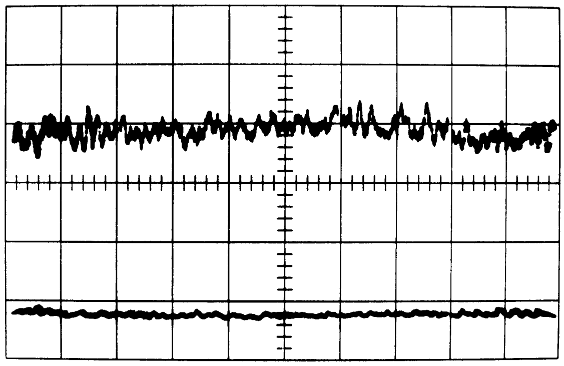
3-12



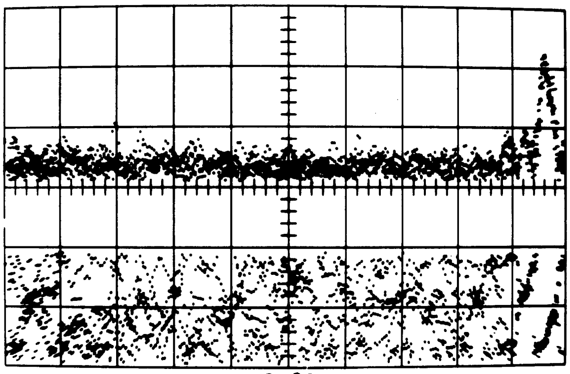
3-12



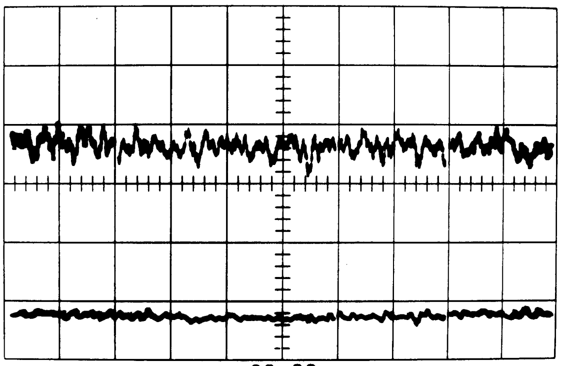
13-22



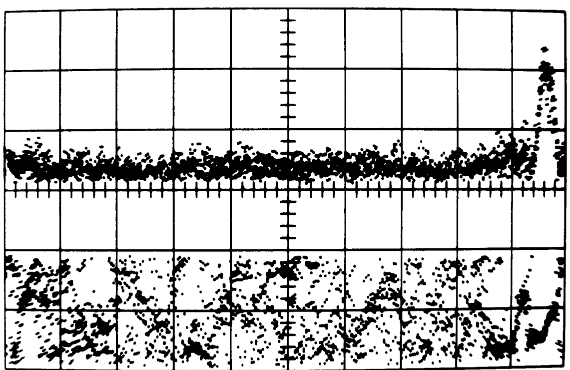
13-22



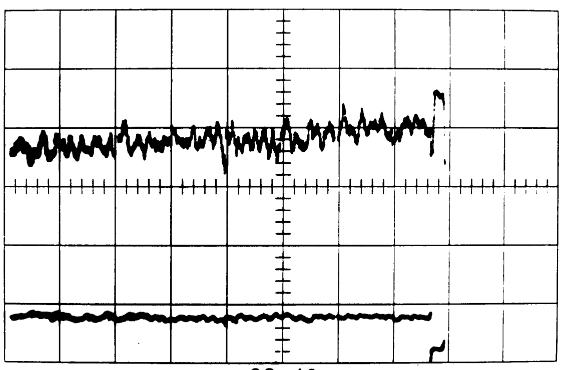
23-30



23-32



31-39

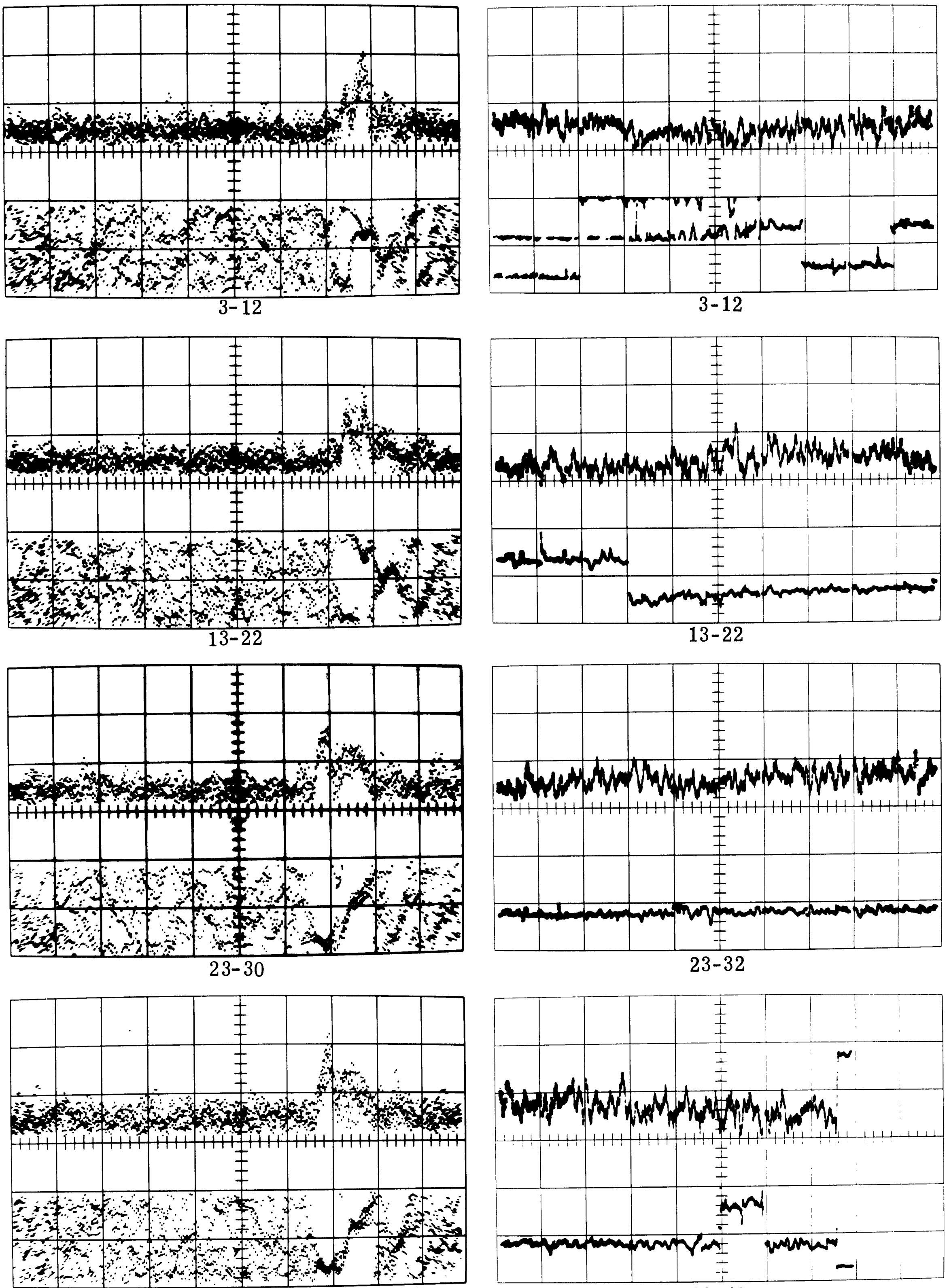


33-40

SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

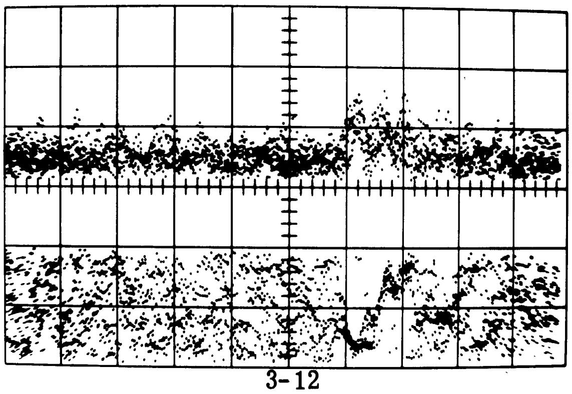
AMSEQ 12 August 1966 0439-0451 hours



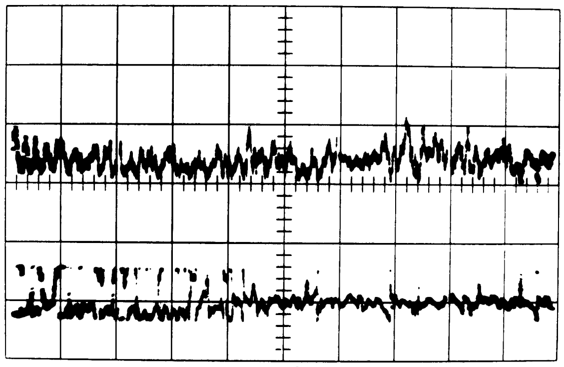
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

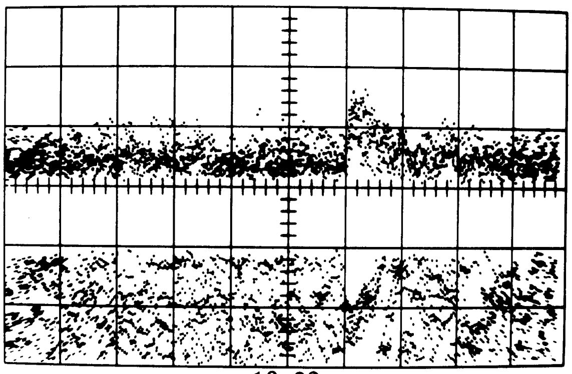
AMSEQ 12 August 1966 0503 - 0515 hours



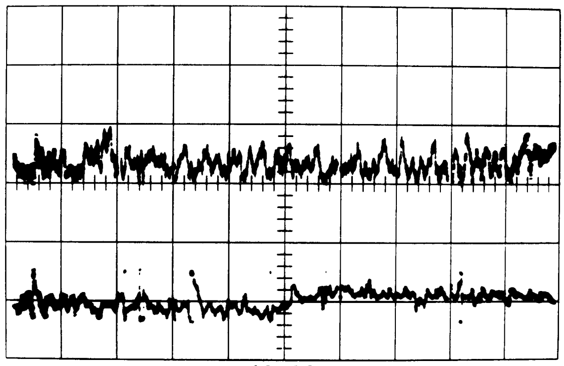
3-12



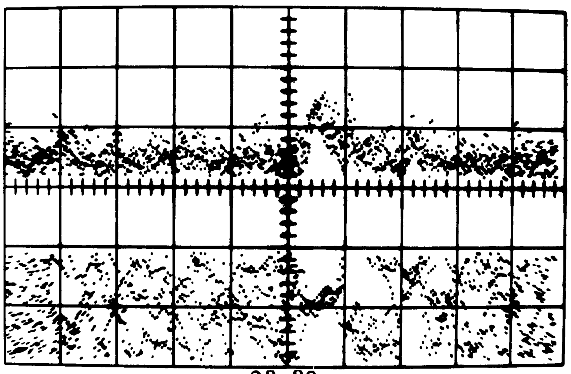
3-12



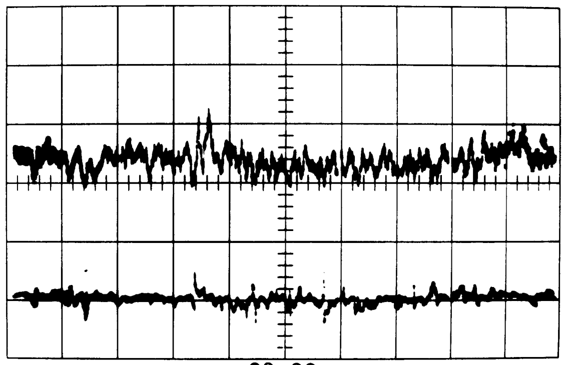
13-22



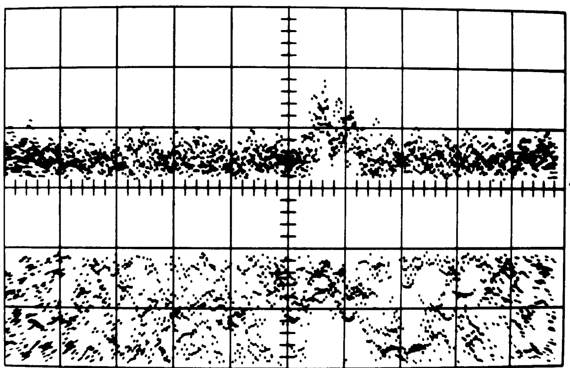
13-22



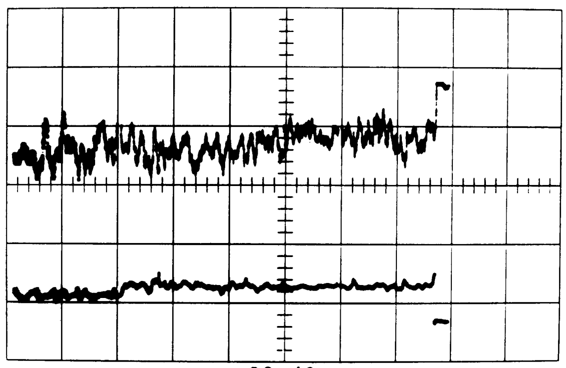
23-30



23-32



32-39

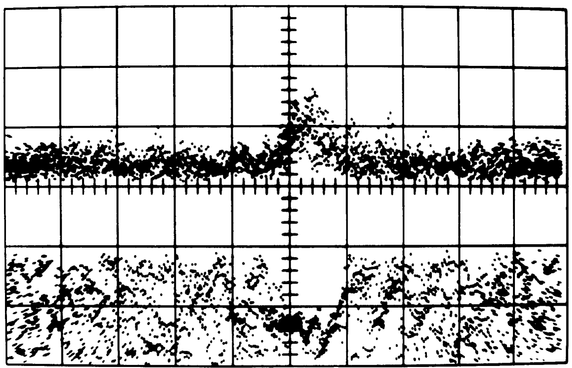


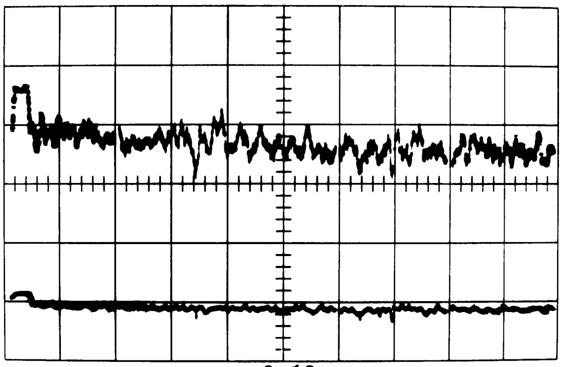
33-40

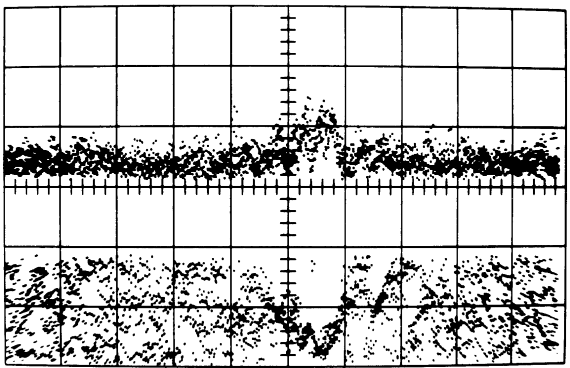
SEQ, R = 0.5V/cm

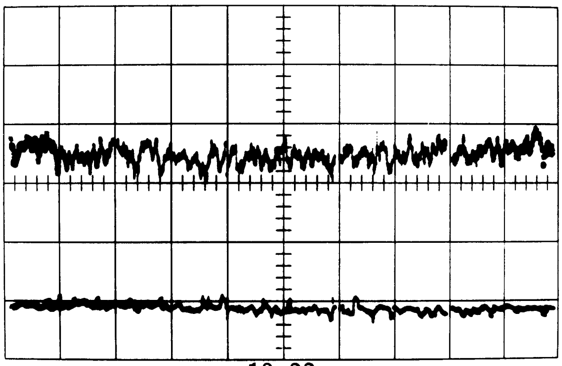
CW, R = 0.2V/cm

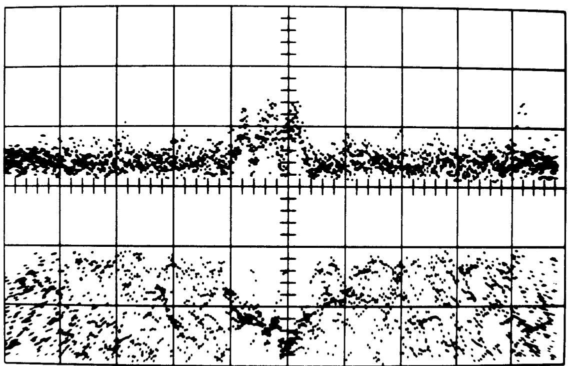
AMSEQ 12 August 1966 0515 - 0527 hours

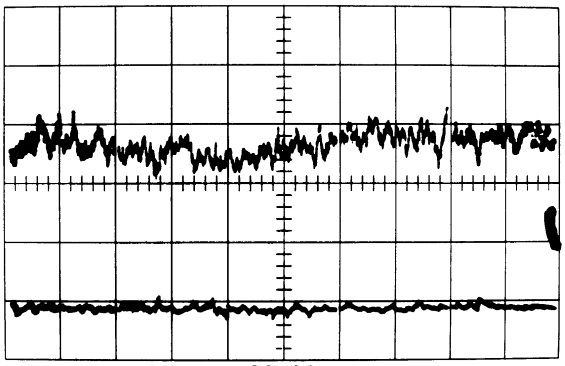

3-12

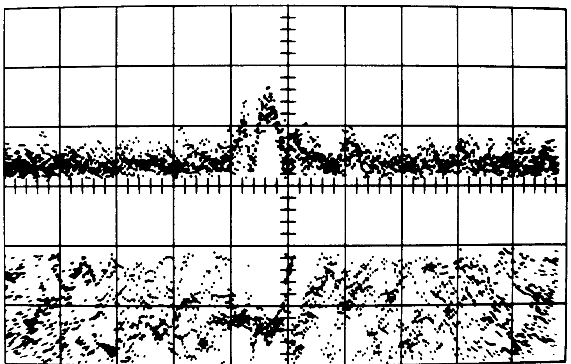

3-12

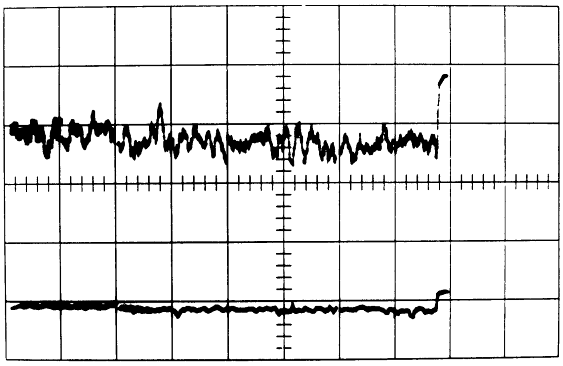

13-22


13-22


23-30


23-32

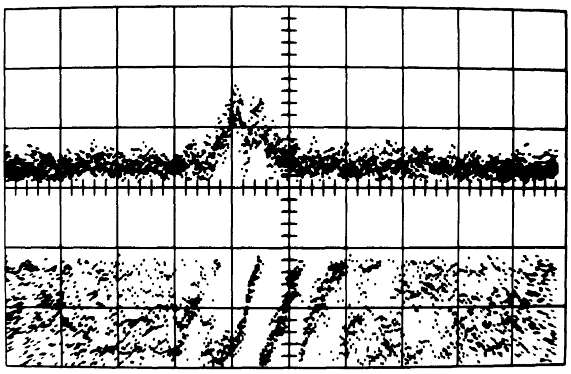

31-39

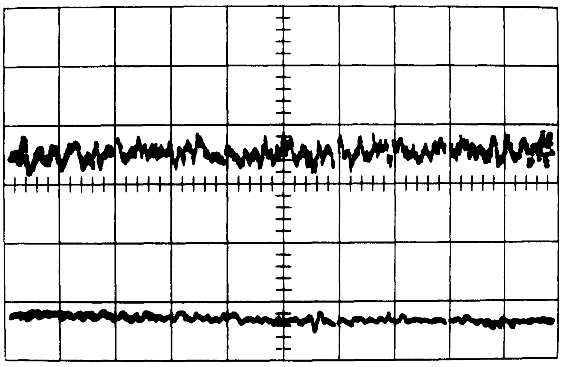

33-40

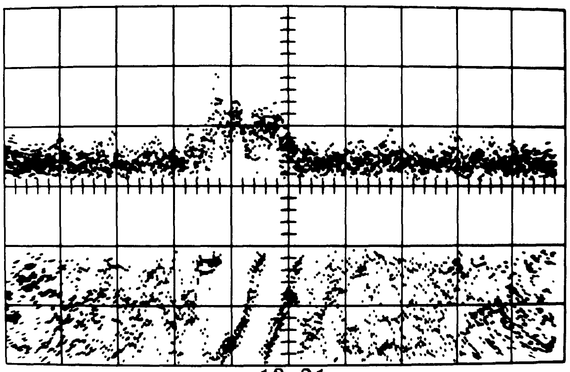
SEQ, R = 0.5V/cm

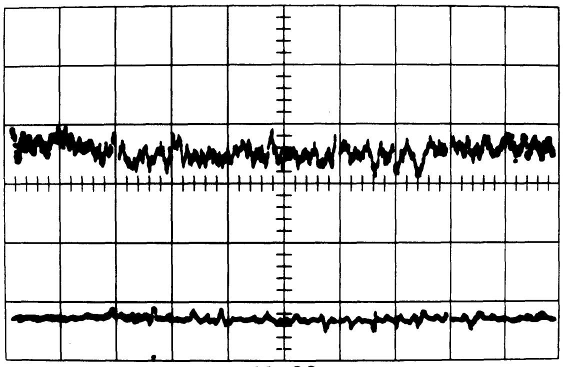
CW, R = 0.2V/cm

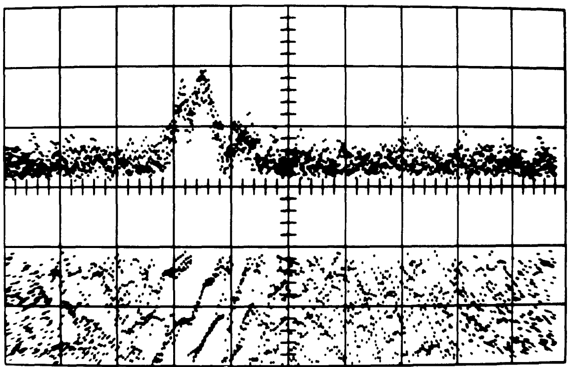
AMSEQ 12 August 1966 0527-0539 hours

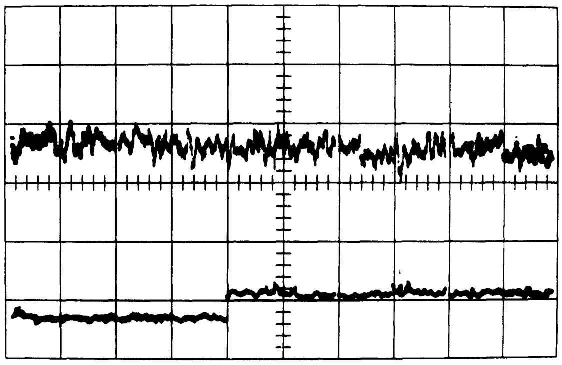

3-12

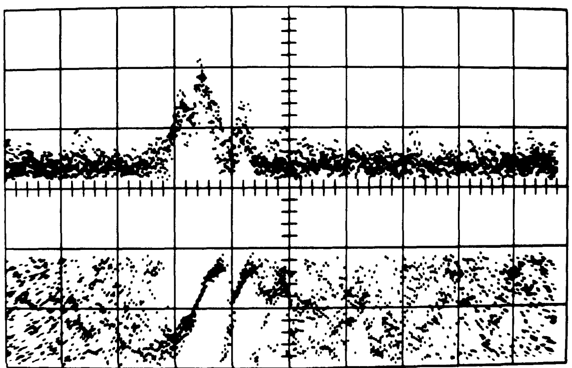

3-12

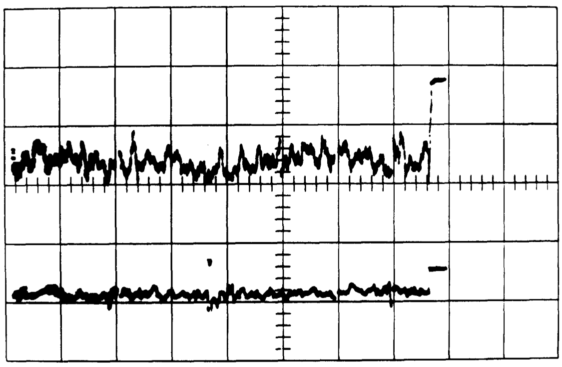

13-21


13-22


23-30


23-32

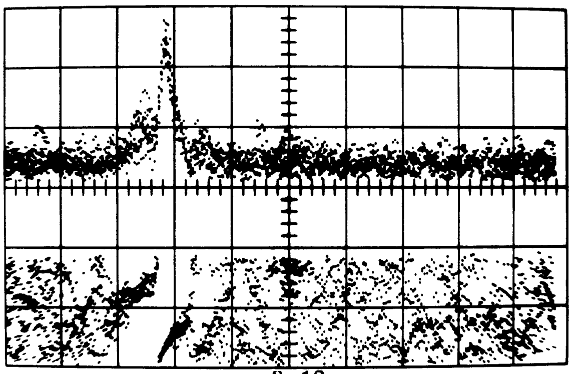

31-39

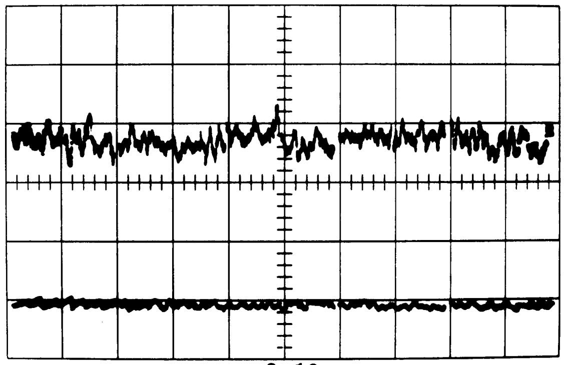

33-40

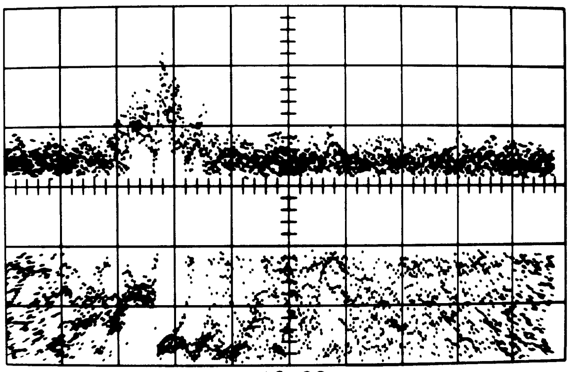
SEQ, R = 0.5V/cm

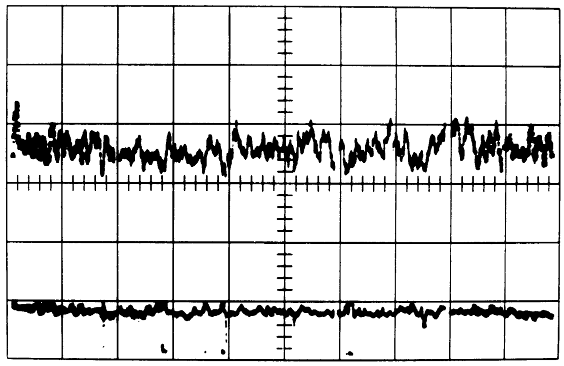
CW, R = 0.2V/cm

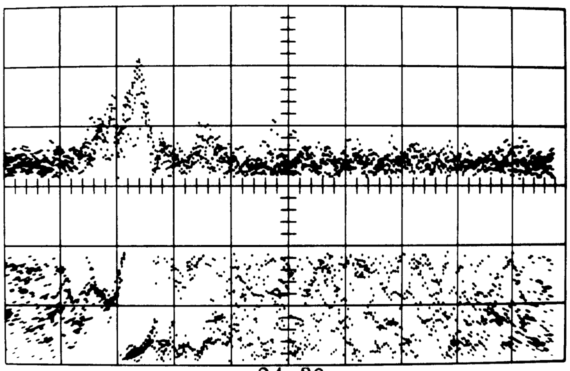
AMSEQ 12 August 1966 0539-0551 hours

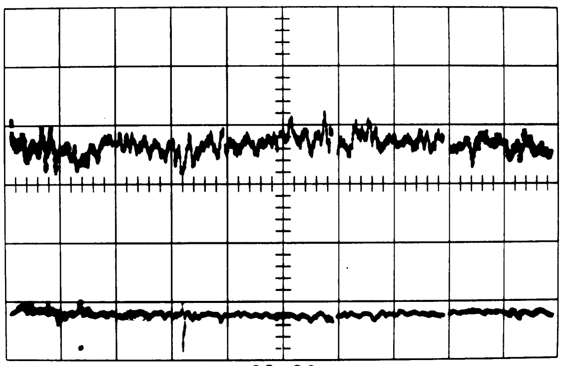

3-12

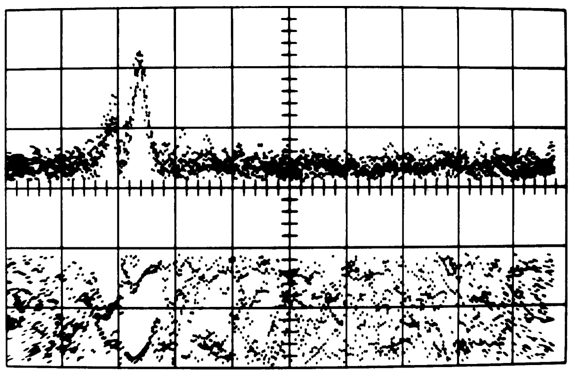

3-12

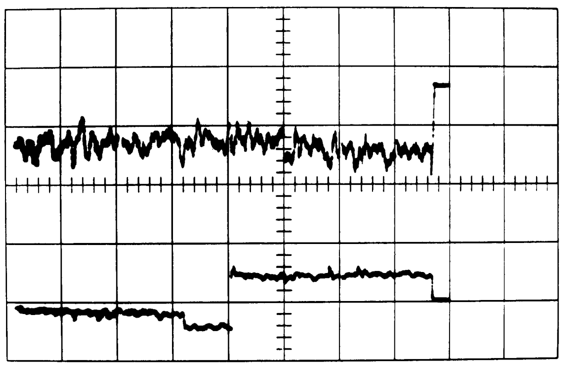

13-22


13-22


24-30


23-32

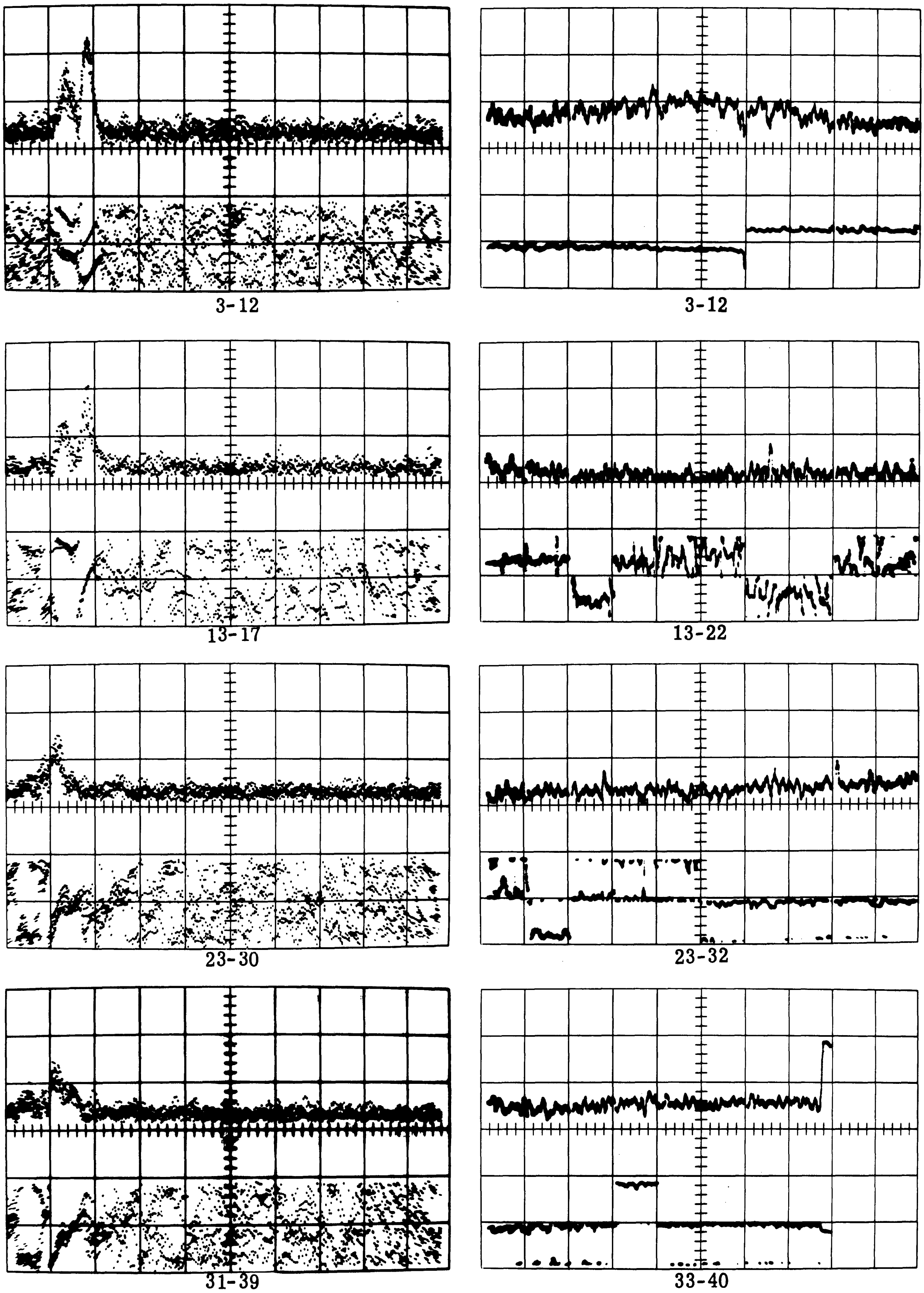

31-39


33-40

SEQ, R = 0.5V/cm

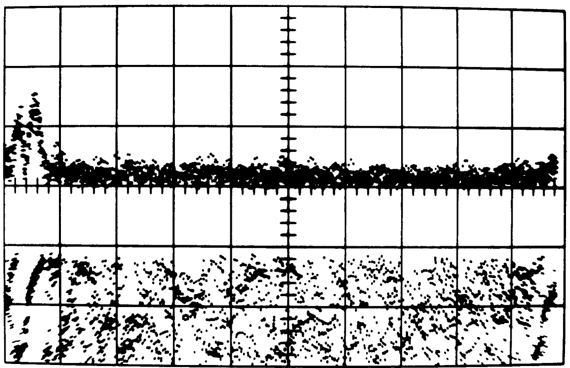
CW, R = 0.2V/cm

AMSEQ 12 August 1966 0551-0603 hours

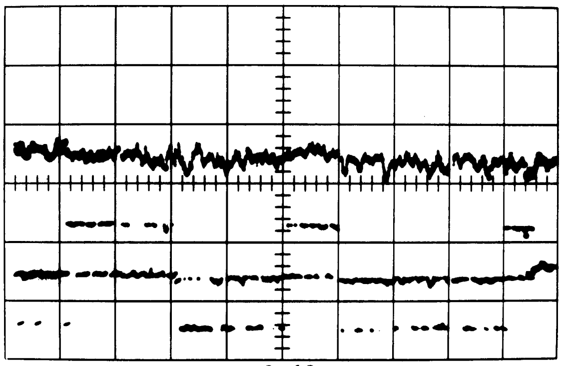


SEQ, R = 0.5V/cm　　　　CW, R = 0.2V/cm

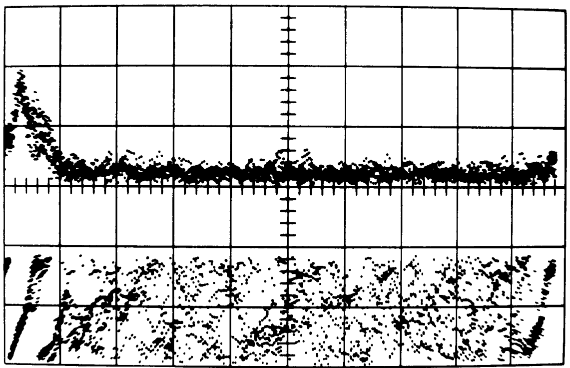
AMSEQ 12 August 1966 0603 - 0615 hours



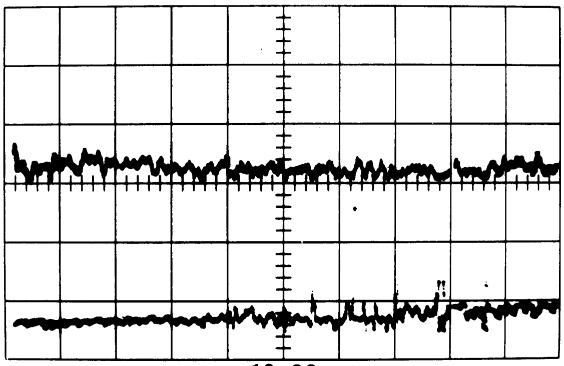
3-12



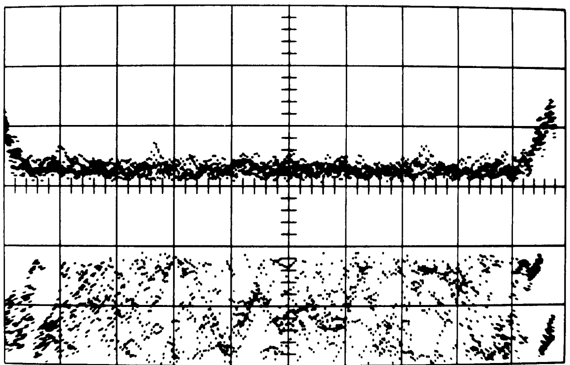
3-12



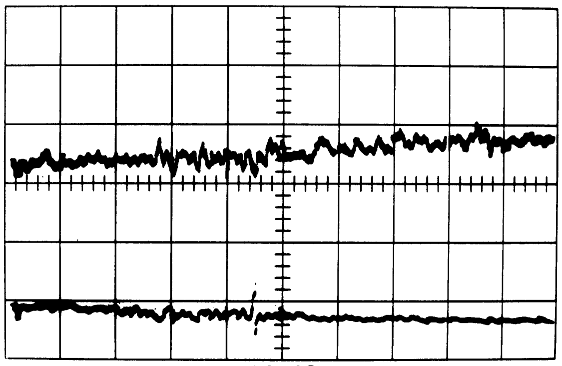
13-22



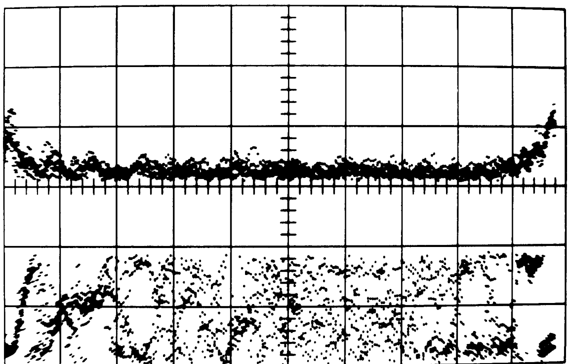
13-22



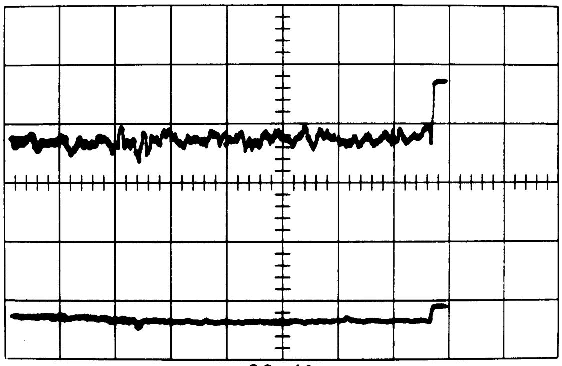
23-30



23-32



31-39

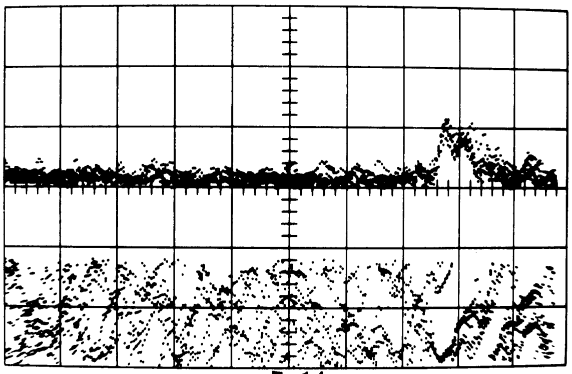


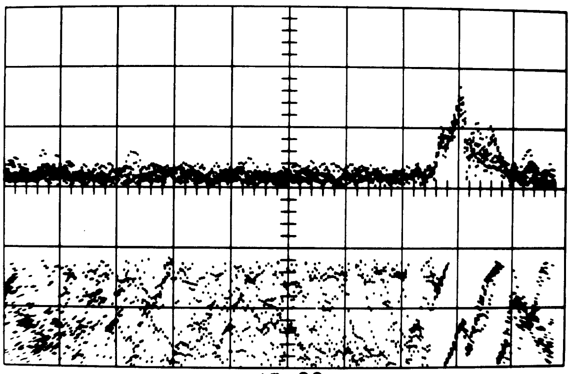
33-40

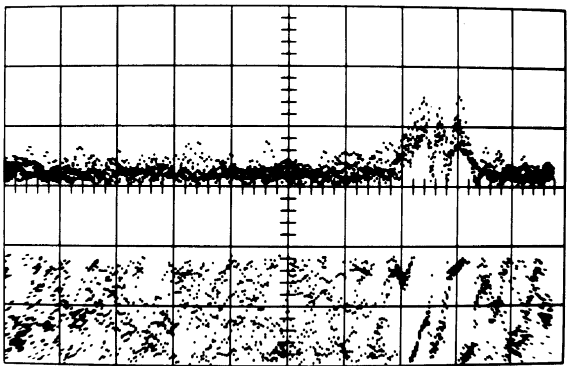
SEQ, R = 0.5V/cm

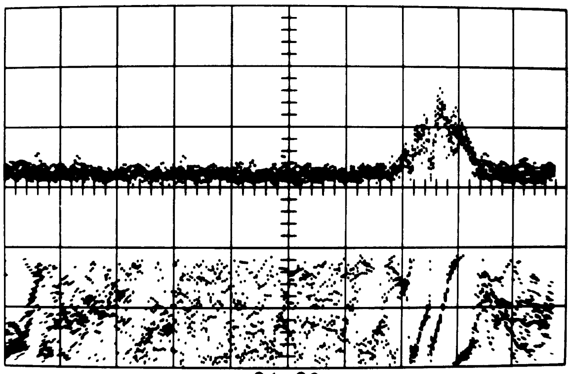
CW, R = 0.2V/cm

AMSEQ 12 August 1966 0615 - 0627 hours

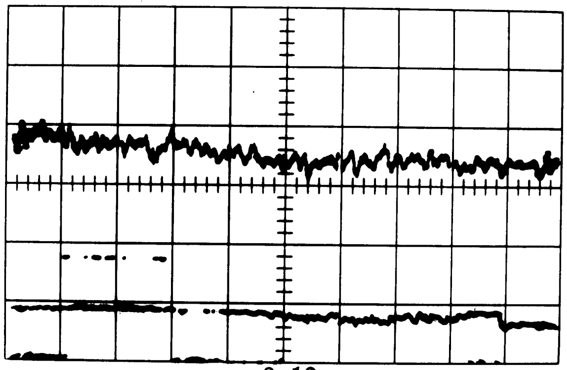

7-14

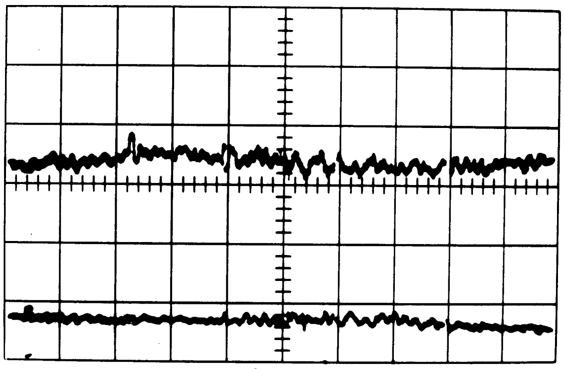

15-22

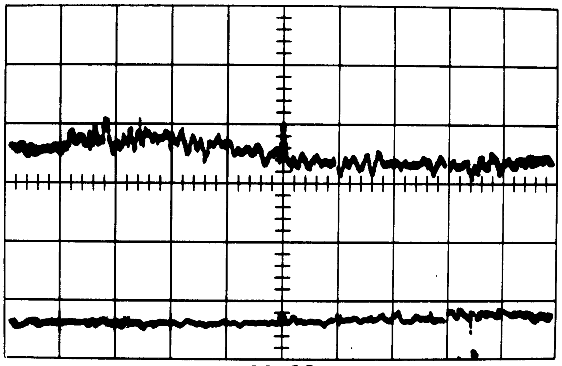

23-30

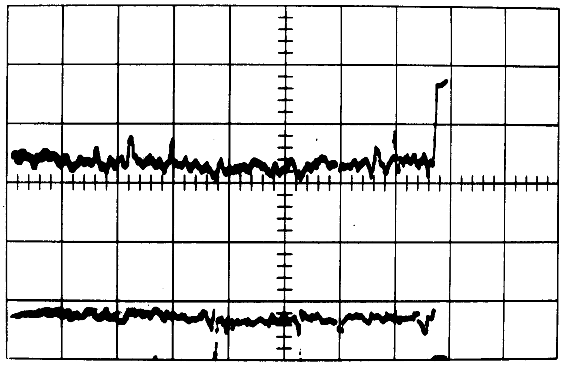

31-39

SEQ, R = 0.5V/cm


3-12

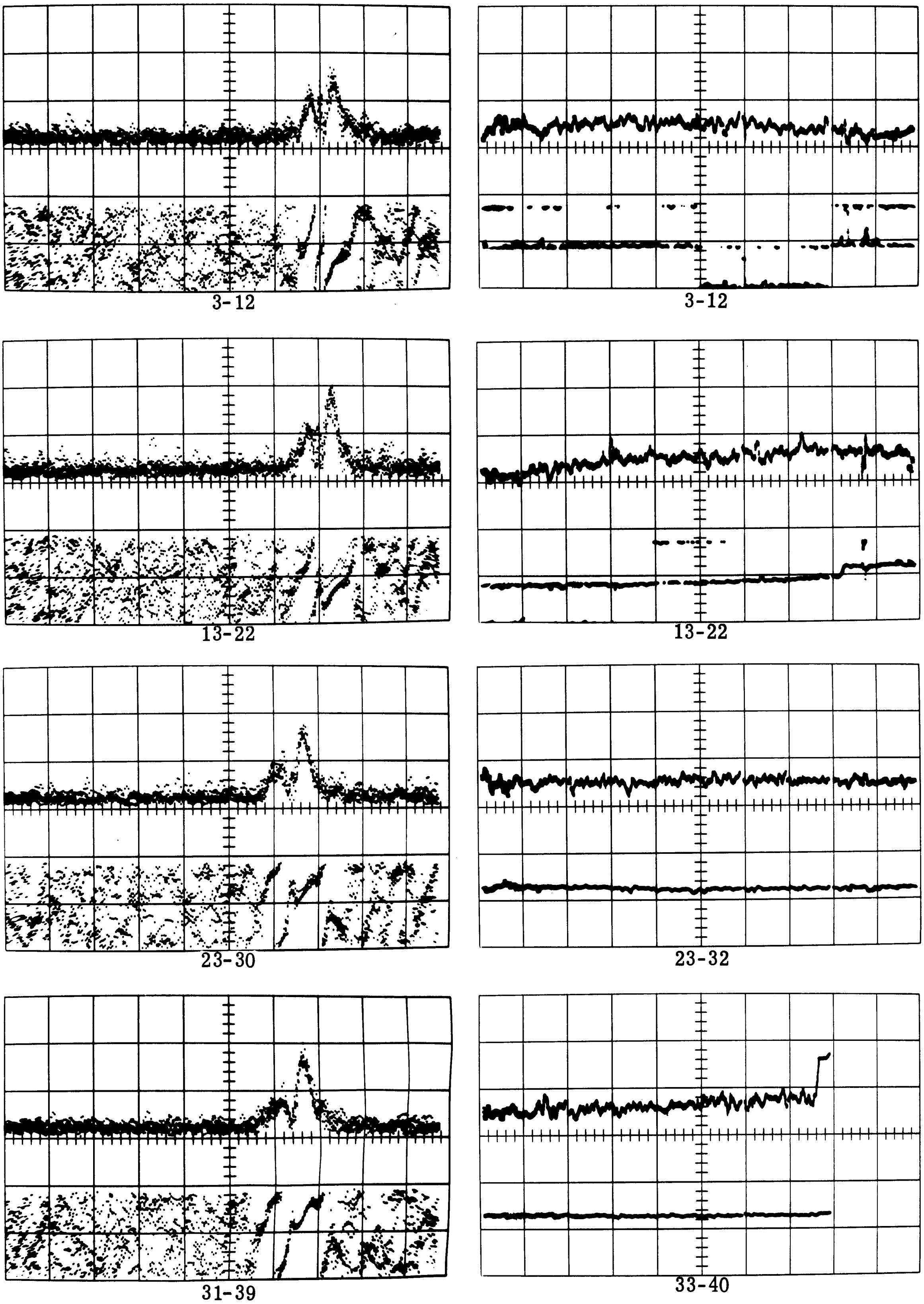

13-22


23-32


33-40

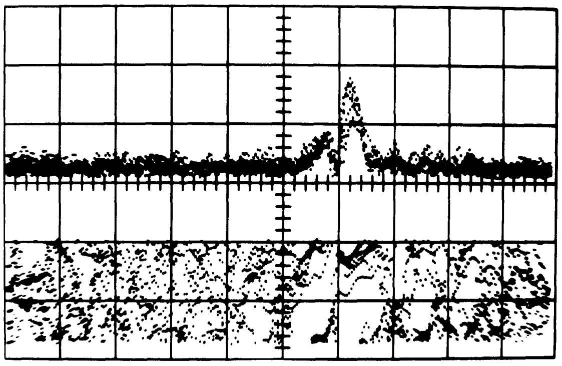
CW, R = 0.2V/cm

AMSEQ 12 August 1966 0627-0639 hours

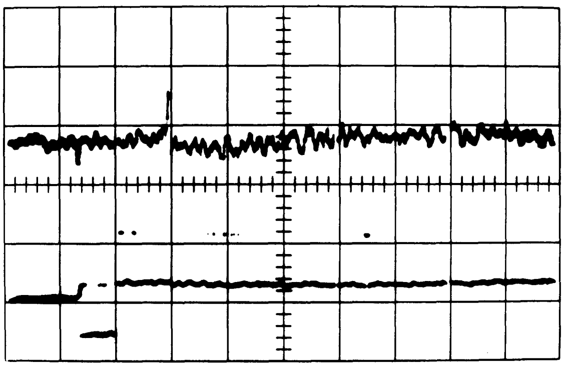


SEQ, R = 0.5V/cm   CW, R = 0.2V/cm

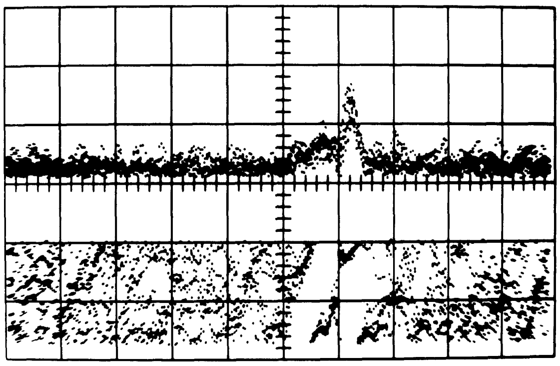
AMSEQ 12 August 1966 0639 - 0651 hours



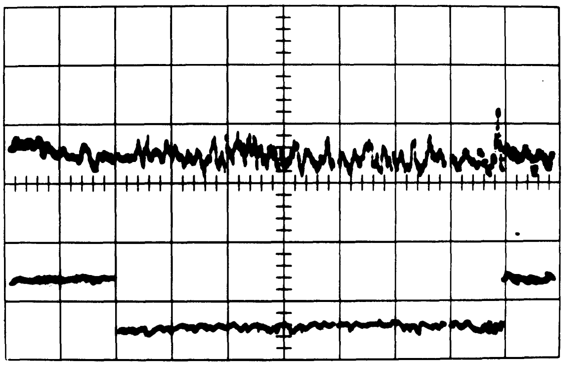
3-12



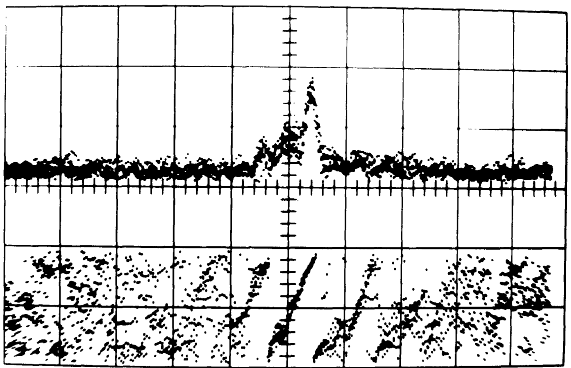
3-12



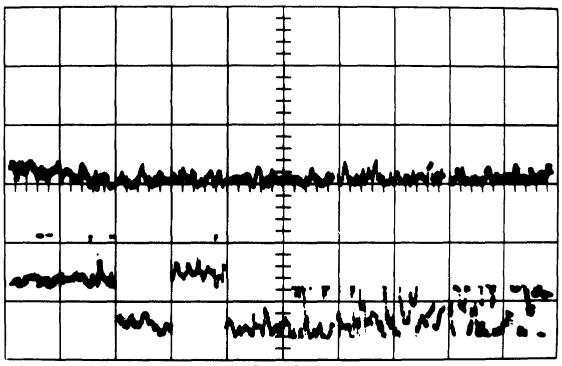
13-22



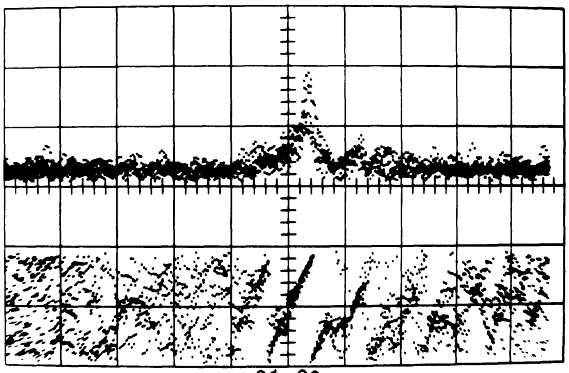
13-22



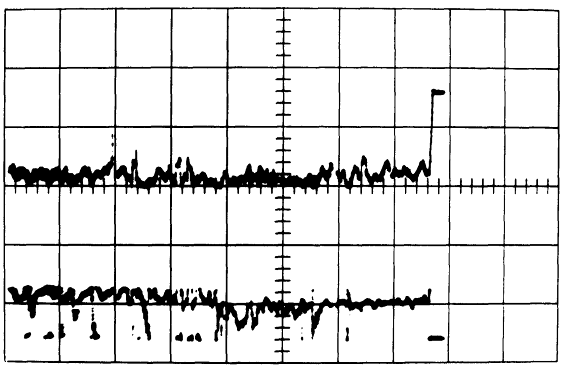
23-30



23-32



31-39

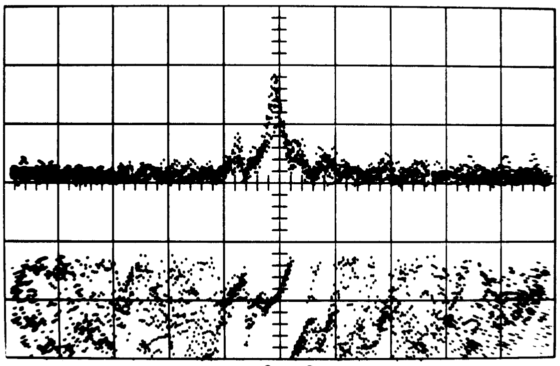


33-40

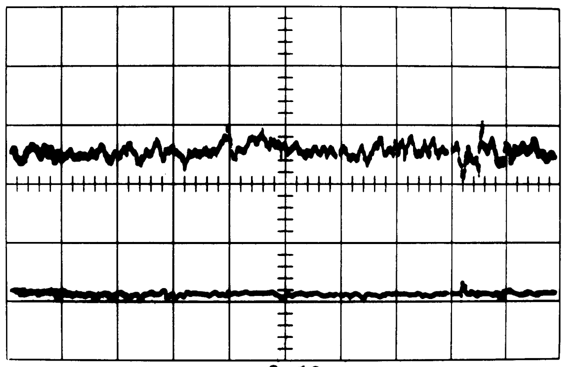
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

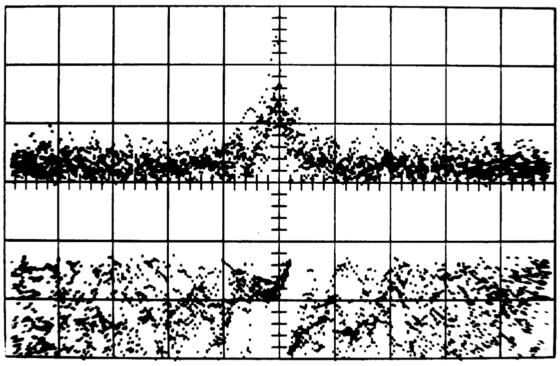
AMSEQ 12 August 1966 0651-0703 hours



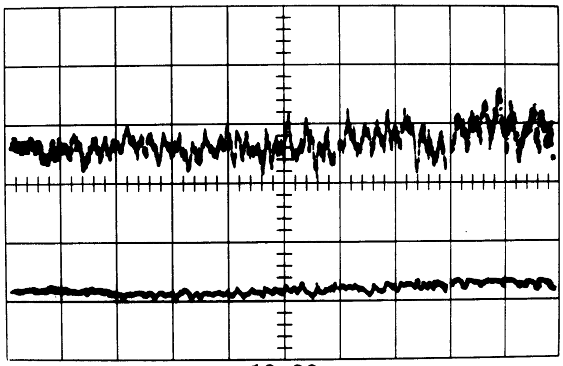
3-12



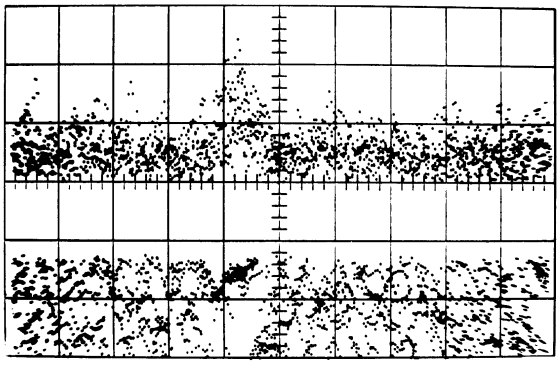
3-12



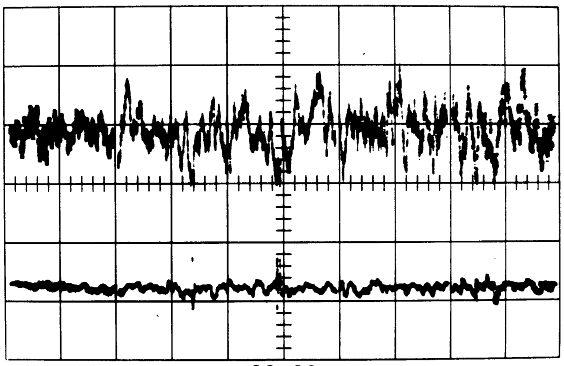
13-22



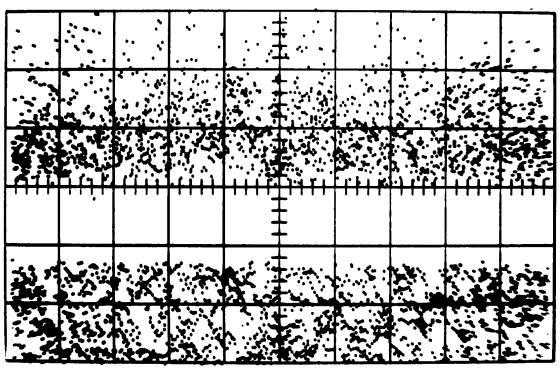
13-22



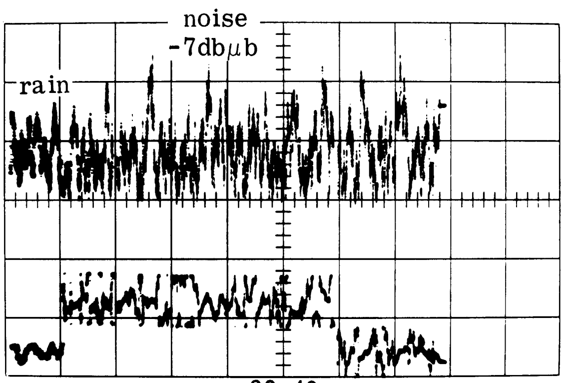
23-30



23-32



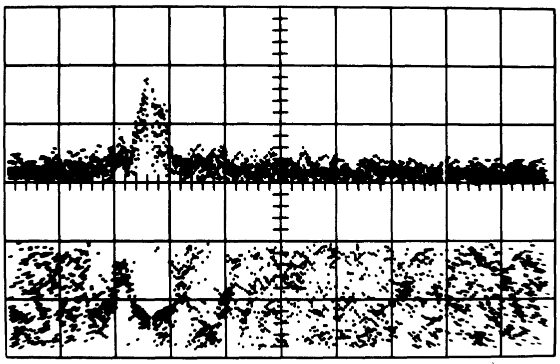
31-39



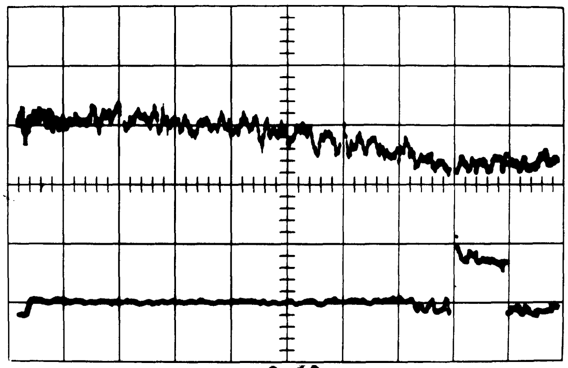
33-40

CW, R = 0.2V/cm

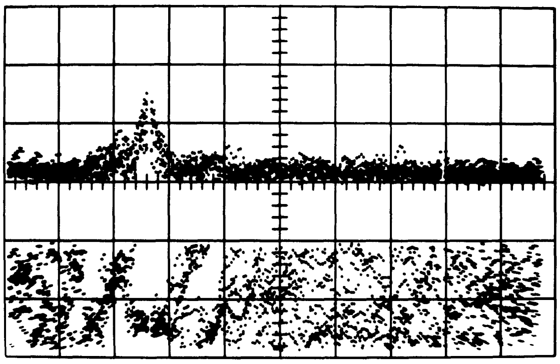
AMSEQ 12 August 1966 0703 - 0715 hours



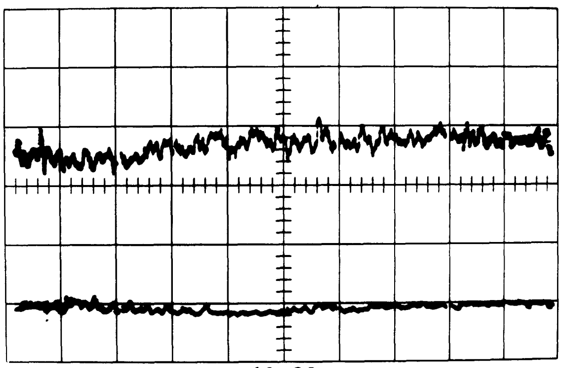
3-12



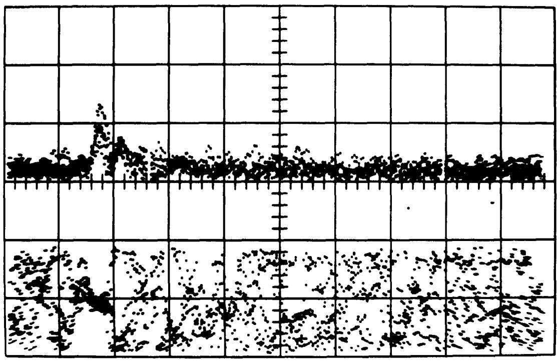
3-12



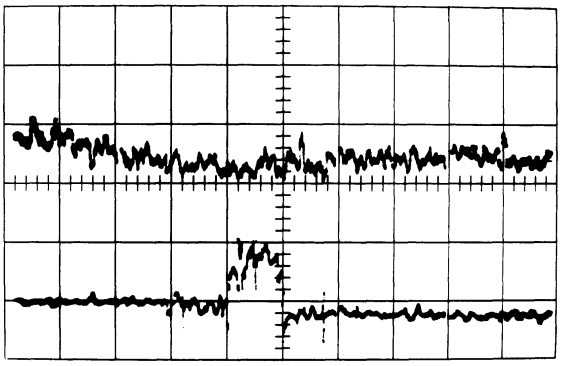
13-22



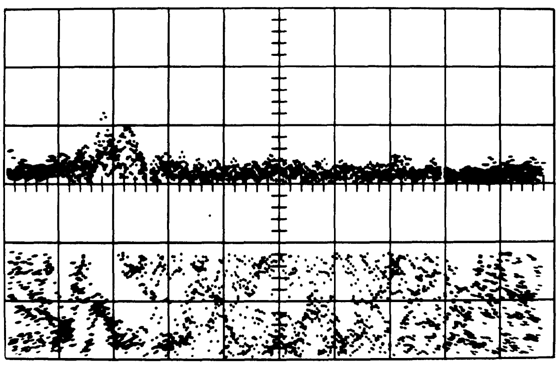
13-22



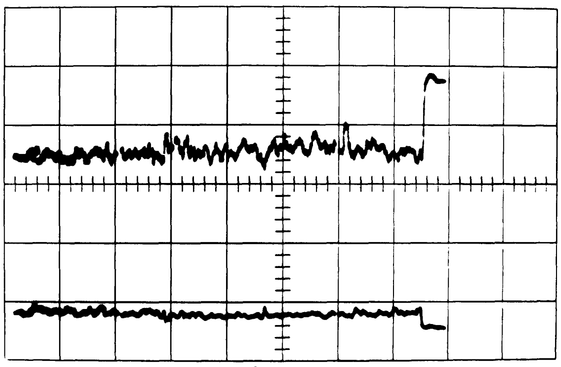
23-30



23-32



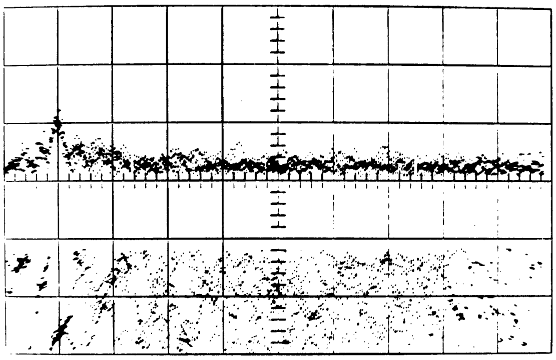
31-39



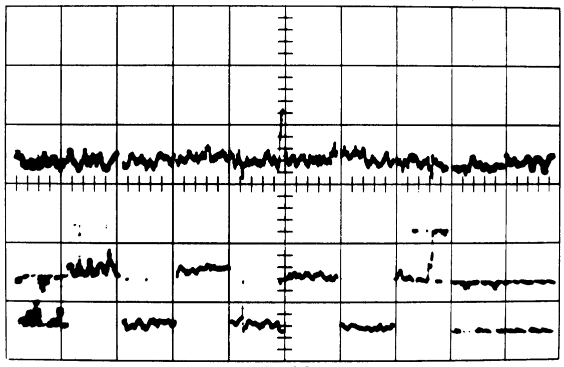
33-40

CW, R = 0.2V/cm

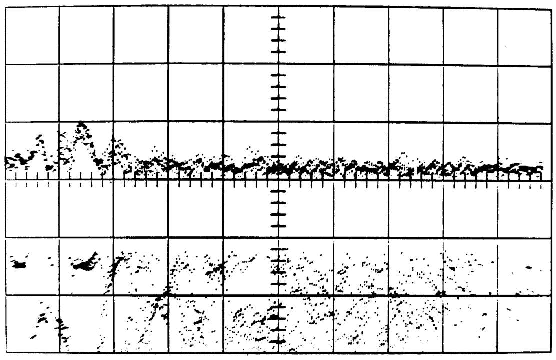
AMSEQ 12 August 1966 0727-0739 hours



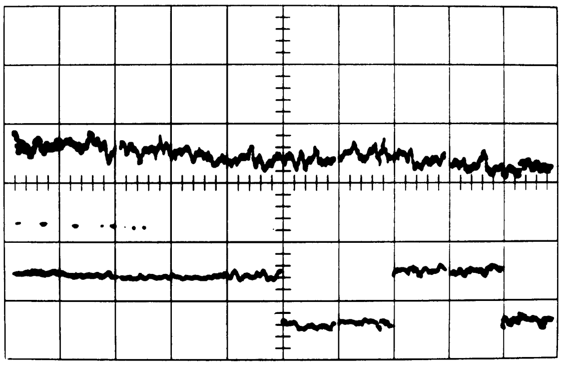
3-12



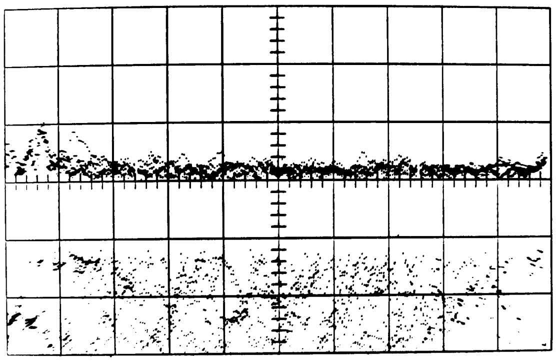
3-12



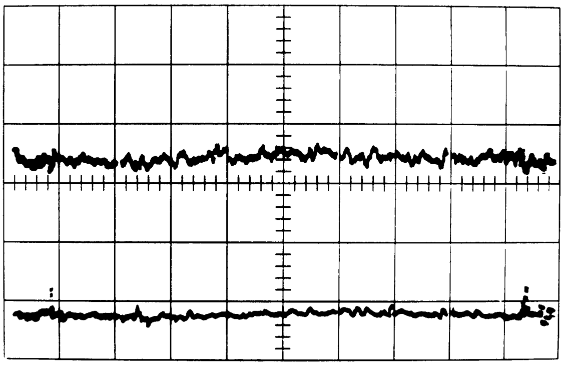
13-19



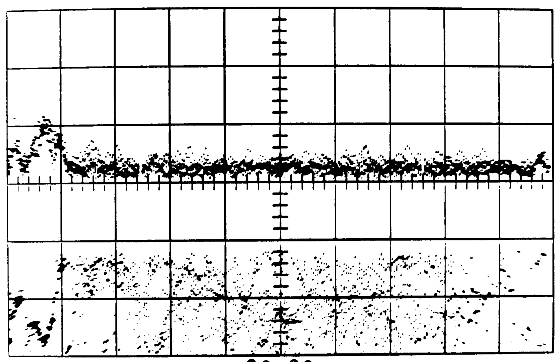
13-22



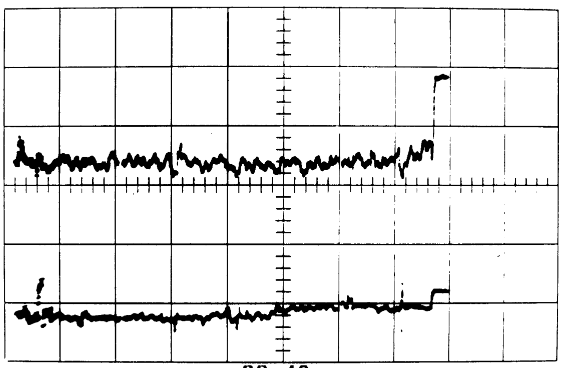
23-30



23-32



30-39

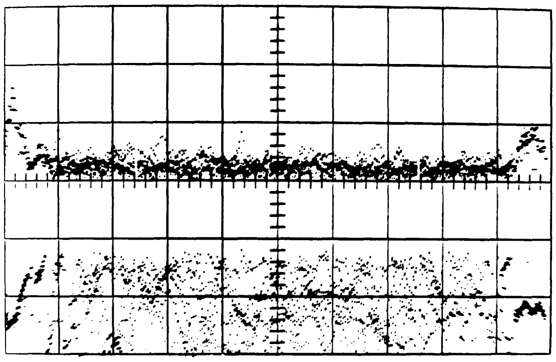


33-40

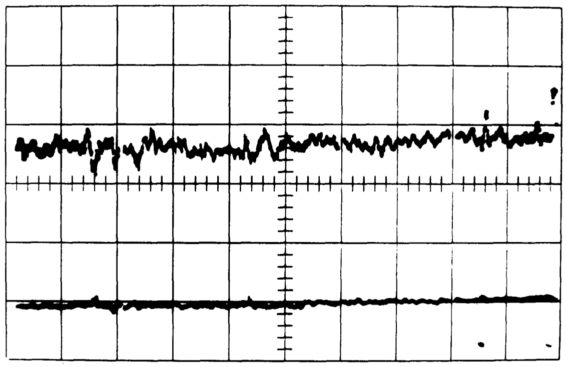
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

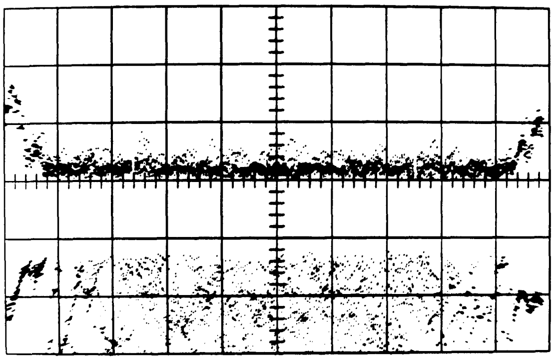
AMSEQ 12 August 1966 0739-0751 hours



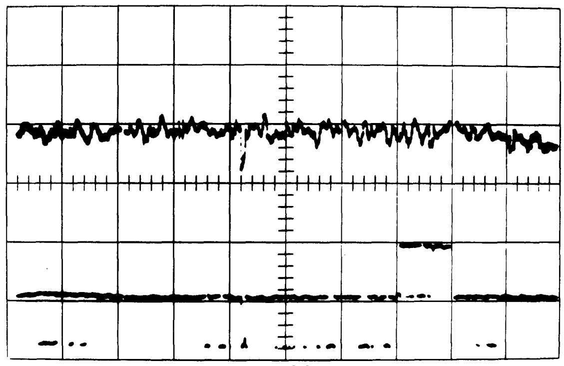
3-12



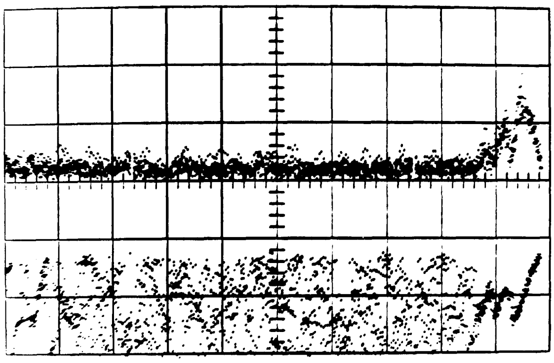
3-12



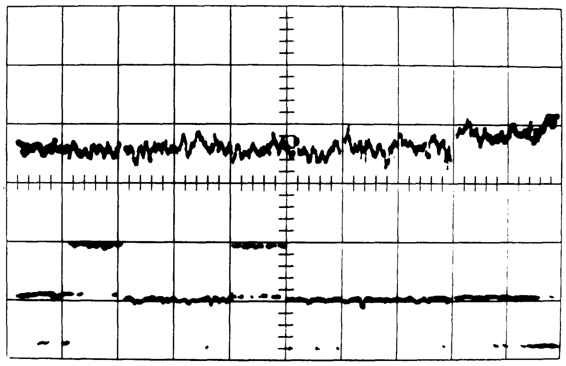
13-22



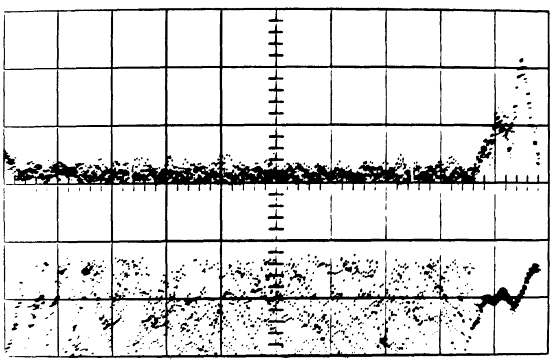
13-22



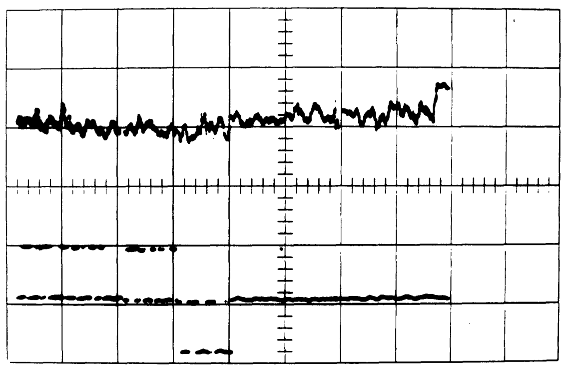
23-30



23-32



31-39

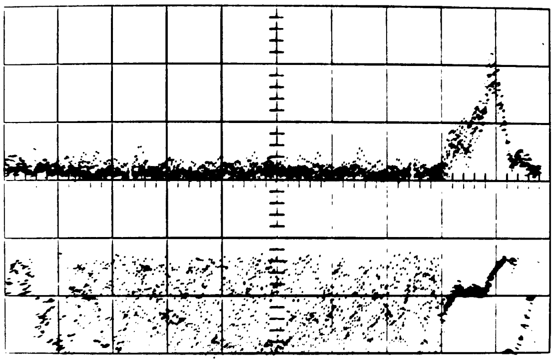


33-40

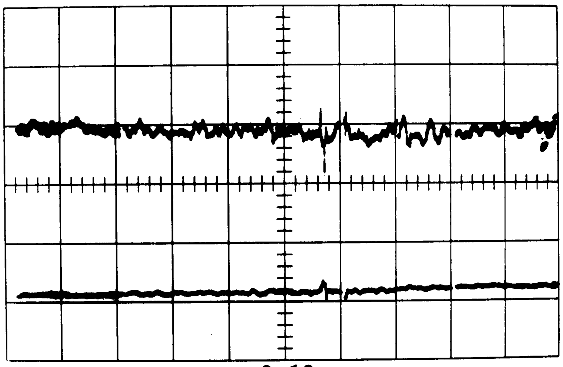
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

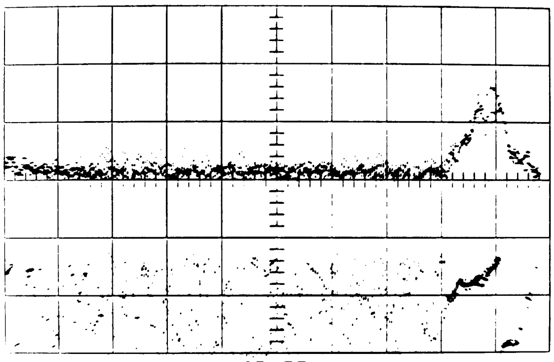
AMSEQ 12 August 1966 0751-0803 hours



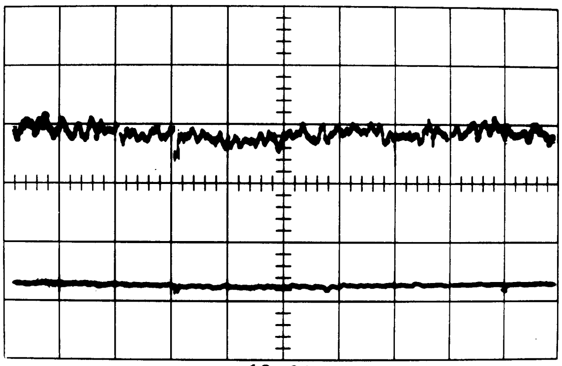
3-12



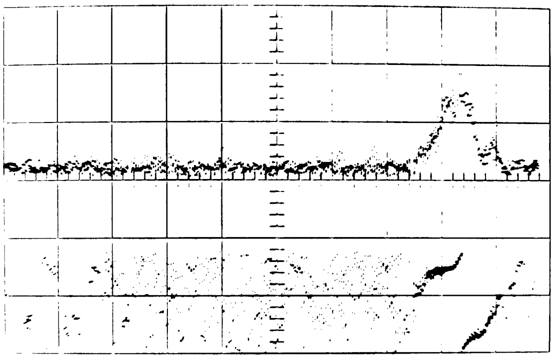
3-12



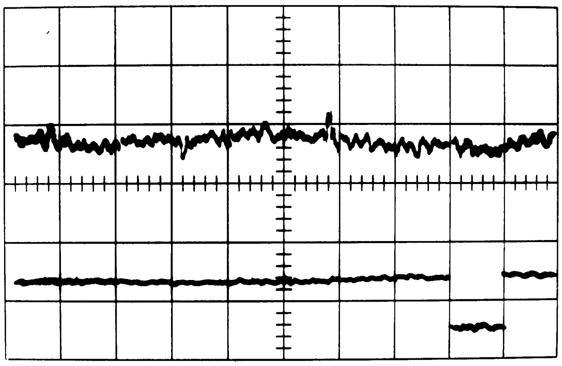
13-22



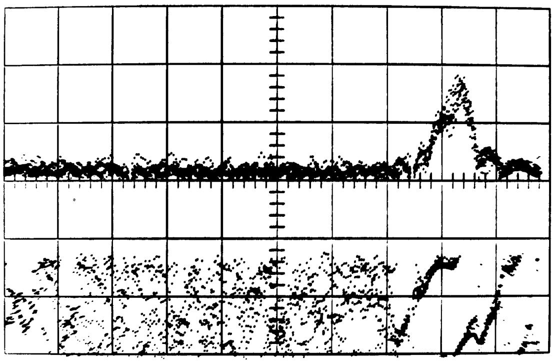
13-22



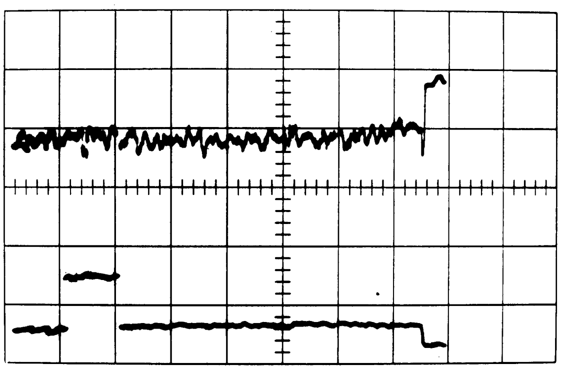
23-30



23-32



31-39

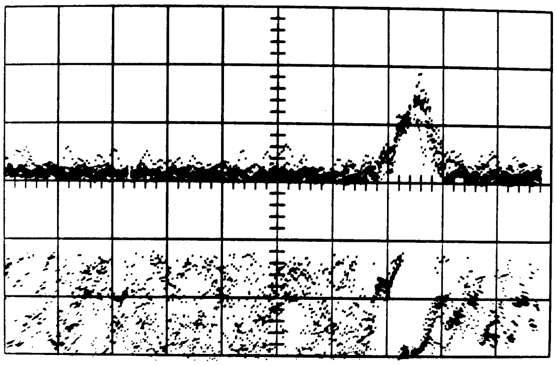


33-40

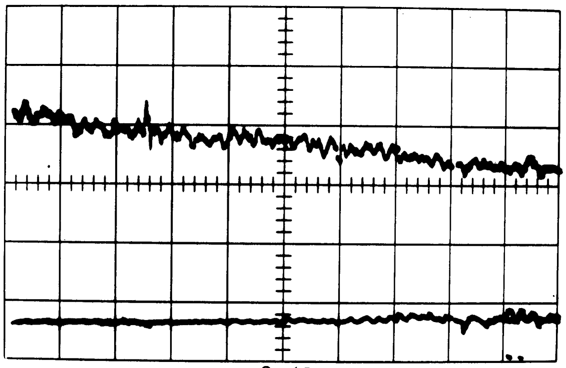
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

AMSEQ 12 August 1966 0803-0815 hours

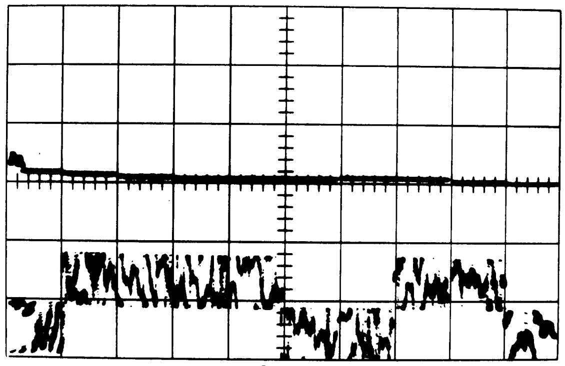


3-12



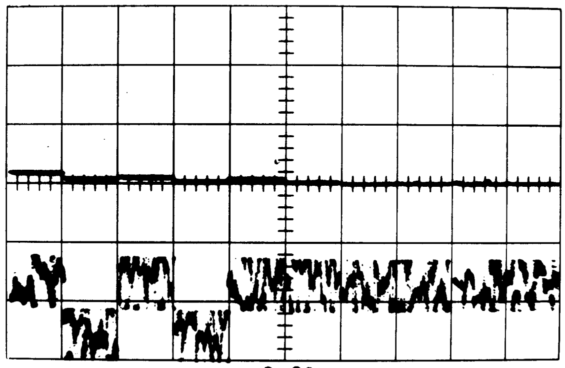
3-12

no signal



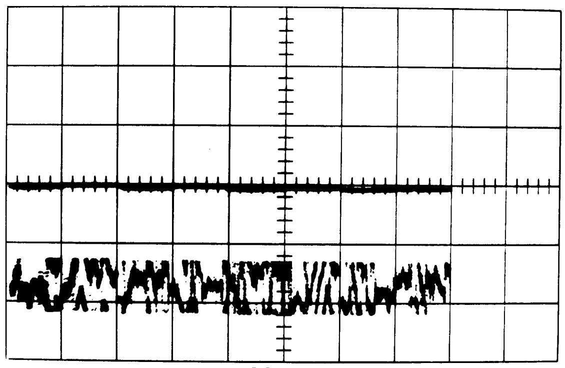
13-22

no signal



23-32

no signal

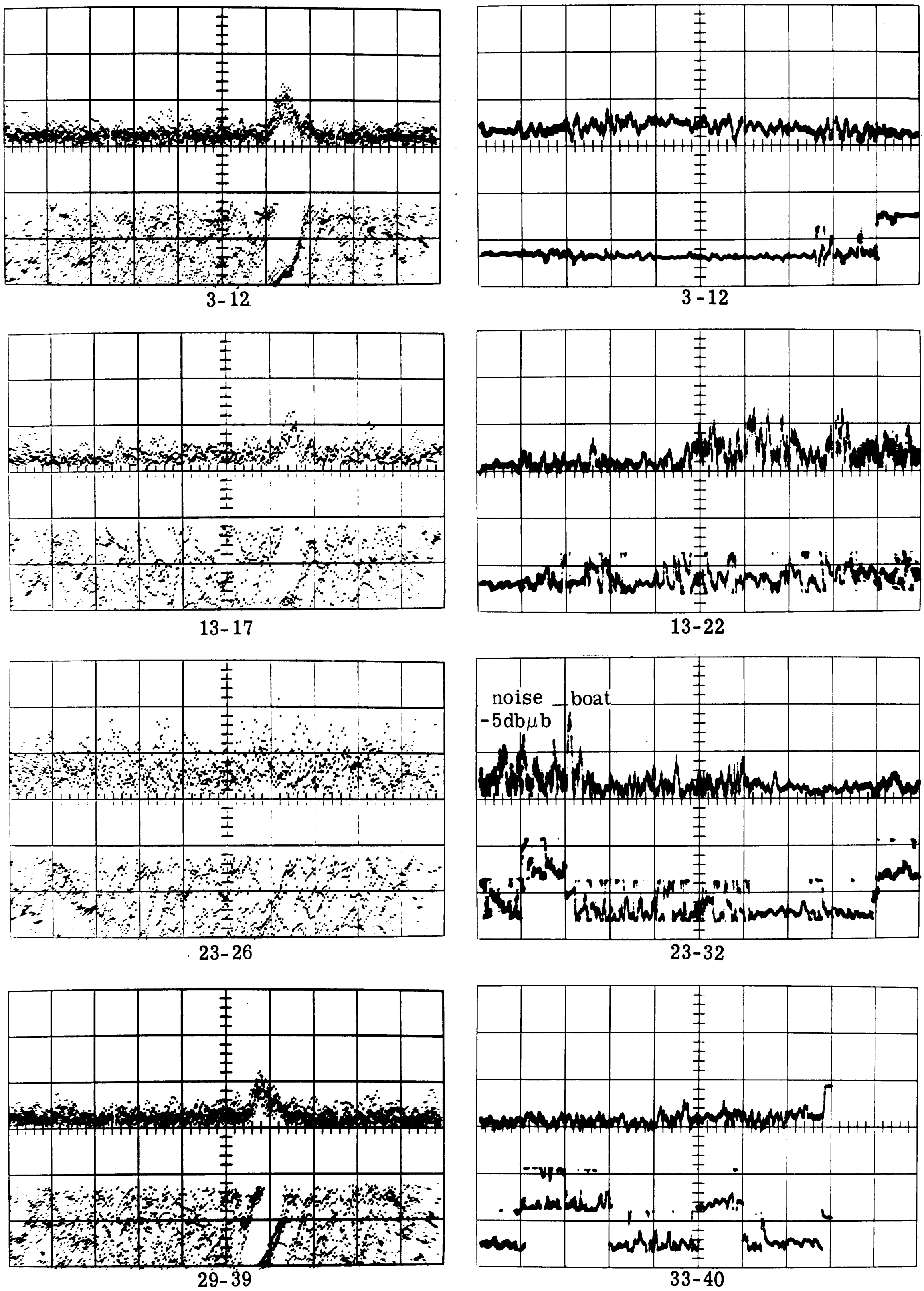


33-40

SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

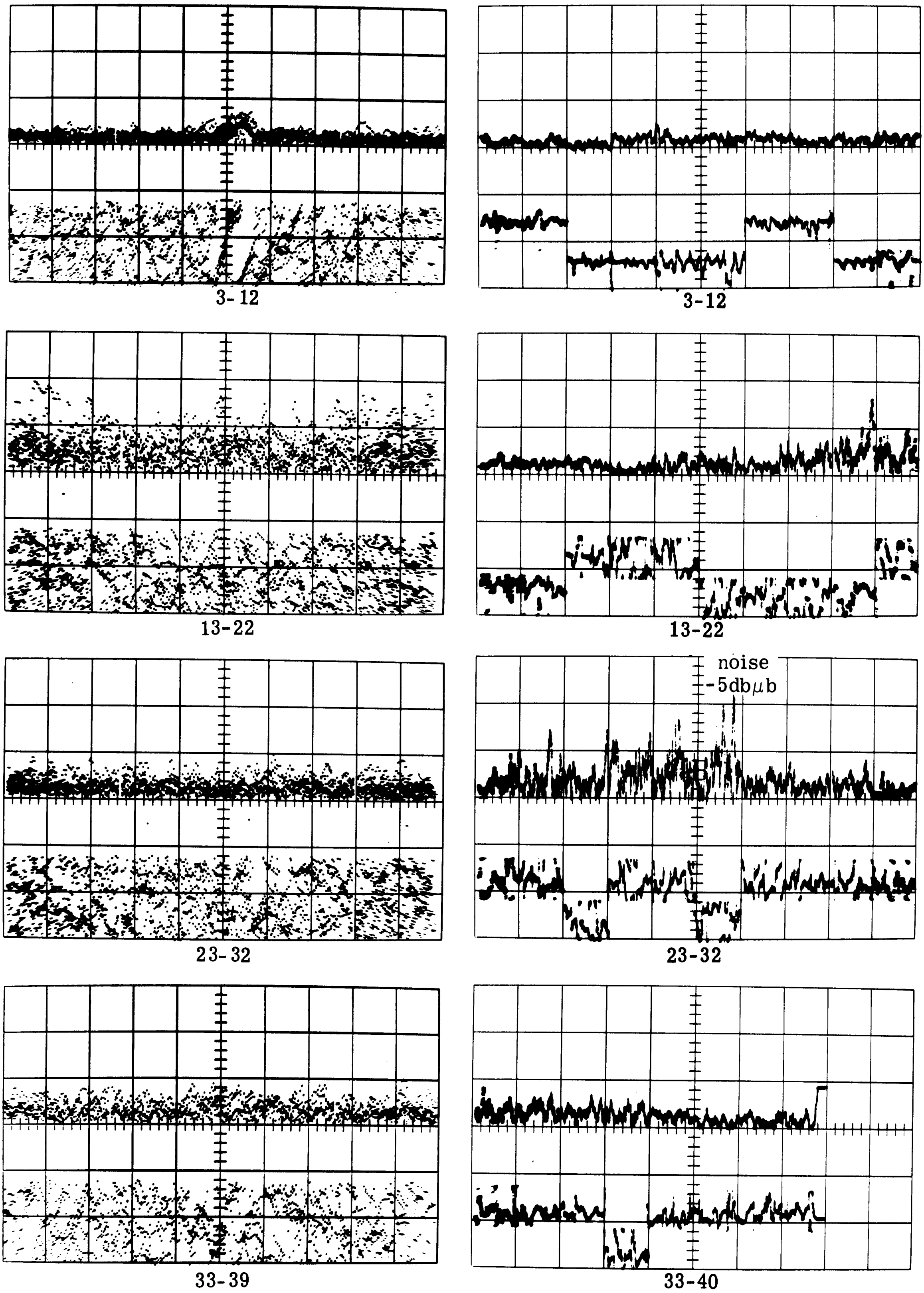
AMSEQ 12 August 1966 0815 - 0827 hours



SEQ, R = 0.5V/cm

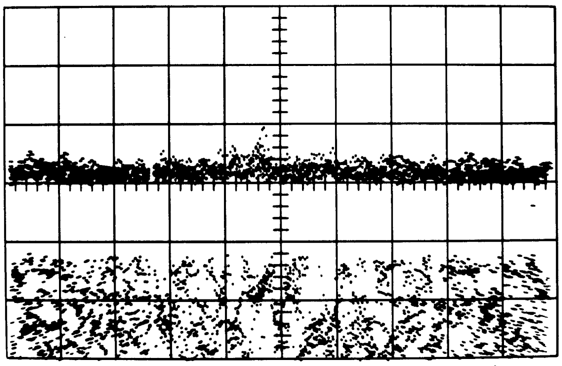
CW, R = 0.2V/cm

AMSEQ 12 August 1966 0827-0839 hours, att. = 14 db

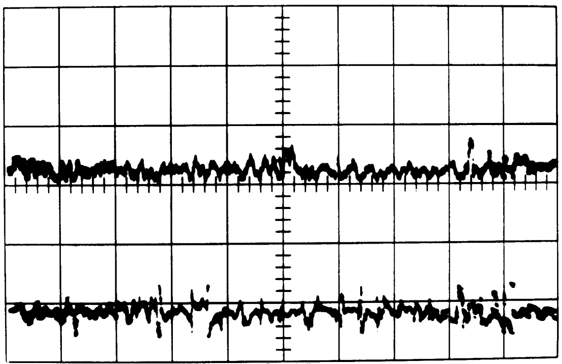


SEQ, R = 0.5V/cm   CW, R = 0.2V/cm

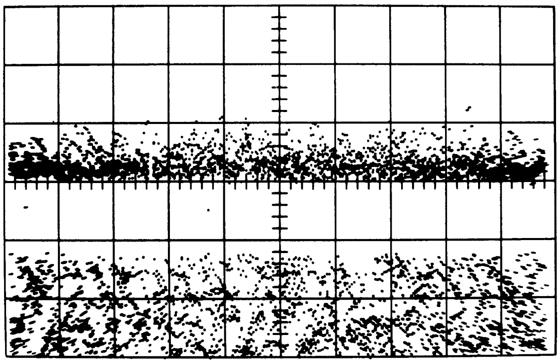
AMSEQ 12 August 1966 0839-0851 hours, att. = 14 db



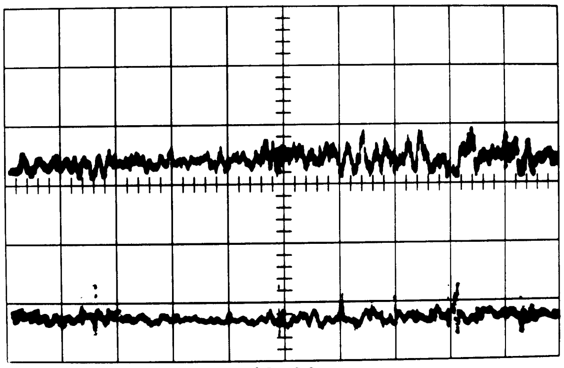
3-12



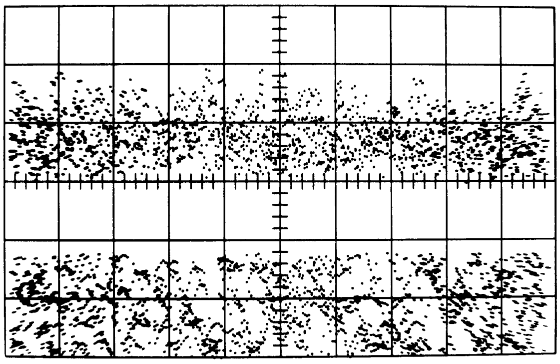
3-12



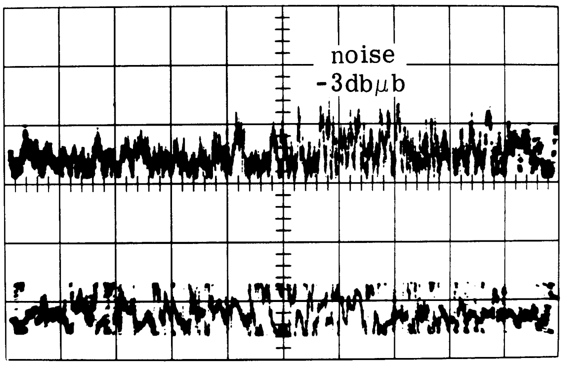
13-22



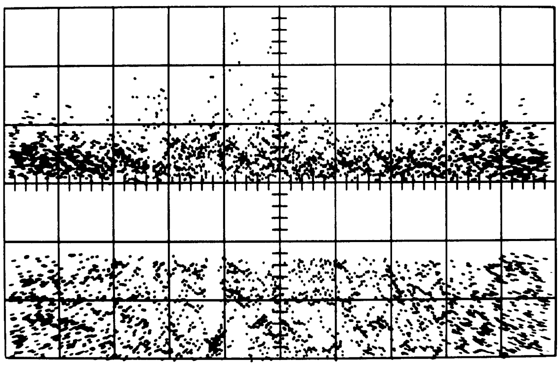
13-22



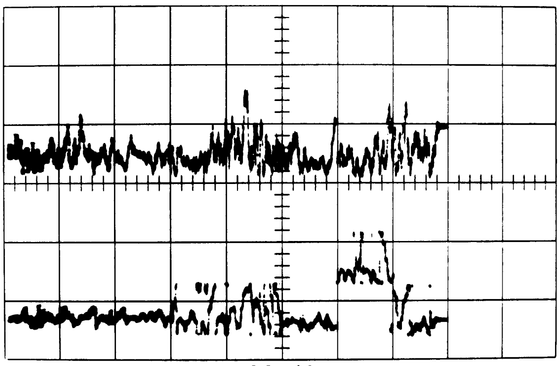
23-30



23-32



31-39

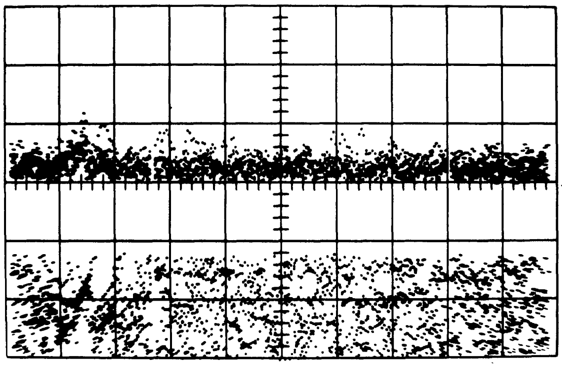


33-40

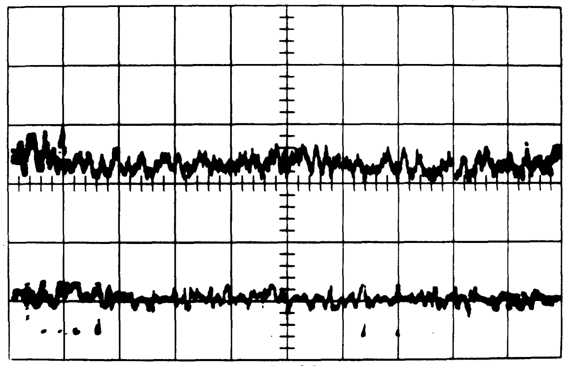
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

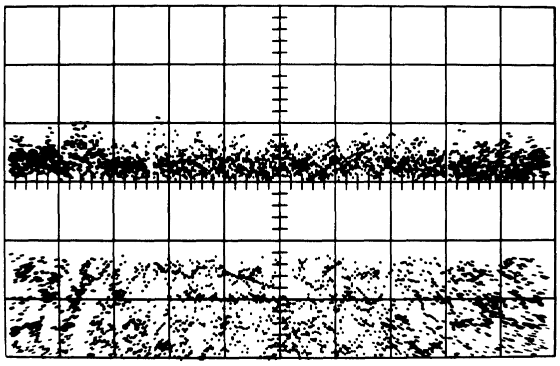
AMSEQ 12 August 1966 0851-0903 hours, att. = 14 db



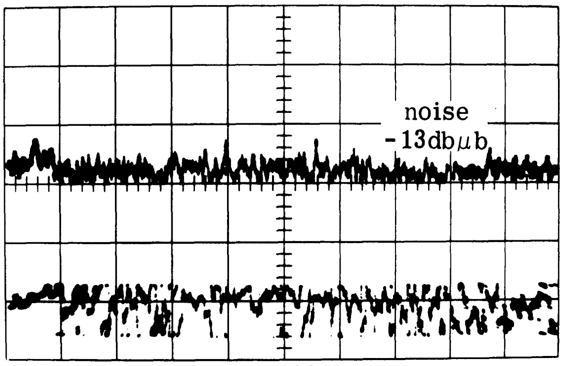
3-12



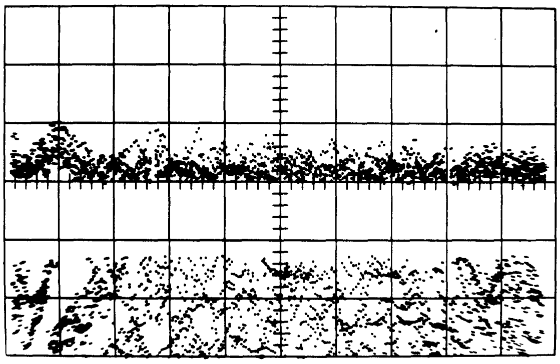
3-12



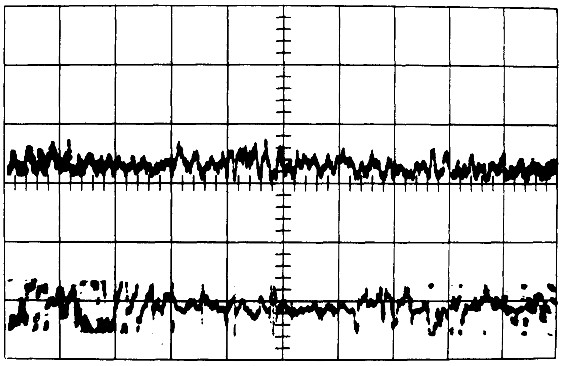
13-22



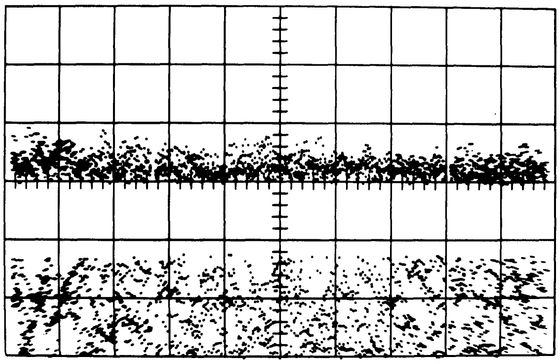
13-22



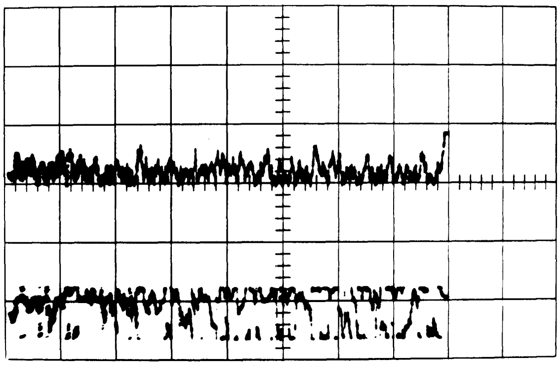
23-30



23-32



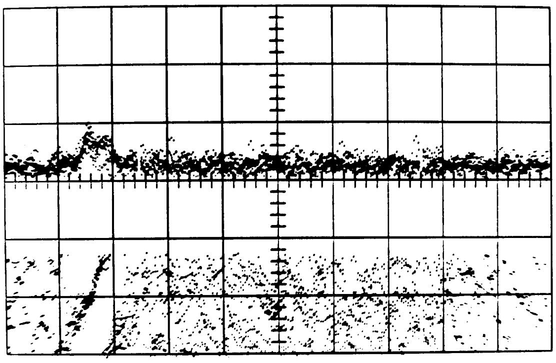
31-39



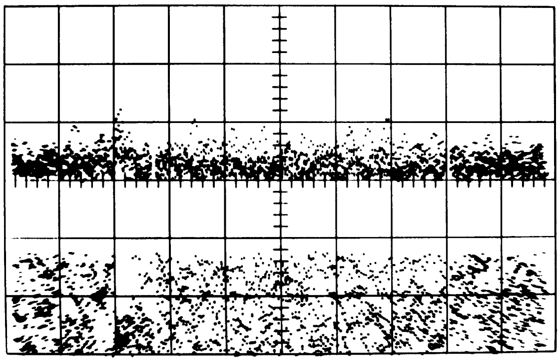
33-40

CW, R = 0.2V/cm

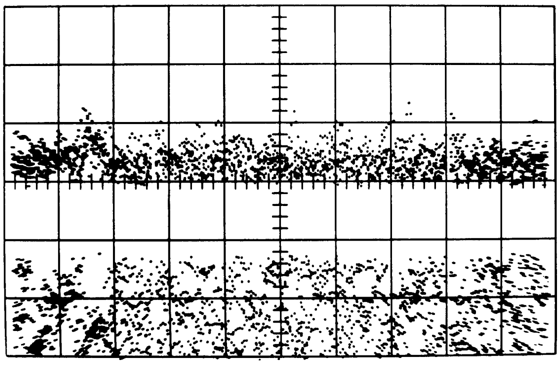
AMSEQ 12 August 1966 0903-0915 hours, att. = 14 db



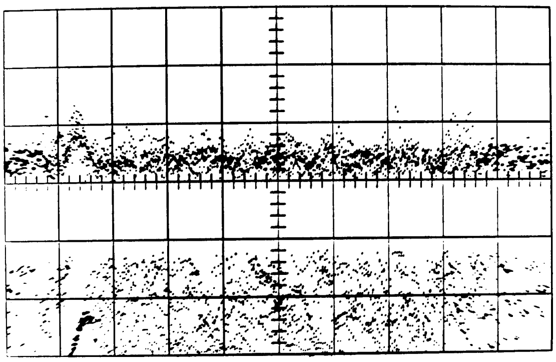
3-12



13-22

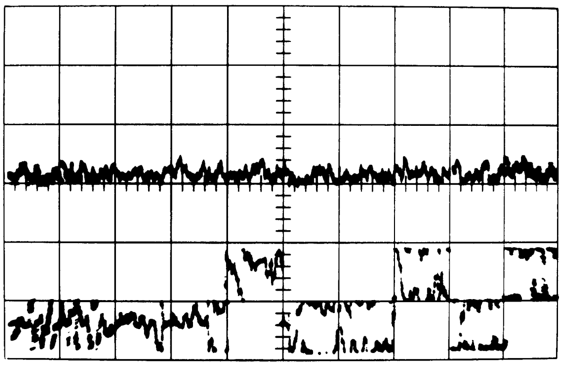


23-30

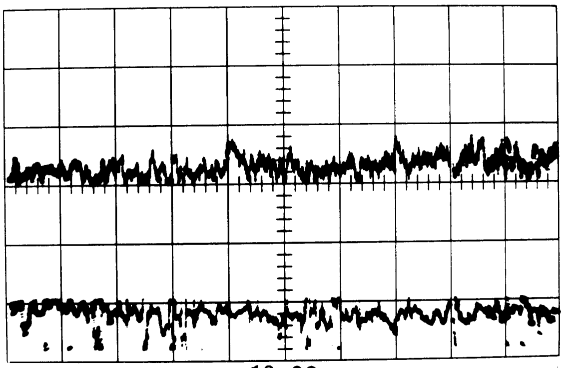


31-39

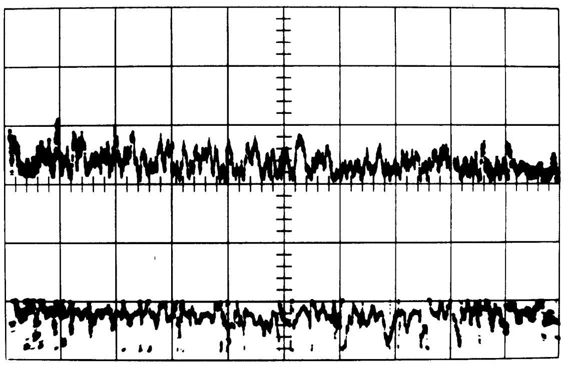
SEQ, R = 0.5V/cm



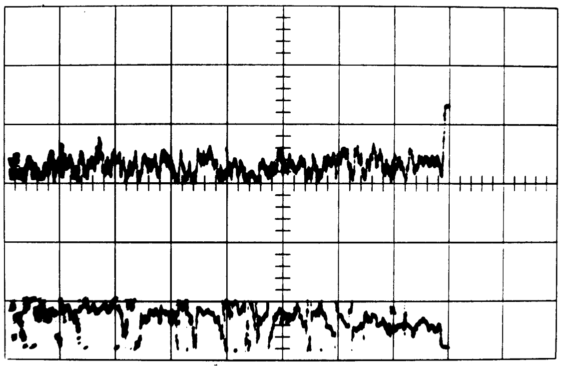
3-12



13-22



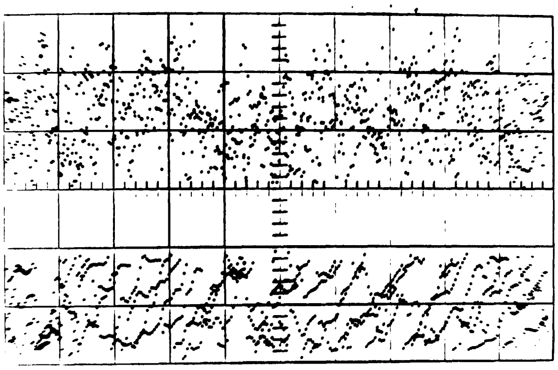
23-32



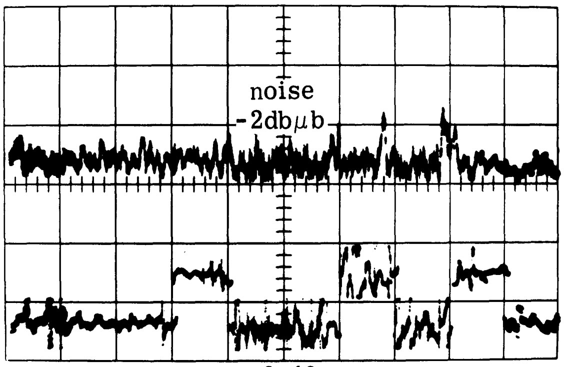
33-40

CW, R = 0.2V/cm

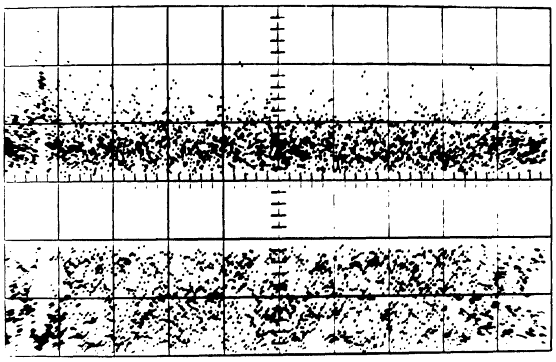
AMSEQ 12 August 1966 0915 - 0927 hours, att. = 14 db



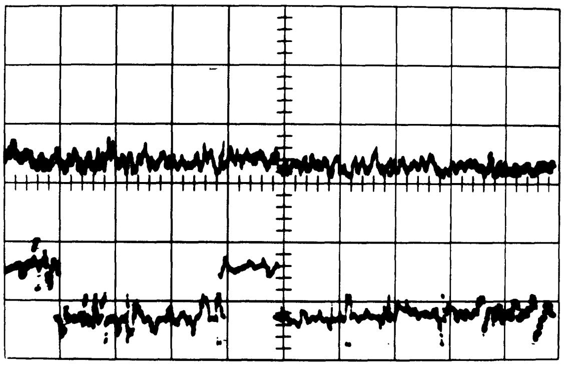
3-6



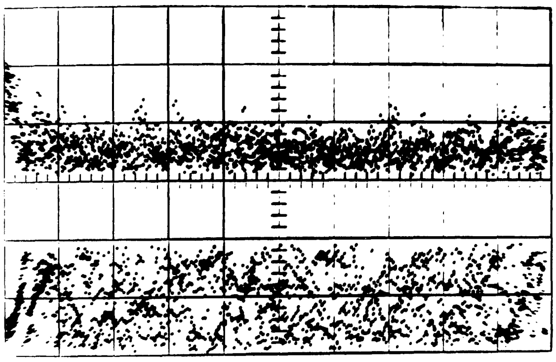
3-12



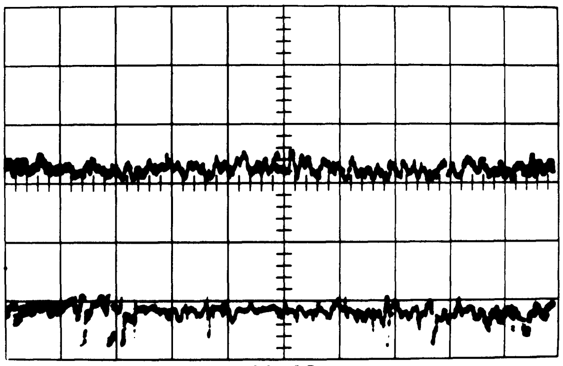
11-22



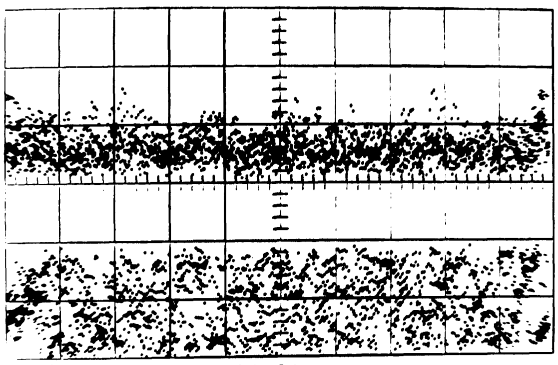
13-22



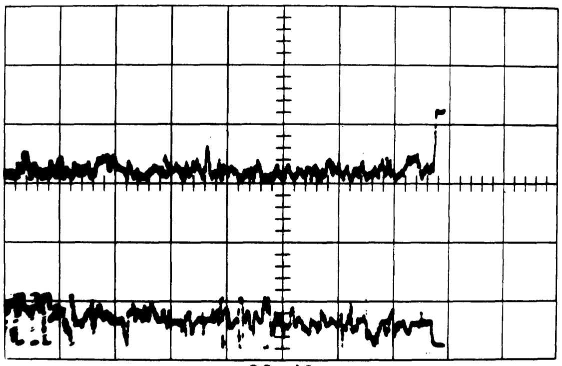
23-30



23-32



31-39

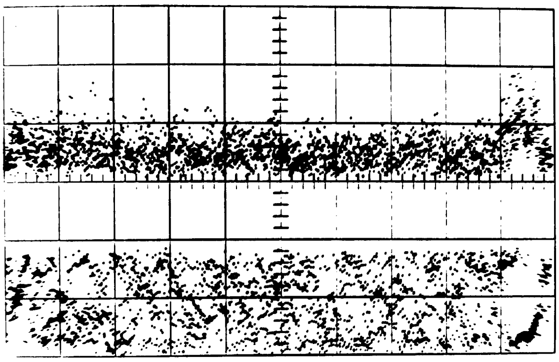


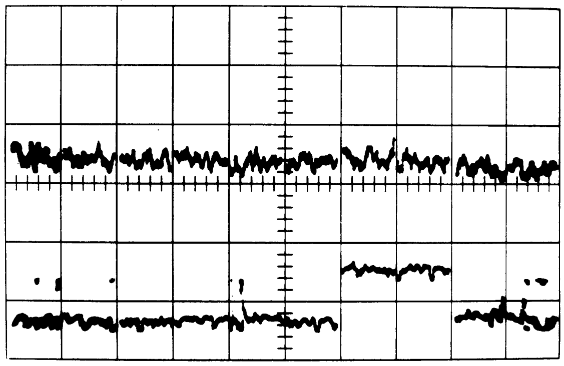
33-40

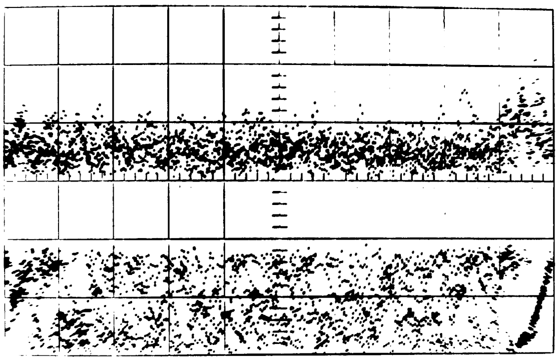
SEQ, R = 0.2V/cm

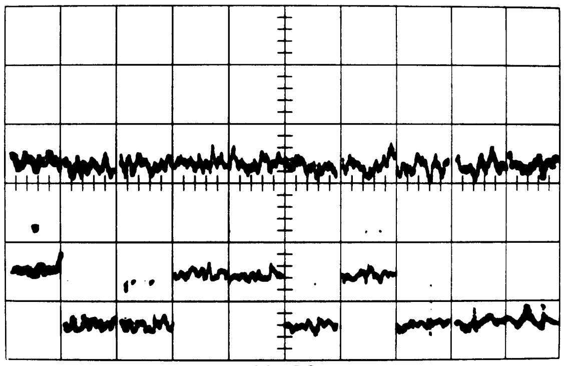
CW, R = 0.2V/cm

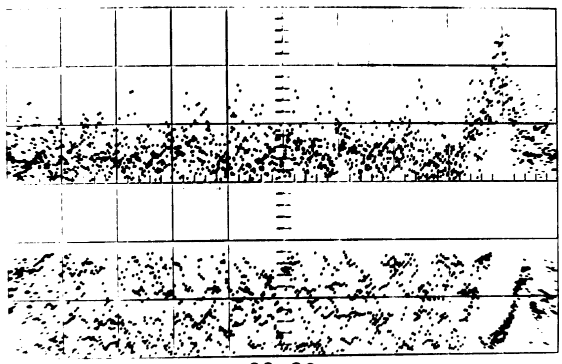
AMSEQ 12 August 1966 0927-0939 hours, att. = 14 db

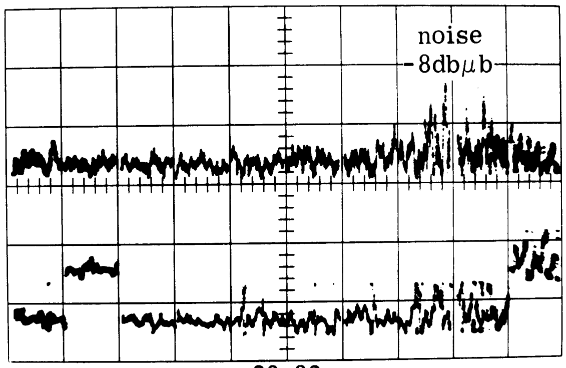

3-12


3-12

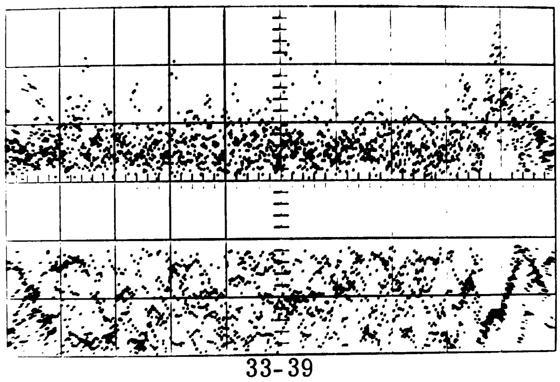

13-22

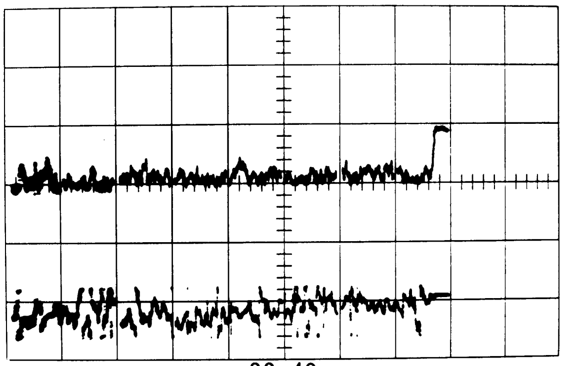

13-22


23-28



23-32

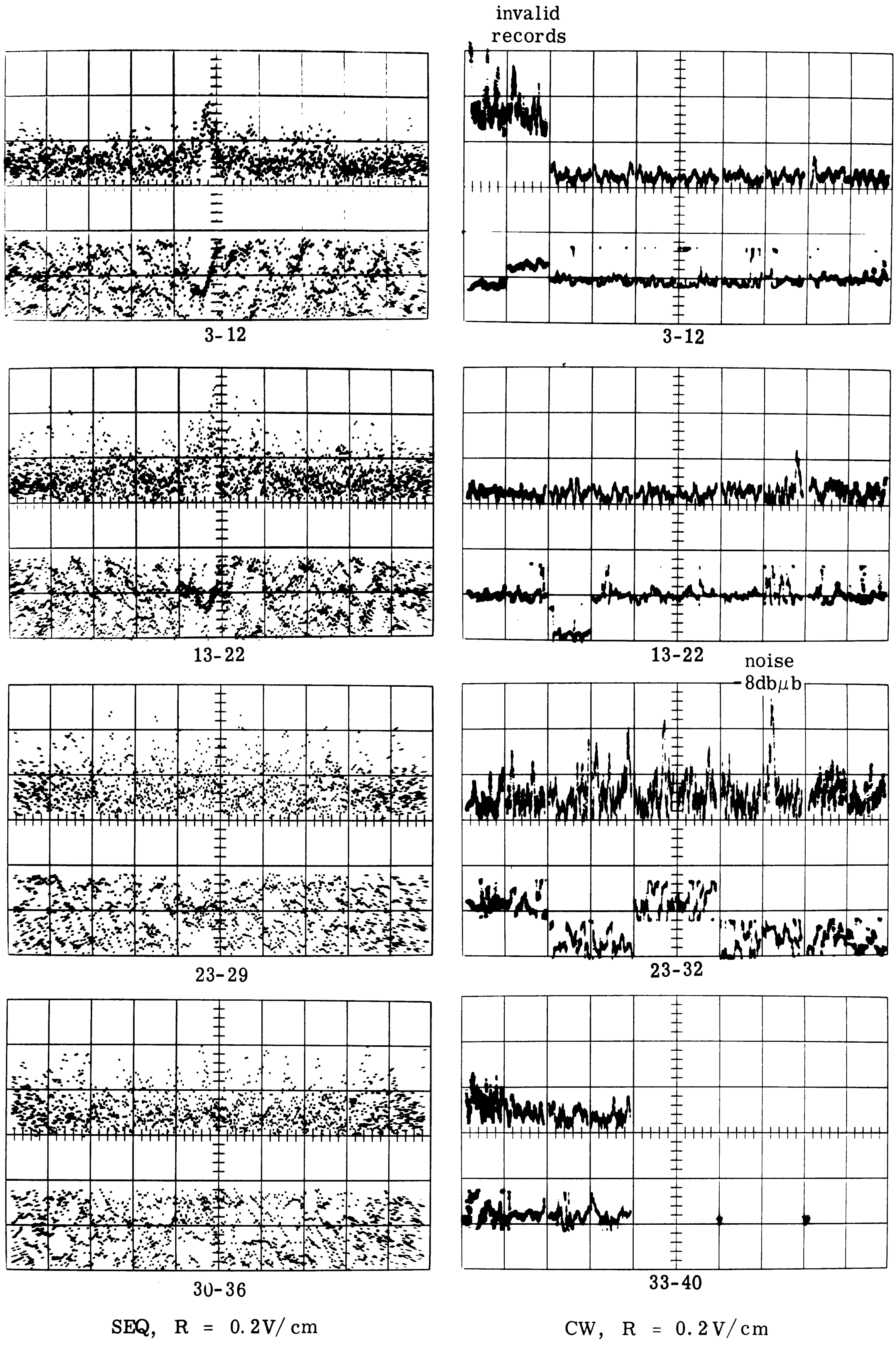

33-39


33-40

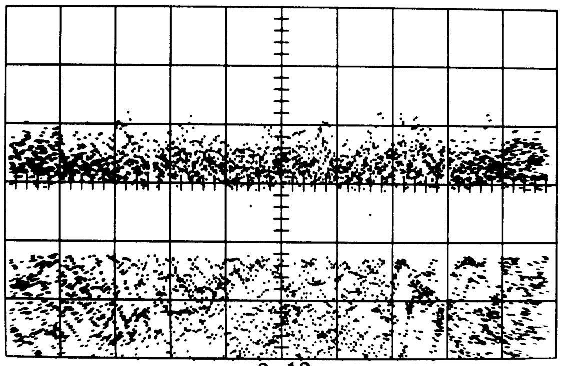
SEQ, R = 0.2V/cm

CW, R = 0.2V/cm

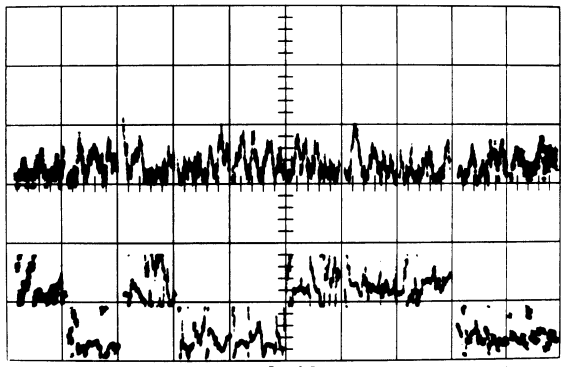
AMSEQ 12 August 1966 0939-0951 hours, att. = 14 db



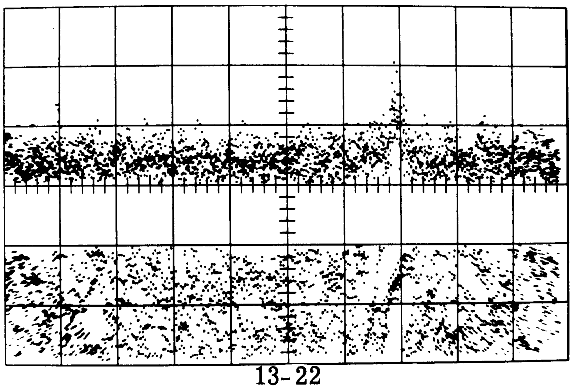
AMSEQ 12 August 1966 0951-1003 hours, att. = 14 db



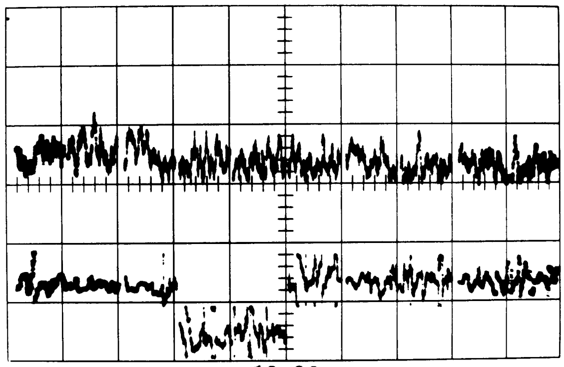
3-12



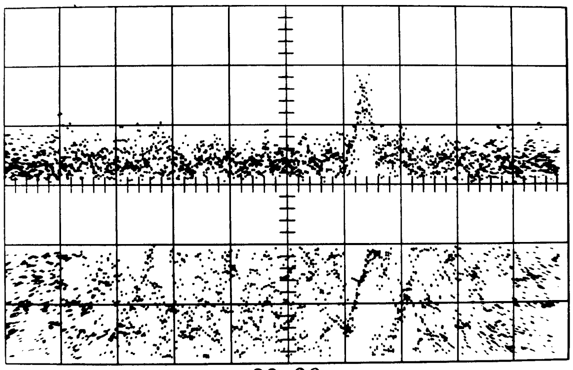
3-12



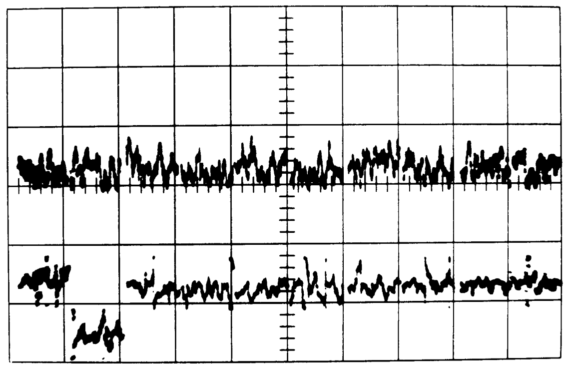
13-22



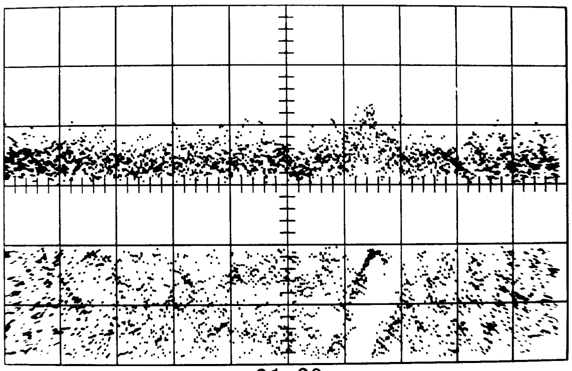
13-22



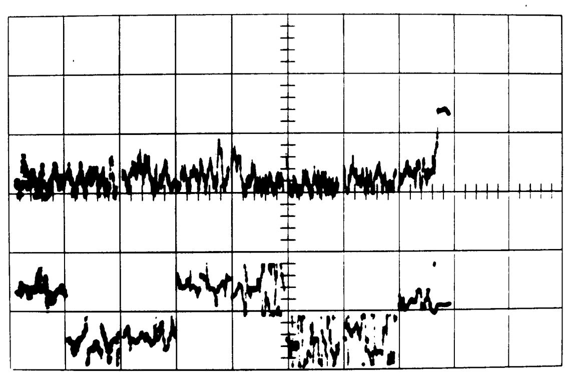
23-30



23-32



31-39

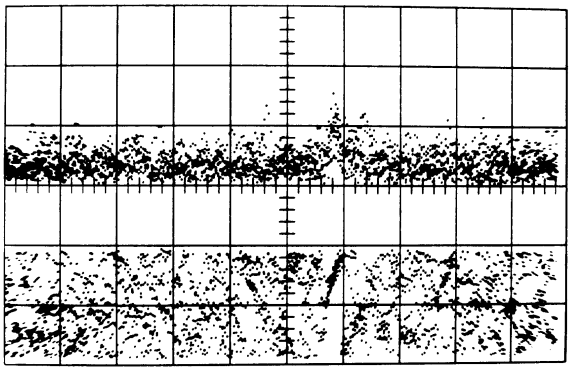


33-40

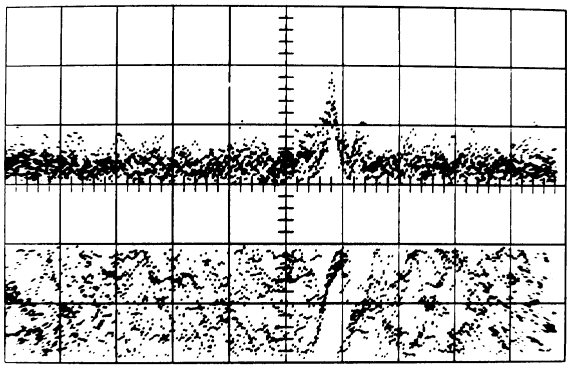
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

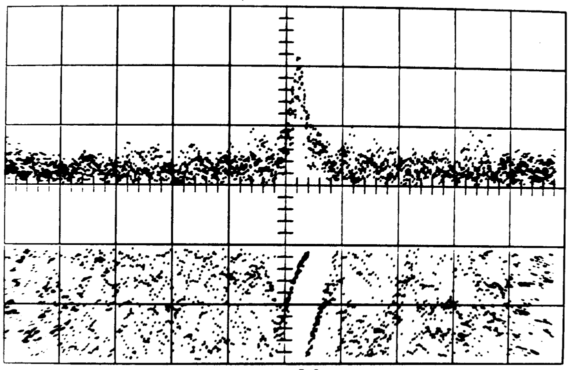
AMSEQ 12 August 1966 1003 - 1015 hours



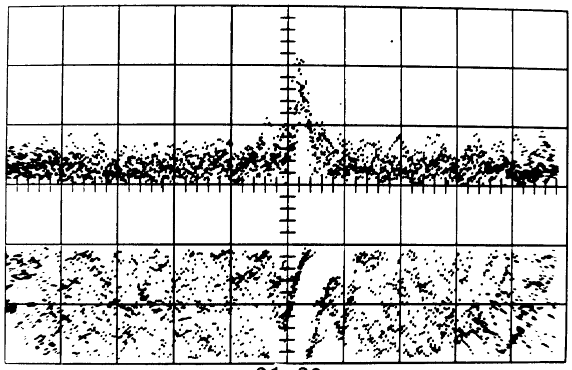
3-12



13-22

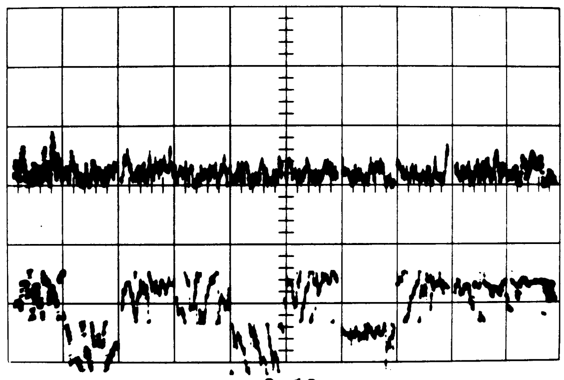


23-30

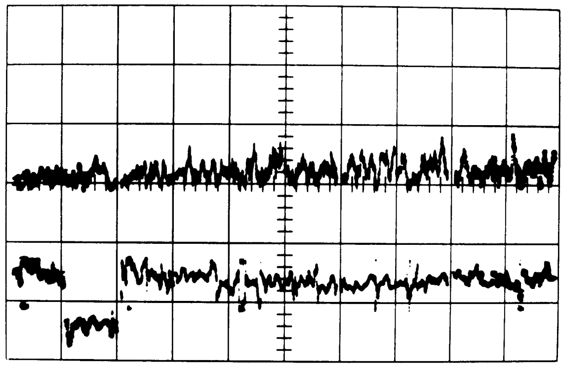


31-39

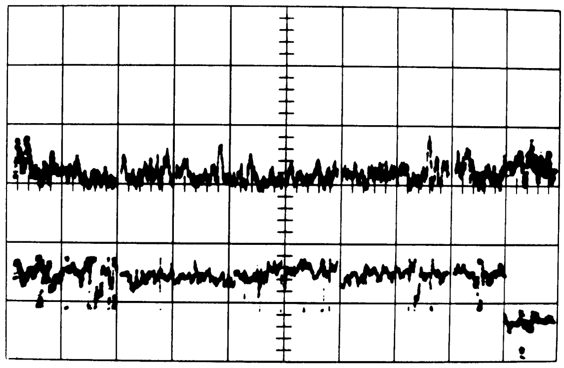
SEQ, R = 0.5V/cm



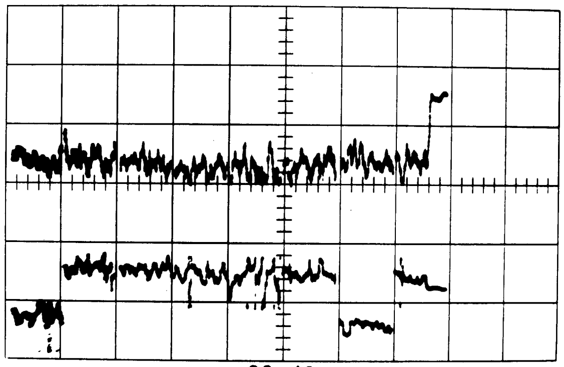
3-12



13-22



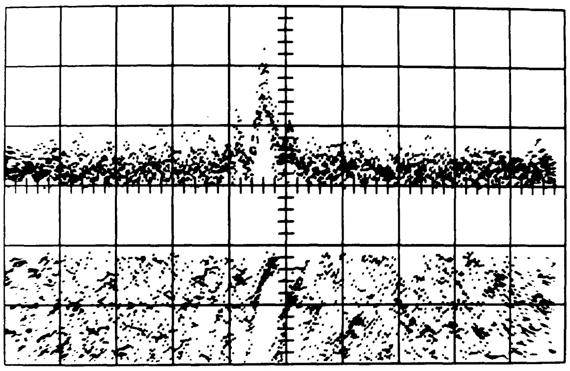
23-32



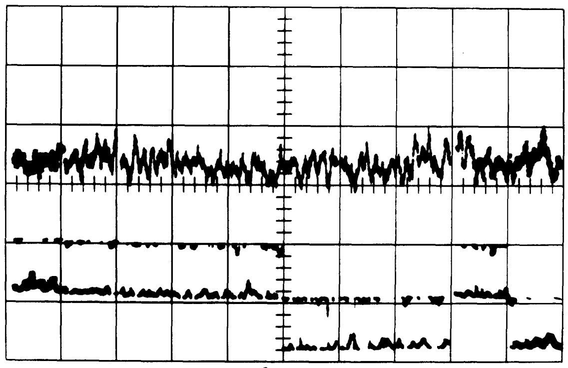
33-40

CW, R = 0.2V/cm

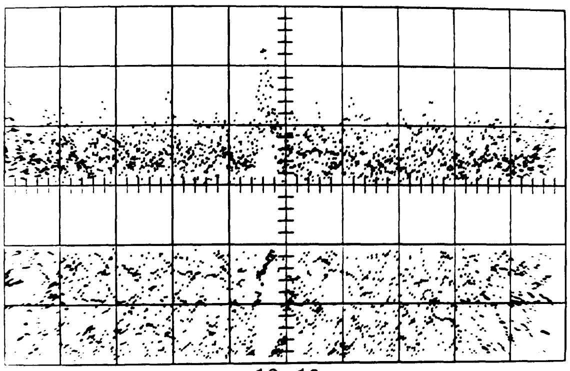
AMSEQ 12 August 1966 1015 - 1027 hours



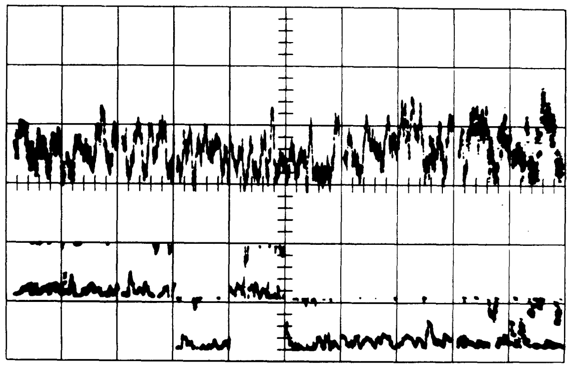
3-12



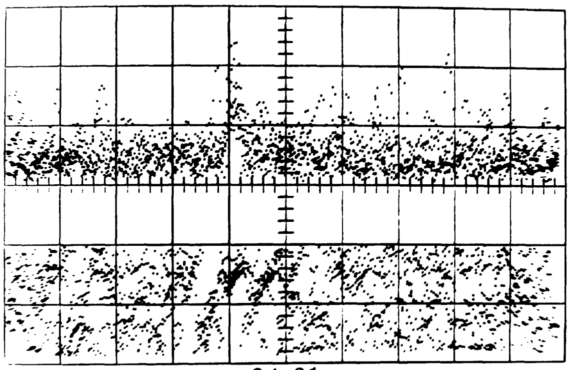
3-12



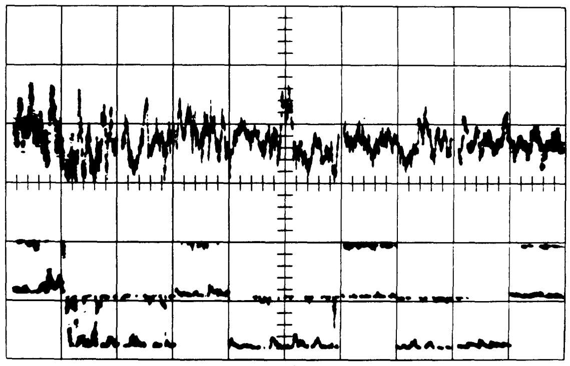
13-19



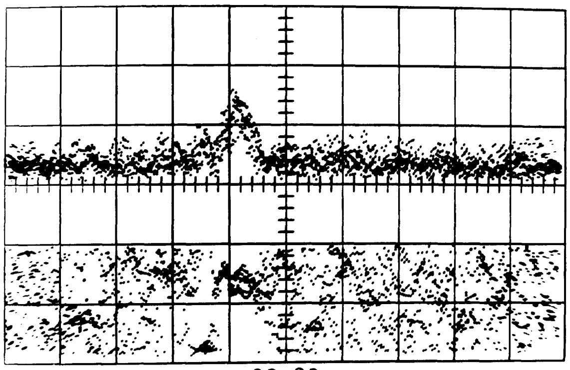
13-22



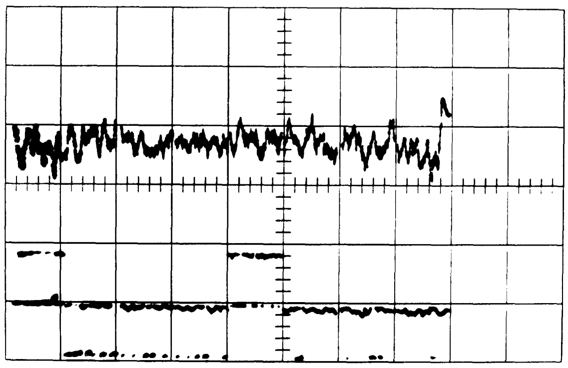
24-31



23-32



32-39

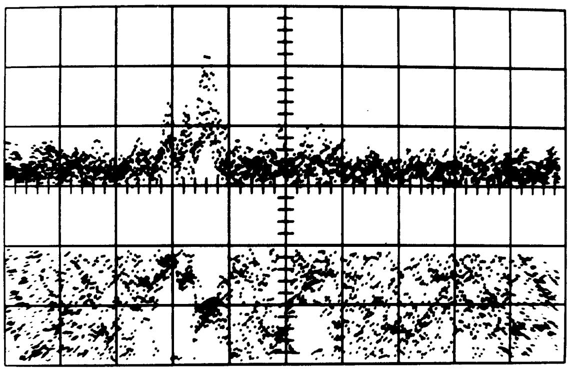


33-40

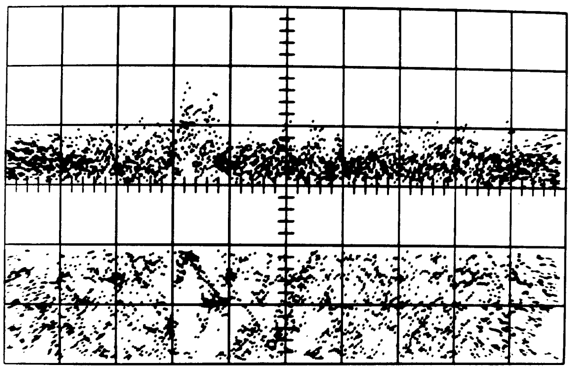
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

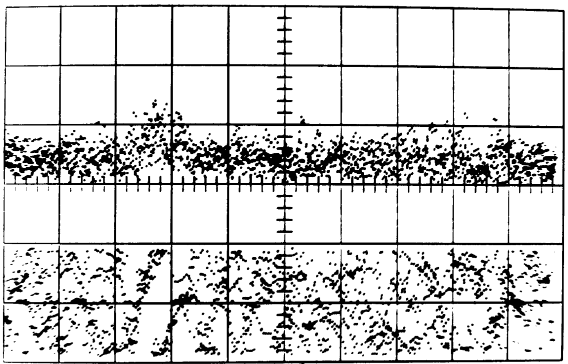
AMSEQ 12 August 1966 1027-1039 hours



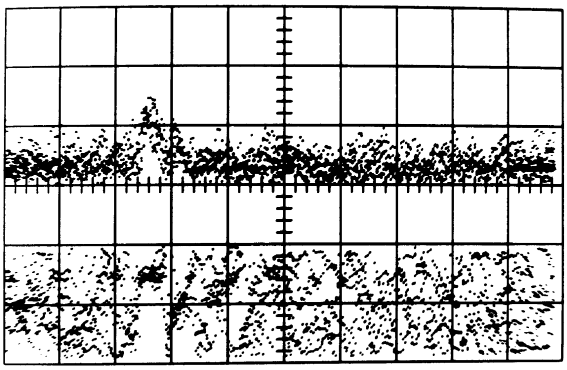
3-12



13-22

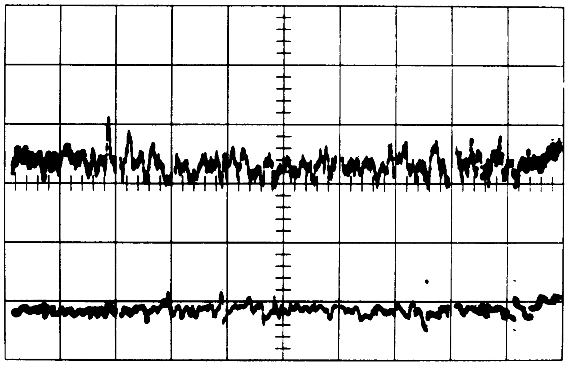


23-30

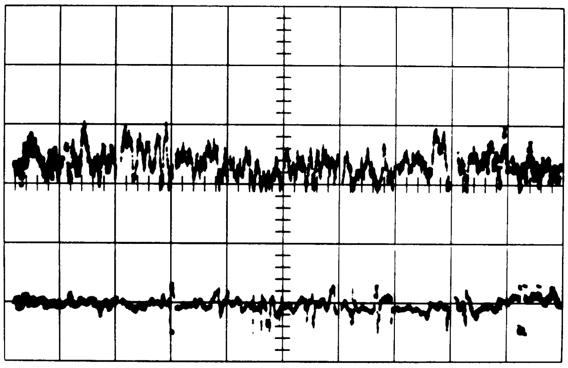


31-39

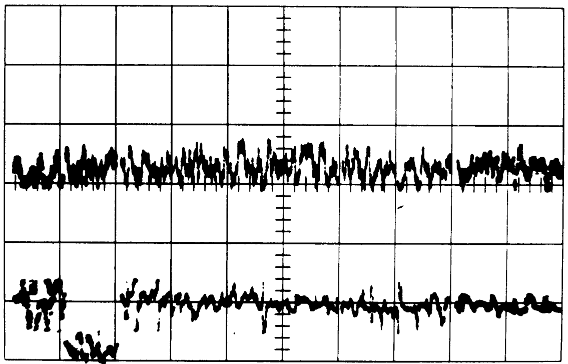
SEQ, R = 0.5V/cm



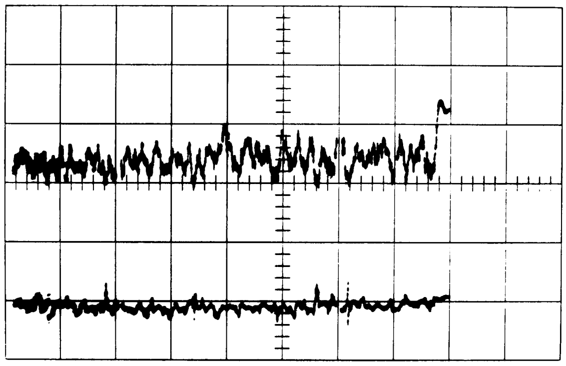
3-12



13-22



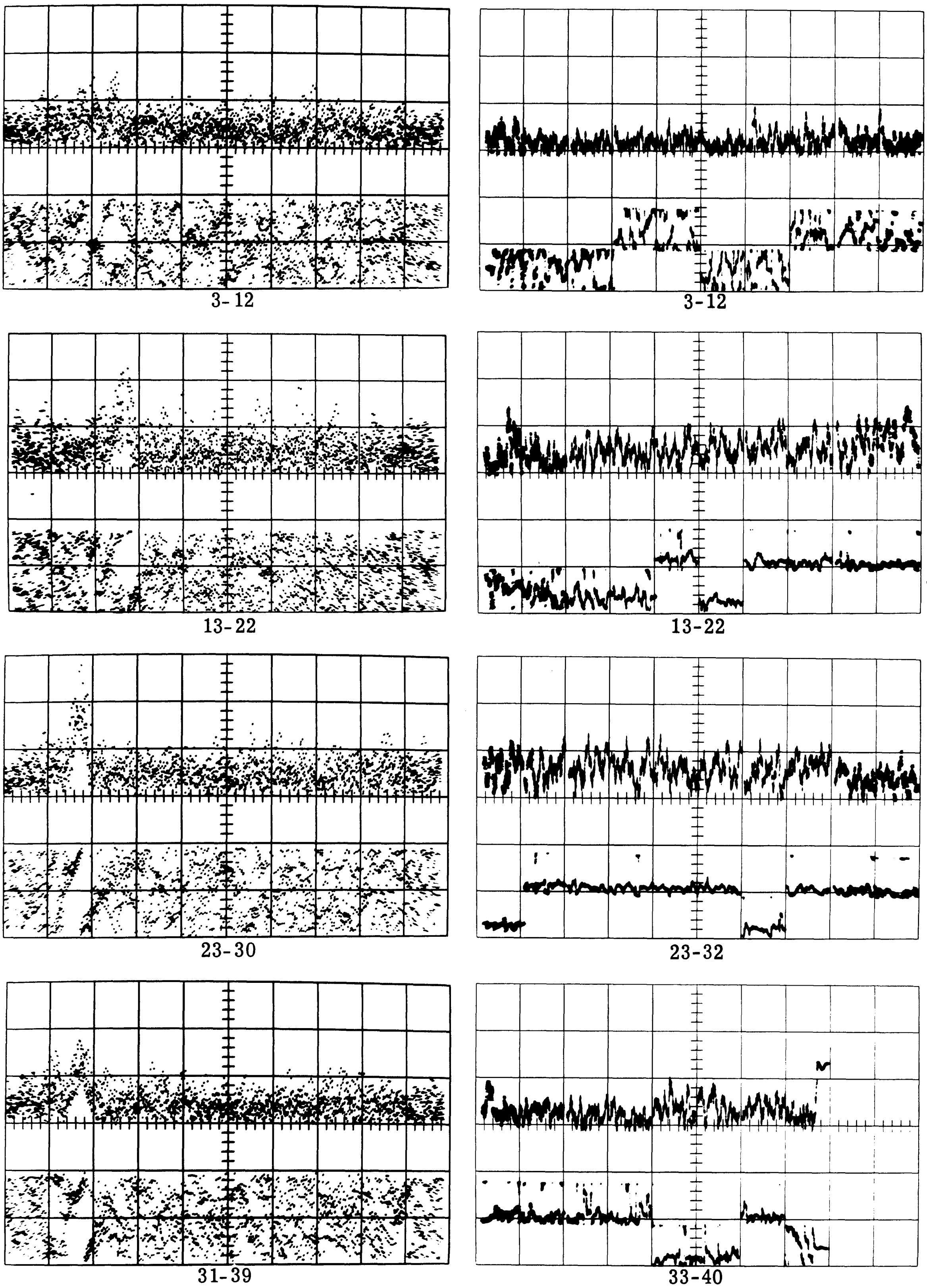
23-32



33-40

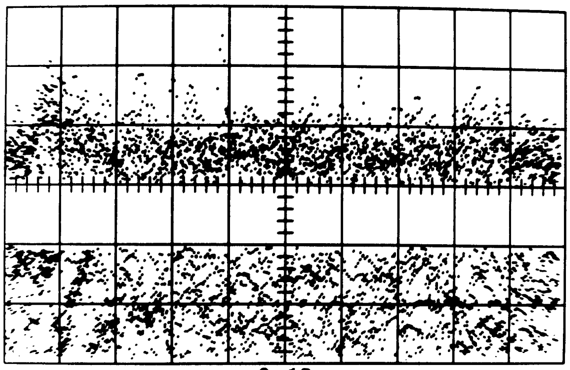
CW, R = 0.2V/cm

AMSEQ 12 August 1966 1039-1051 hours

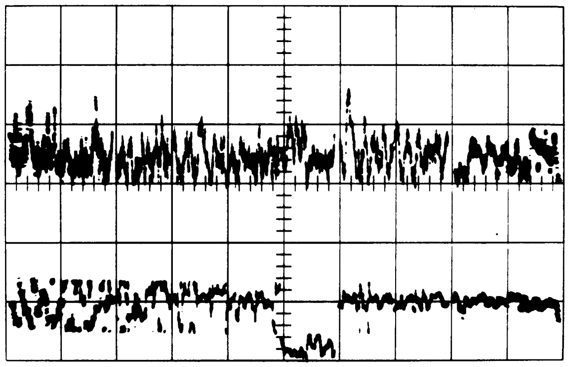


SEQ, R = 0.5V/cm   CW, R = 0.2V/cm

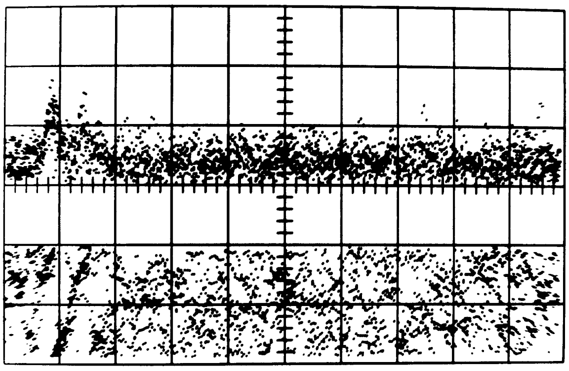
AMSEQ 12 August 1966 1051-1103 hours



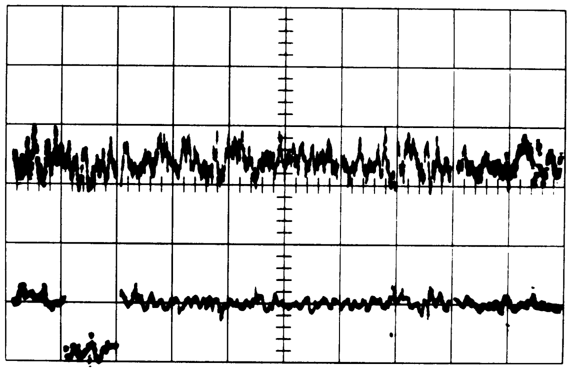
3-12



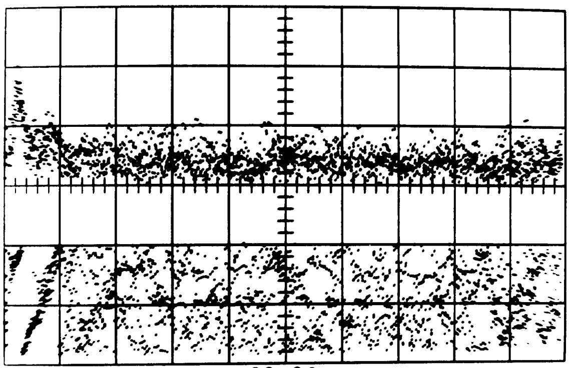
3-12



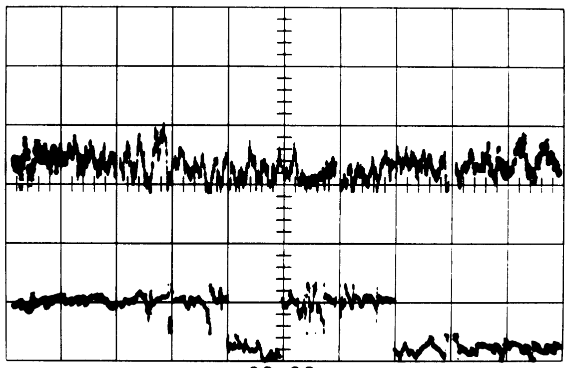
13-22



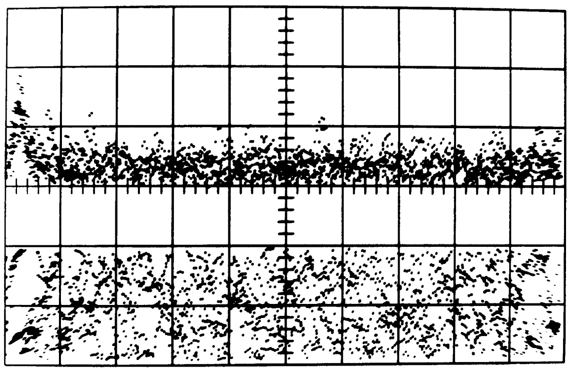
13-22



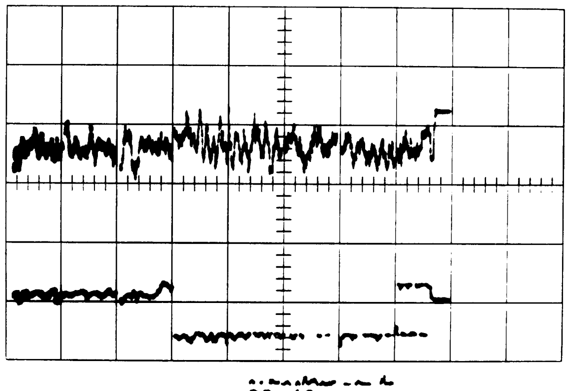
23-30



23-32



31-39

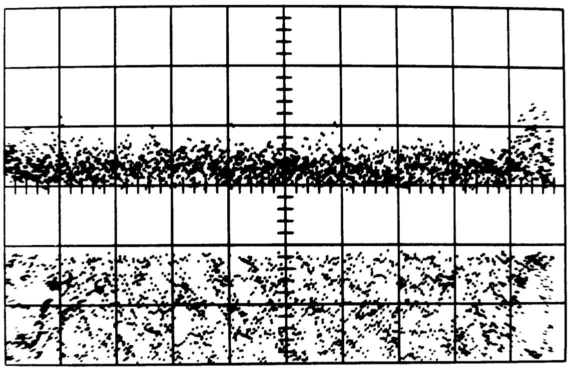


33-40

SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

AMSEQ 12 August 1966 1103 - 1115 hours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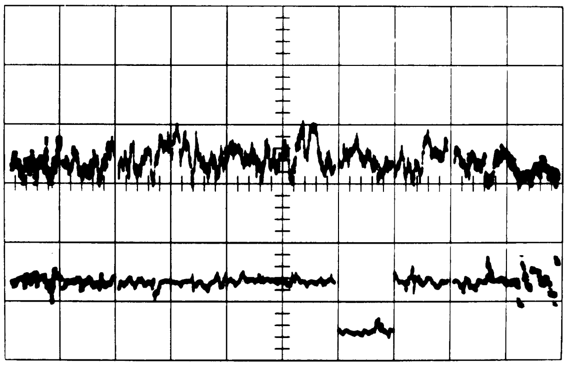
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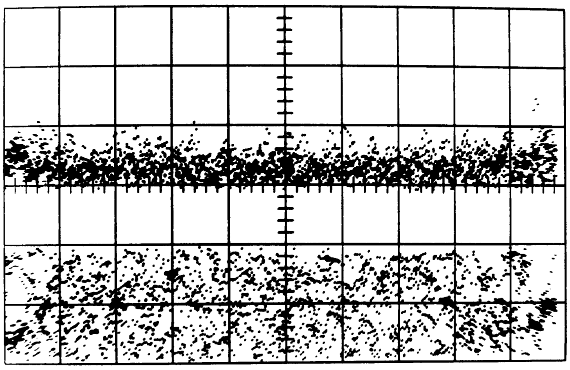
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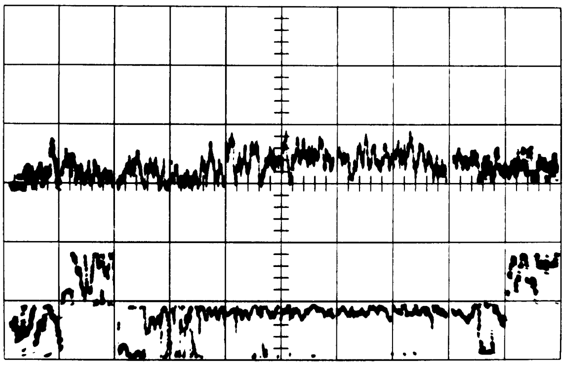
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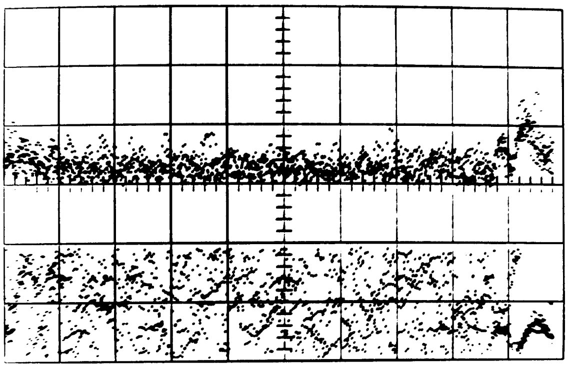
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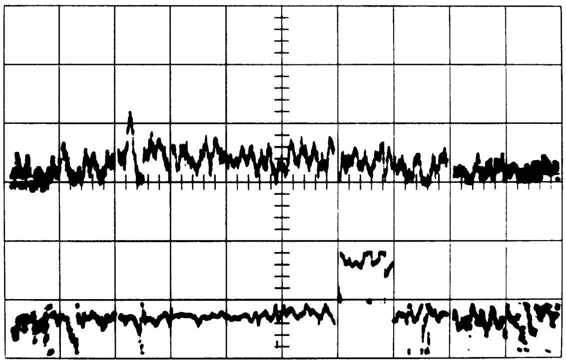
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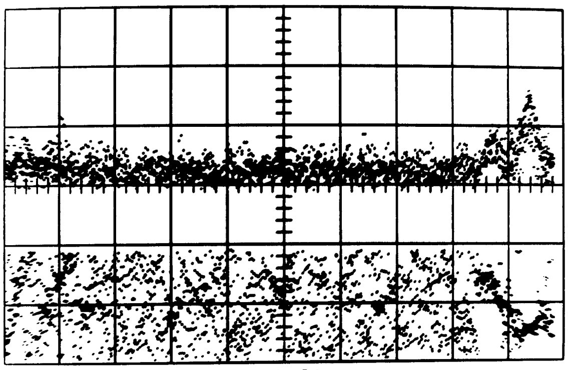
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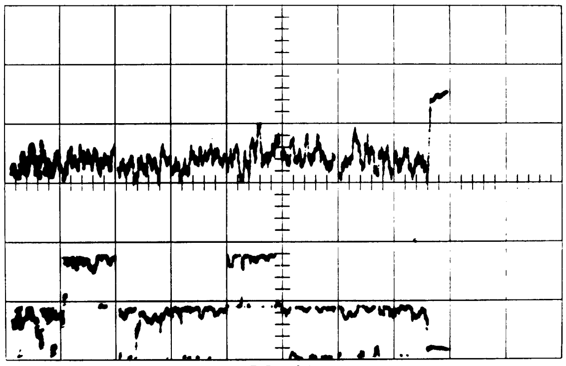
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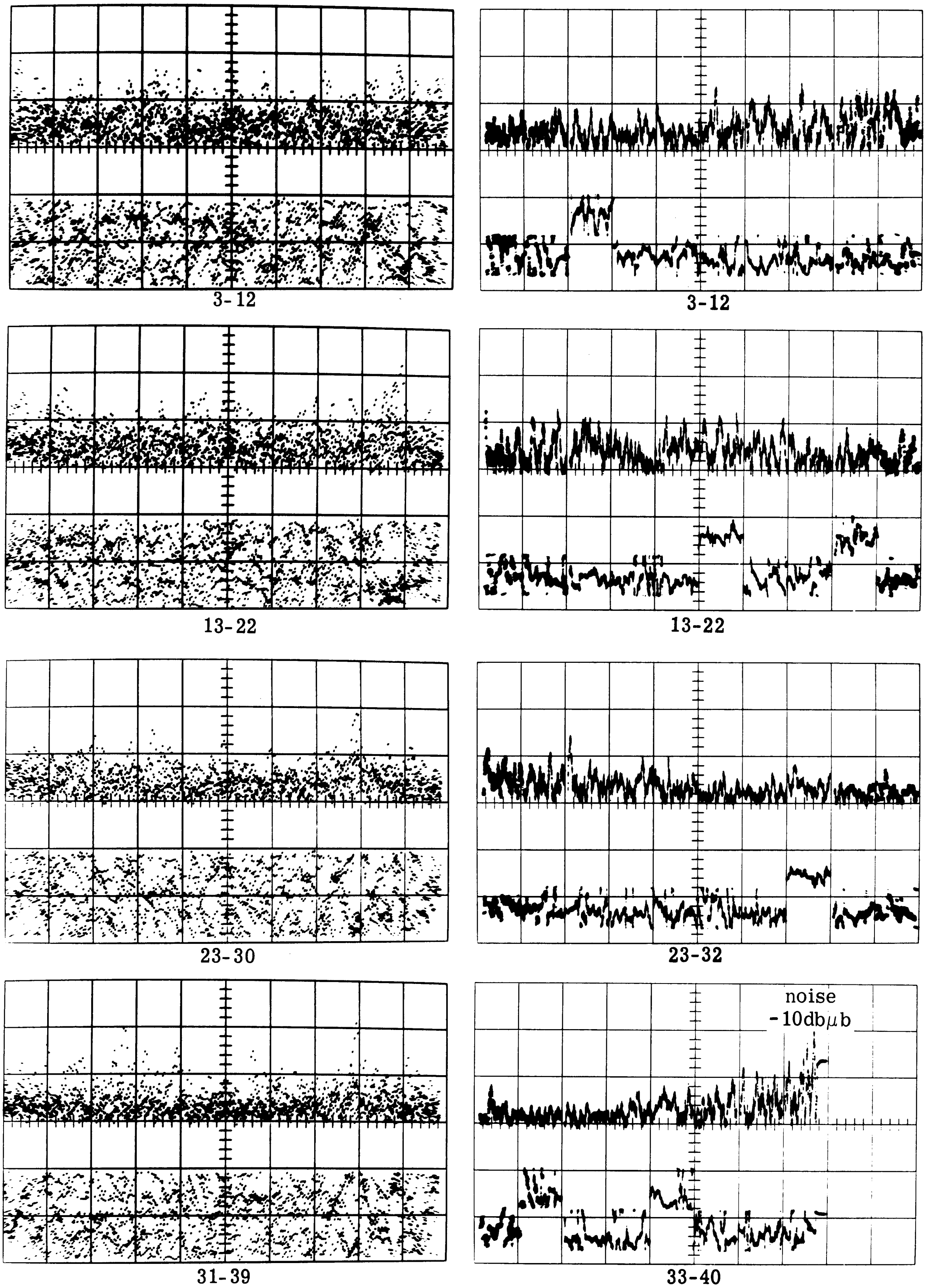
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

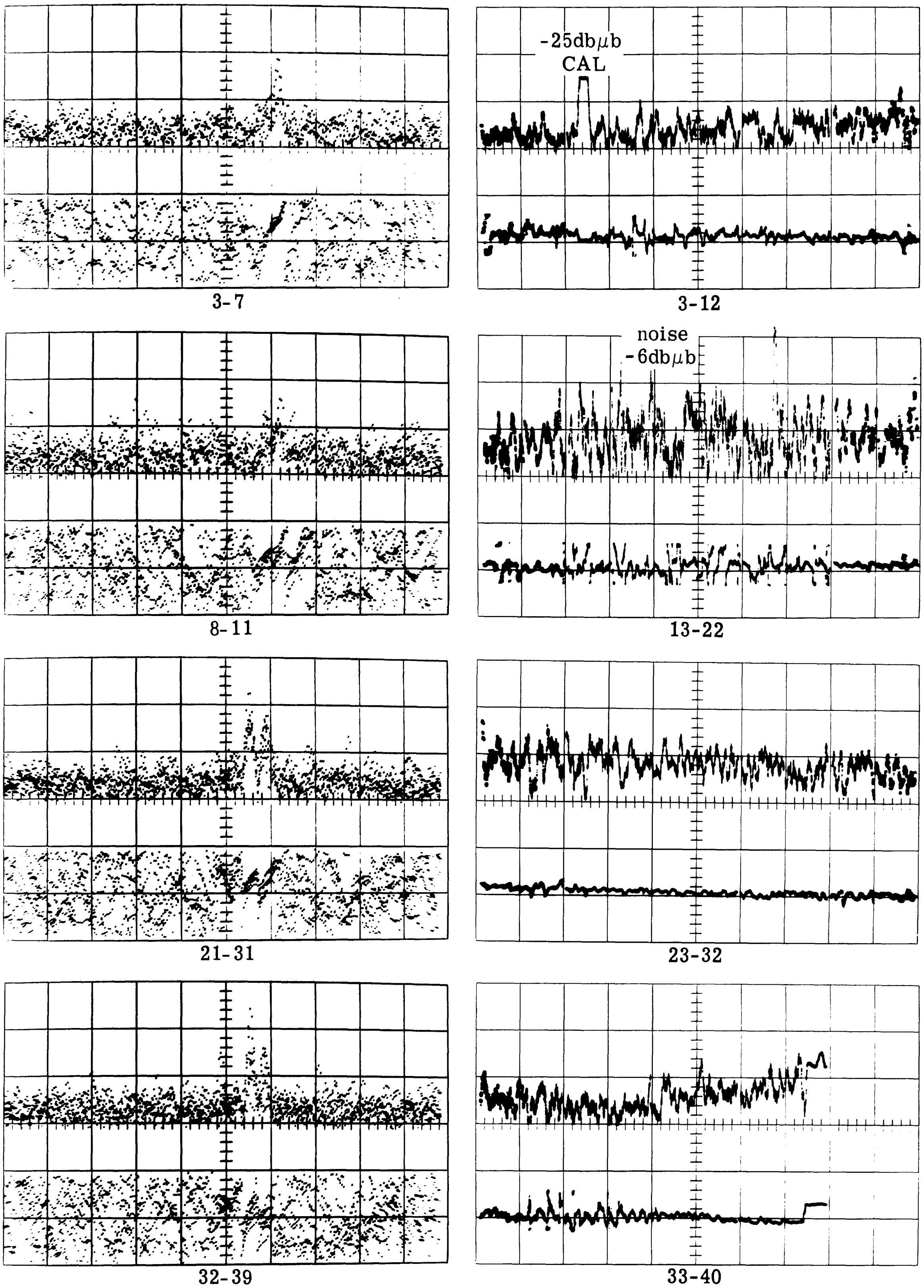
AMSEQ 12 August 1966 1115-1127 hours



SEQ, R = 0.5V/cm

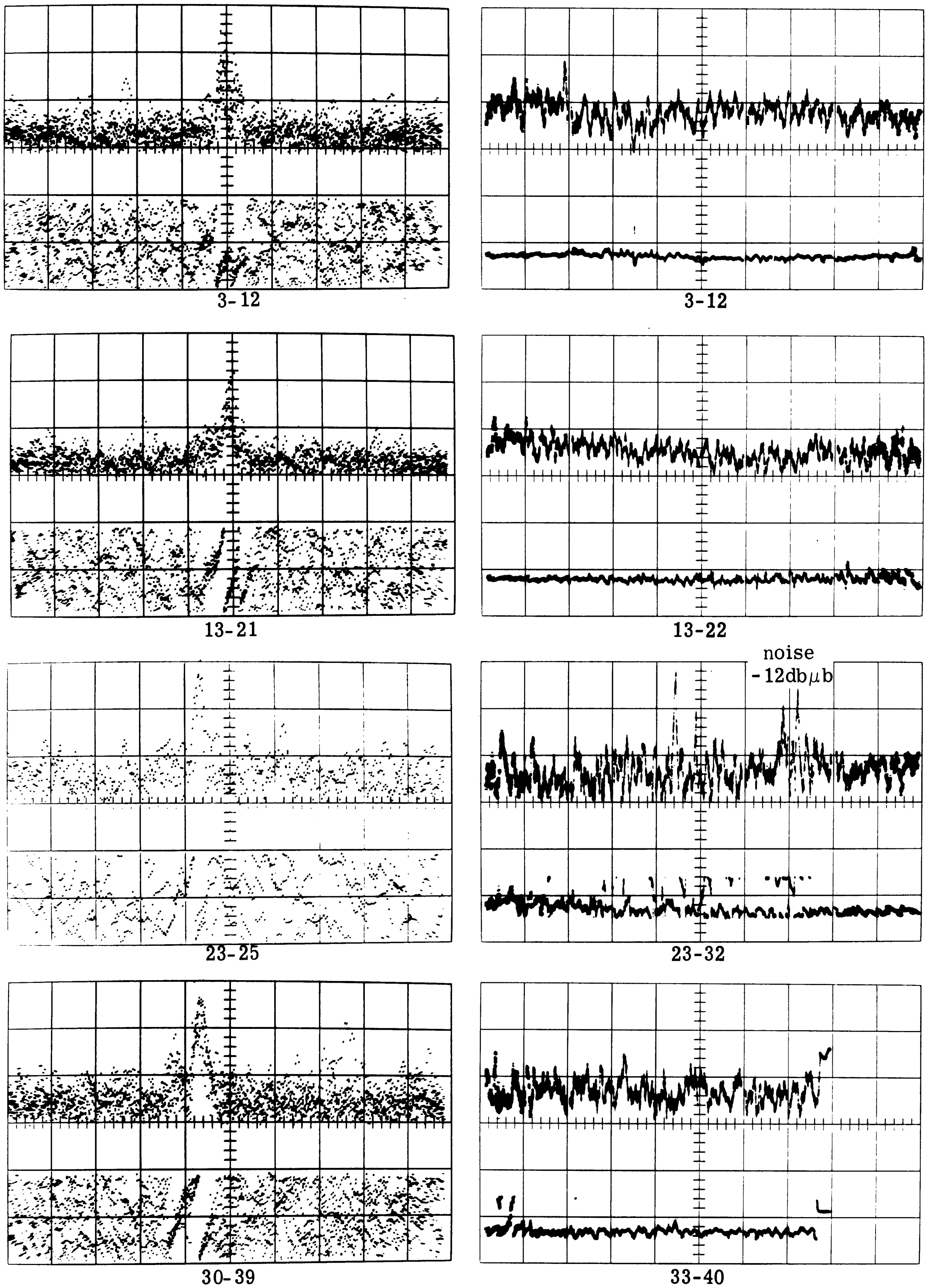
CW, R = 0.2V/cm

AMSEQ 12 August 1966 1127 - 1139 hours



SEQ, R = 0.5V/cm   CW, R = 0.2V/cm

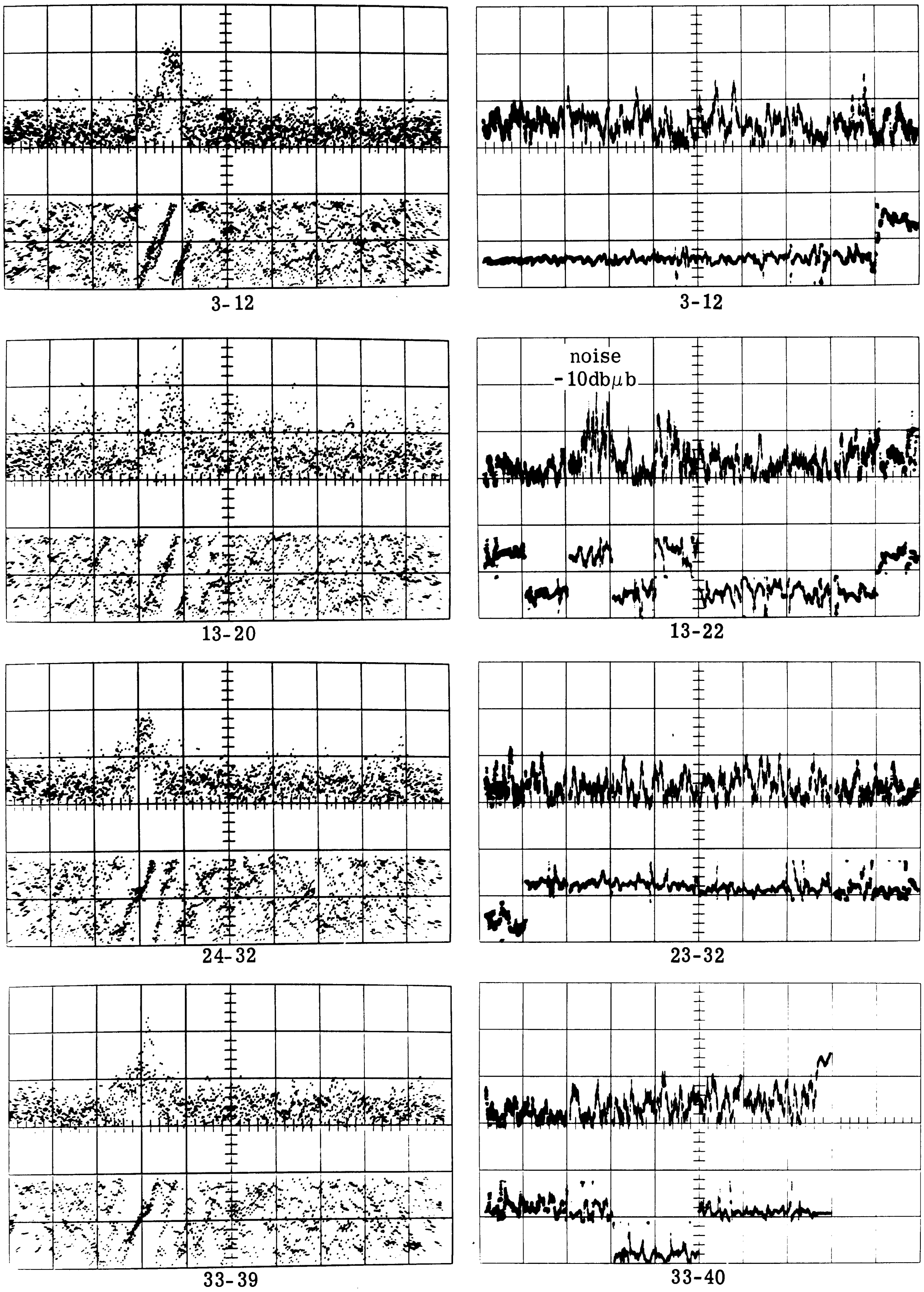
AMSEQ 12 August 1966 1151 - 1203 hours



SEQ, R = 0.5V/cm

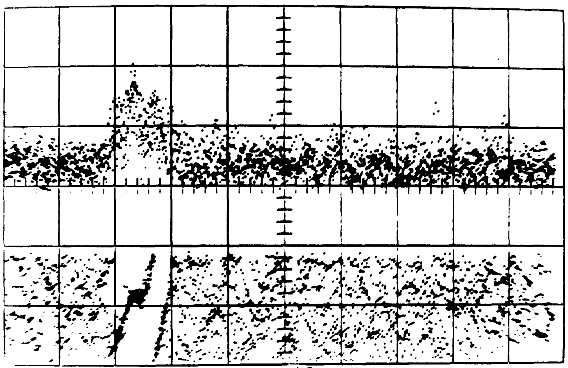
CW, R = 0.2V/cm

AMSEQ 12 August 1966 1203 - 1215 hours



SEQ, R = 0.5V/cm CW, R = 0.2V/cm

AMSEQ 12 August 1966 1215 - 1227 hours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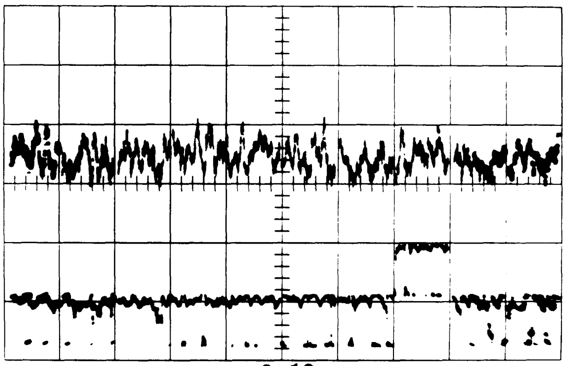
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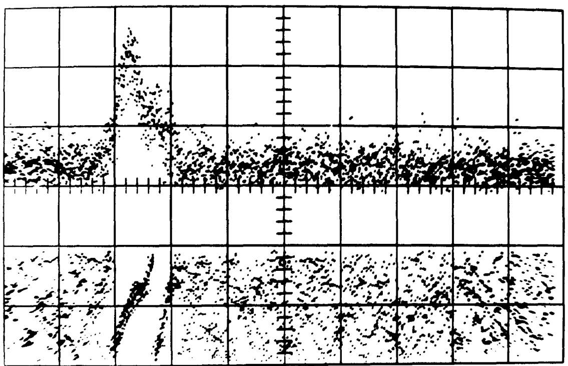
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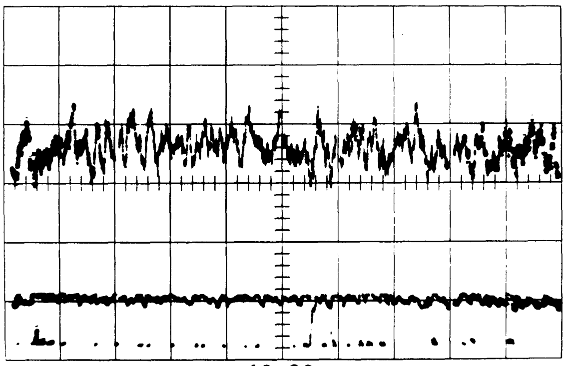
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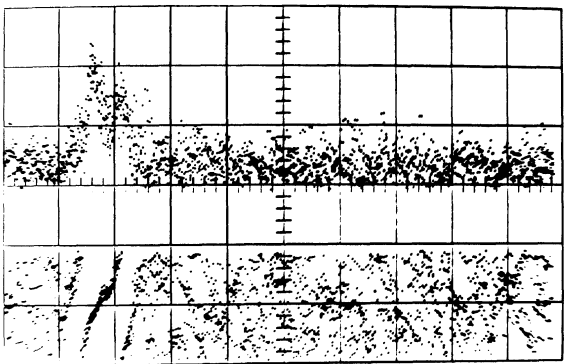
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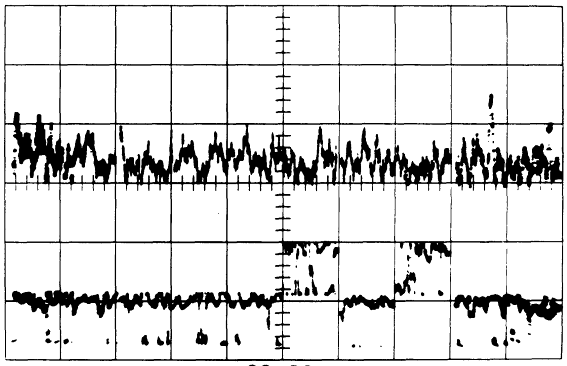
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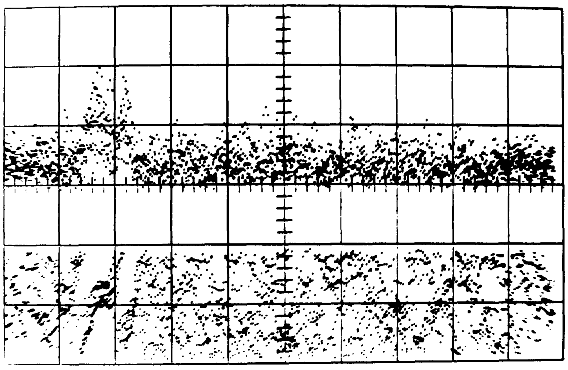
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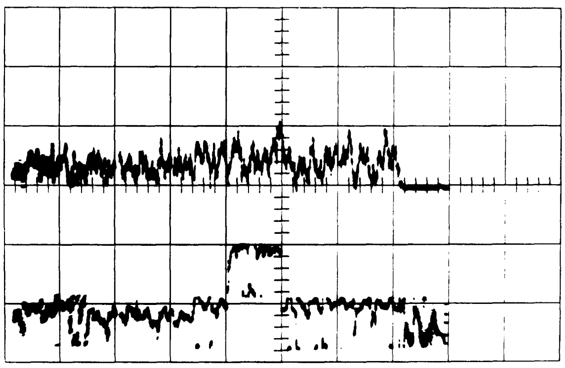

33-40

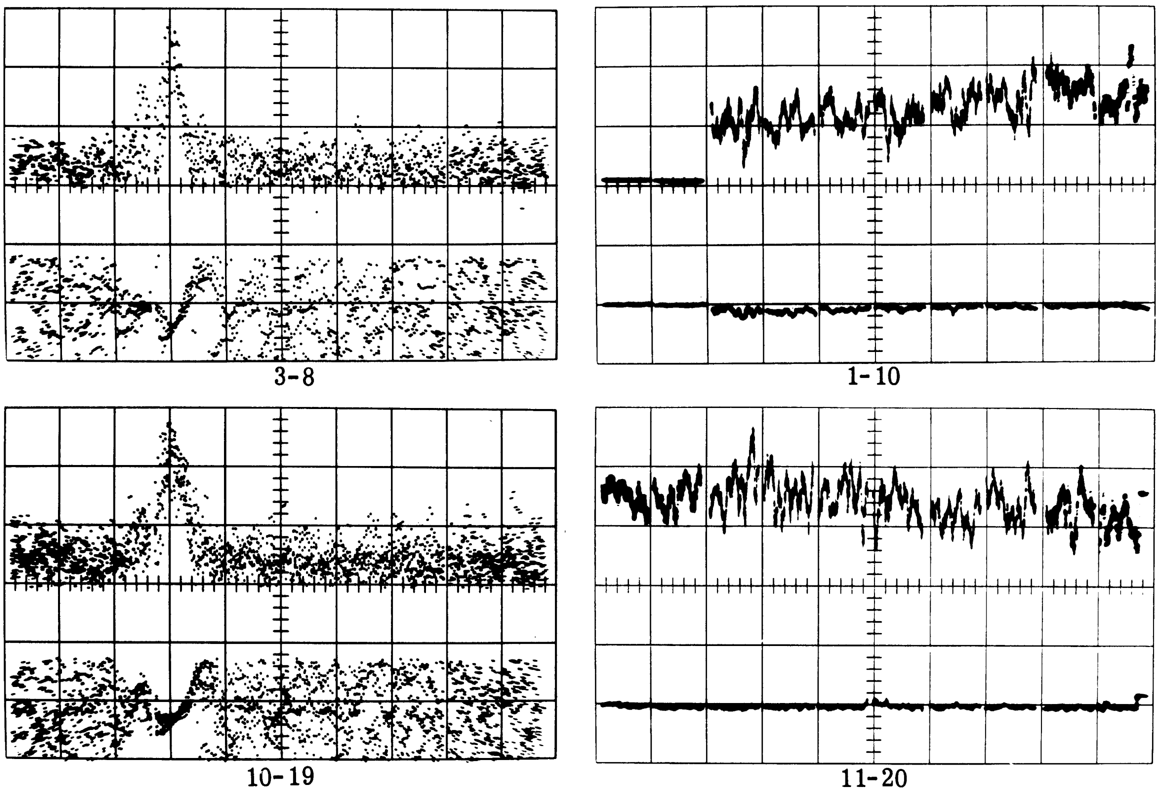
SEQ, R = 0.5V/cm

CW, R = 0.2V/cm

AMSEQ 12 August 1966 1227 - 1239 hours

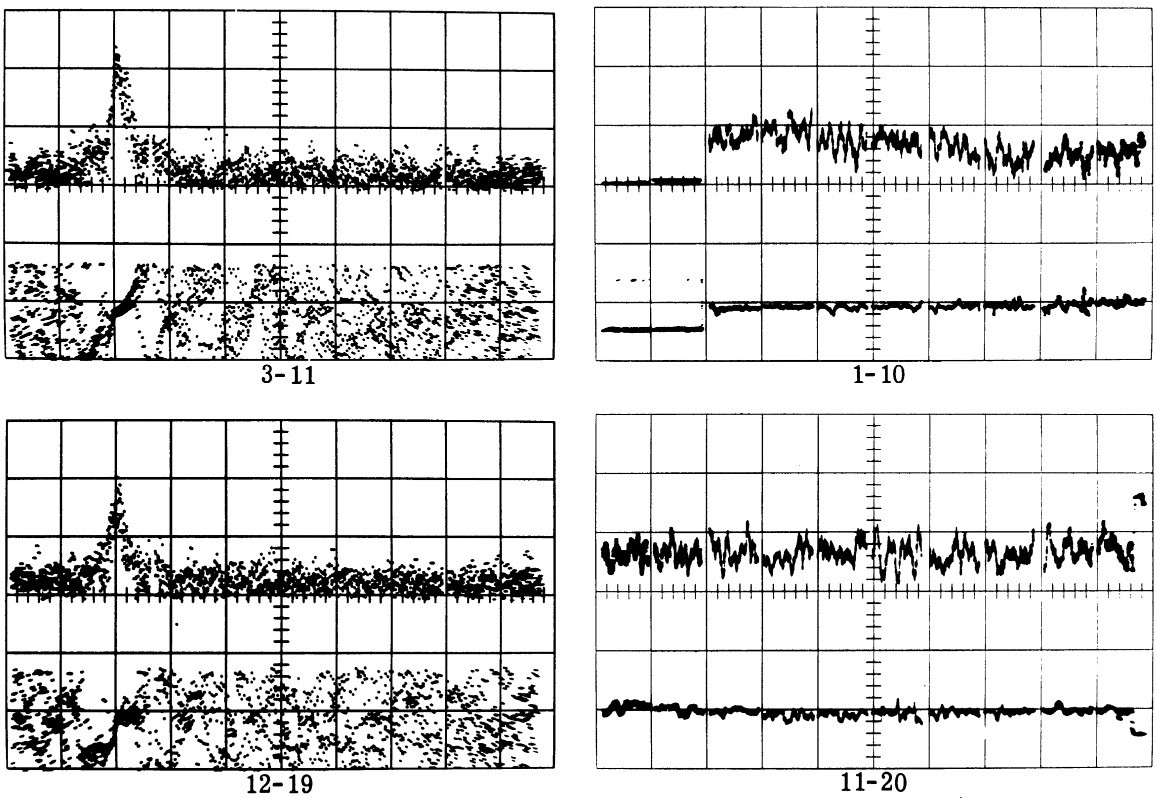
APPENDIX B

RESULTS OF THE 24-HOUR SAMPLED TEST



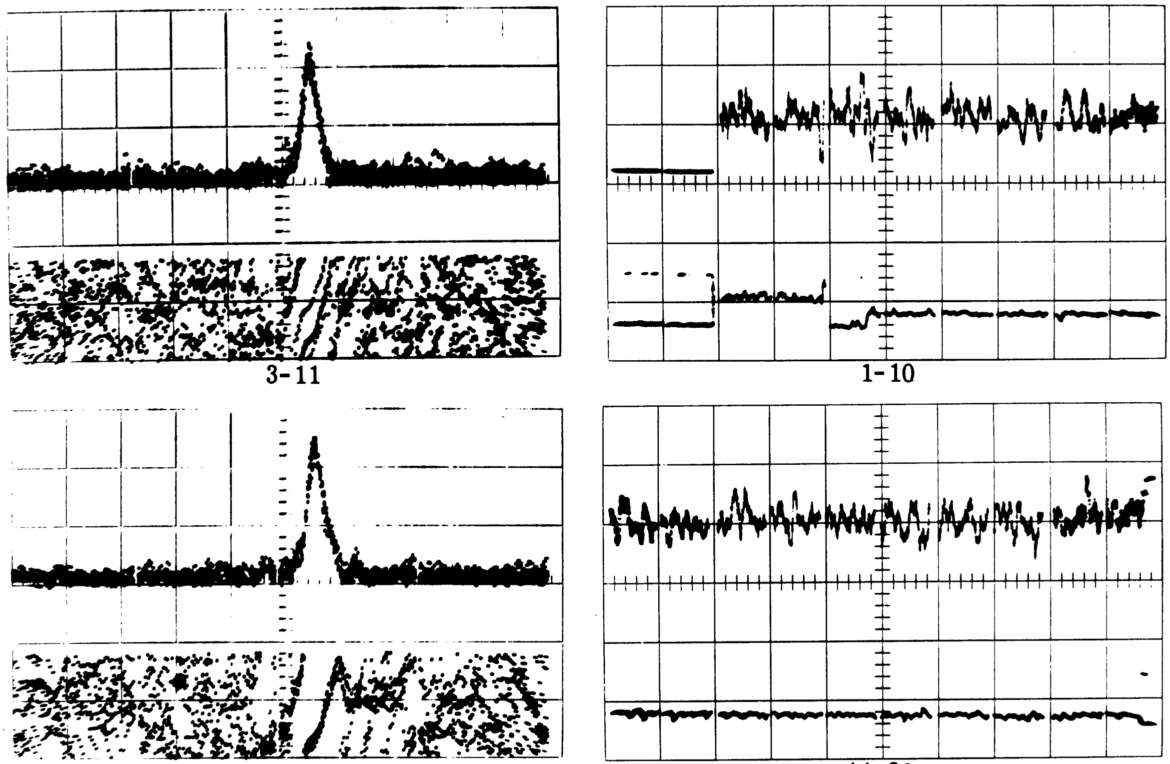
CW, R = 0.2 V/cm

AMSEQ 12 August 1966 1403 - 1409 hours



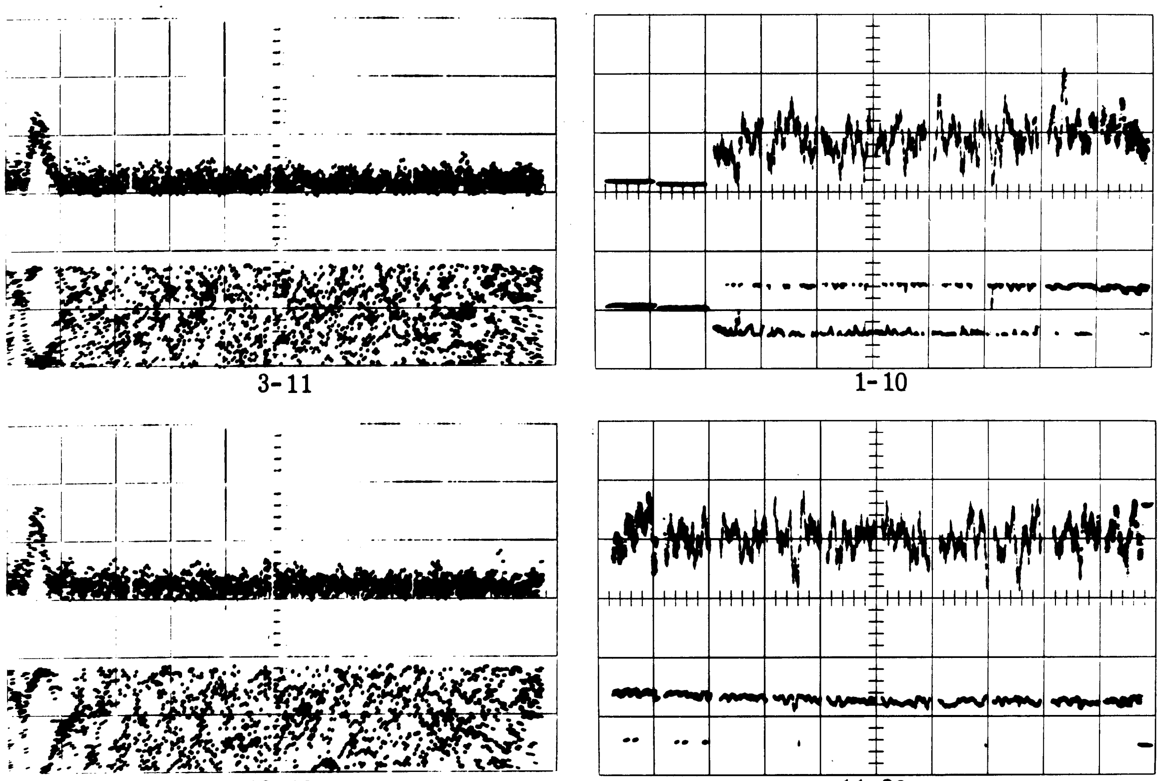
CW, R = 0.2 V/cm

AMSEQ 12 August 1966 1603 - 1609 hours



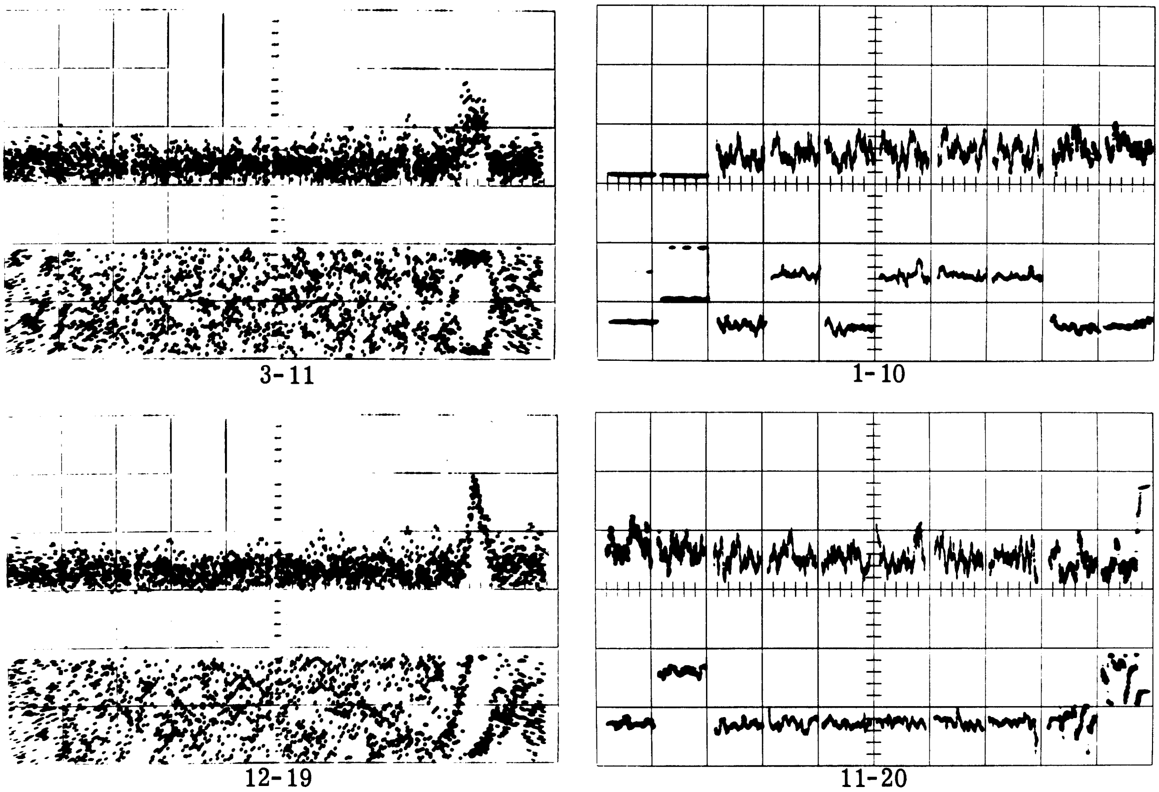
SEQ, R = 1.0 V/cm CW, R = 0.2 V/cm

AMSEQ 12 August 1966 1803 - 1809 hours



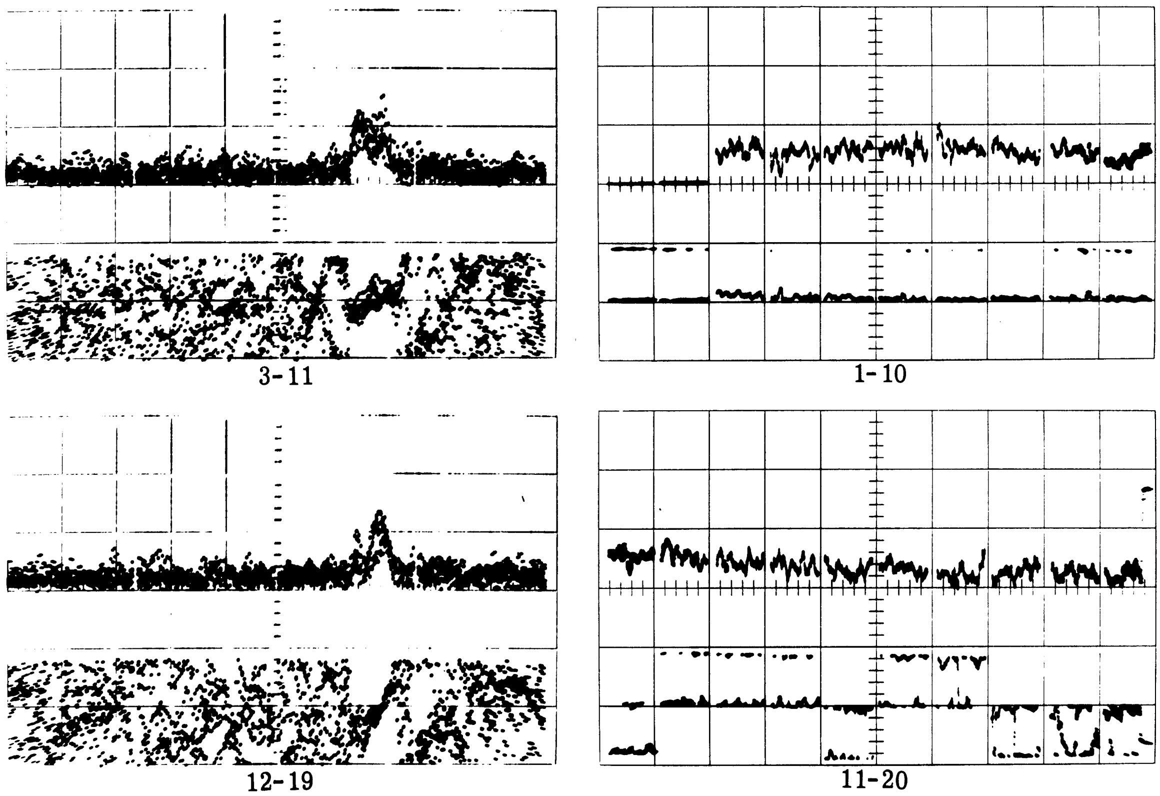
SEQ, R = 1.0 V/cm CW, R = 0.2 V/cm

AMSEQ 12 August 1966 2003 - 2009 hours



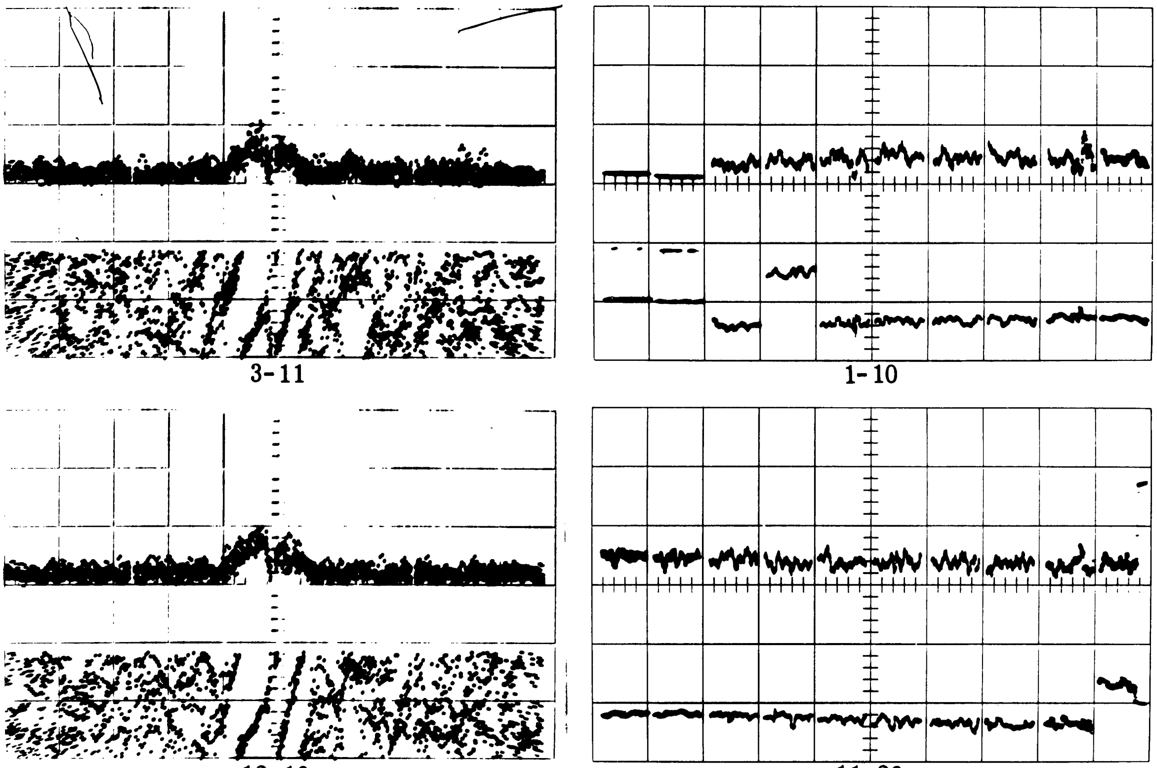
SEQ, R = 0.5 V/cm   CW, R = 0.2 V/cm

AMSEQ 12 August 1966 2203 - 2209 hours



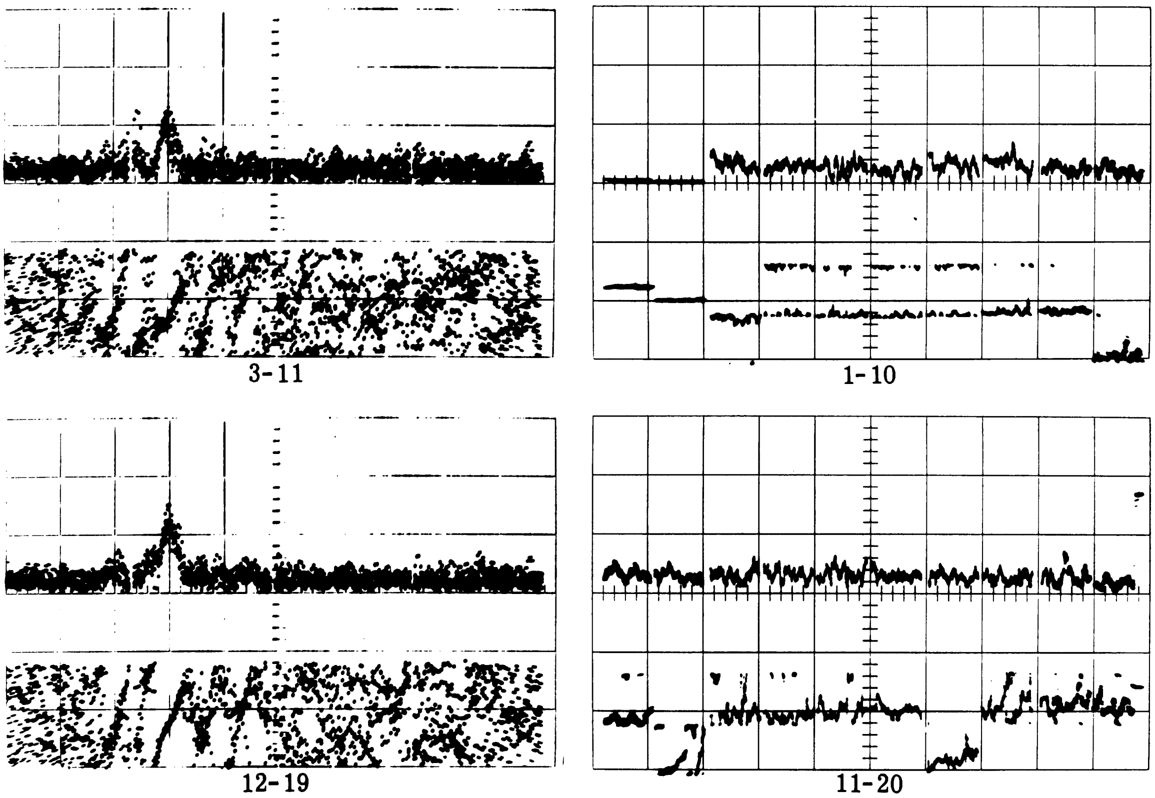
SEQ, R = 0.5 V/cm   CW, R = 0.2 V/cm

AMSEQ 13 August 1966 0003 - 0009 hours



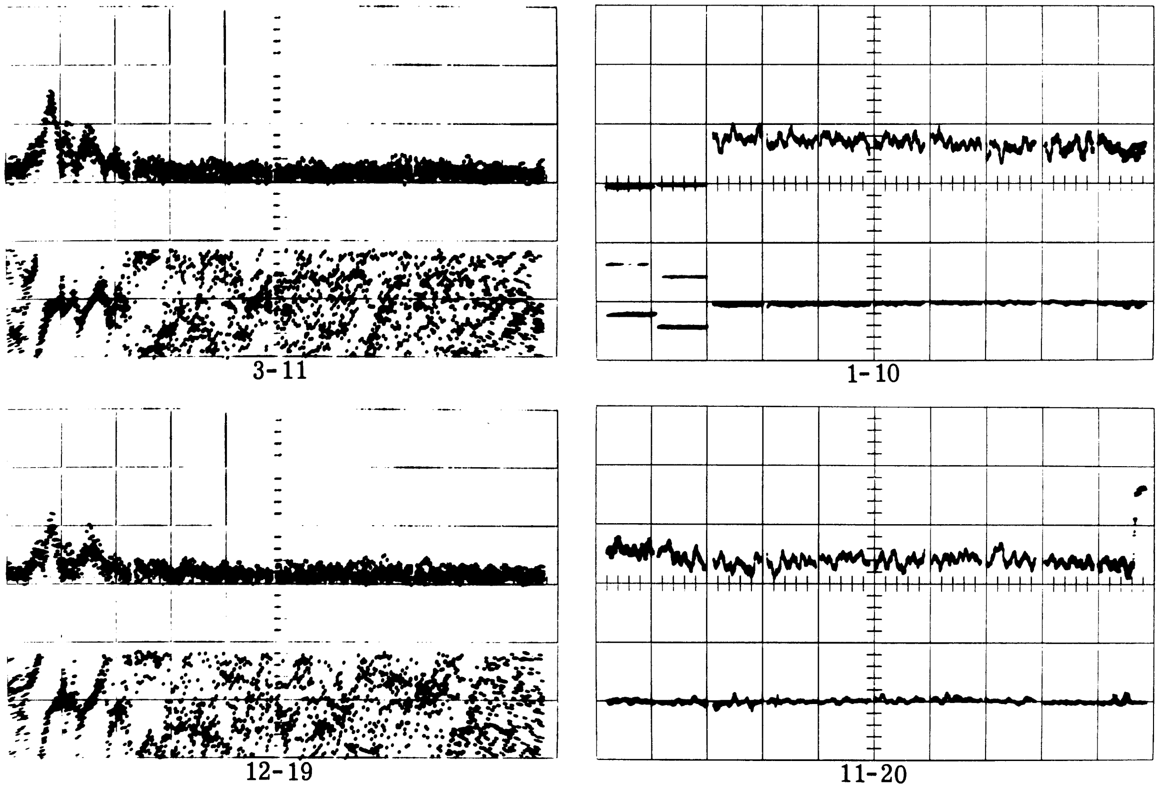
SEQ, R = 0.5 V/cm　　CW, R = 0.2 V/cm

AMSEQ 13 August 1966 0203 - 0209 hours



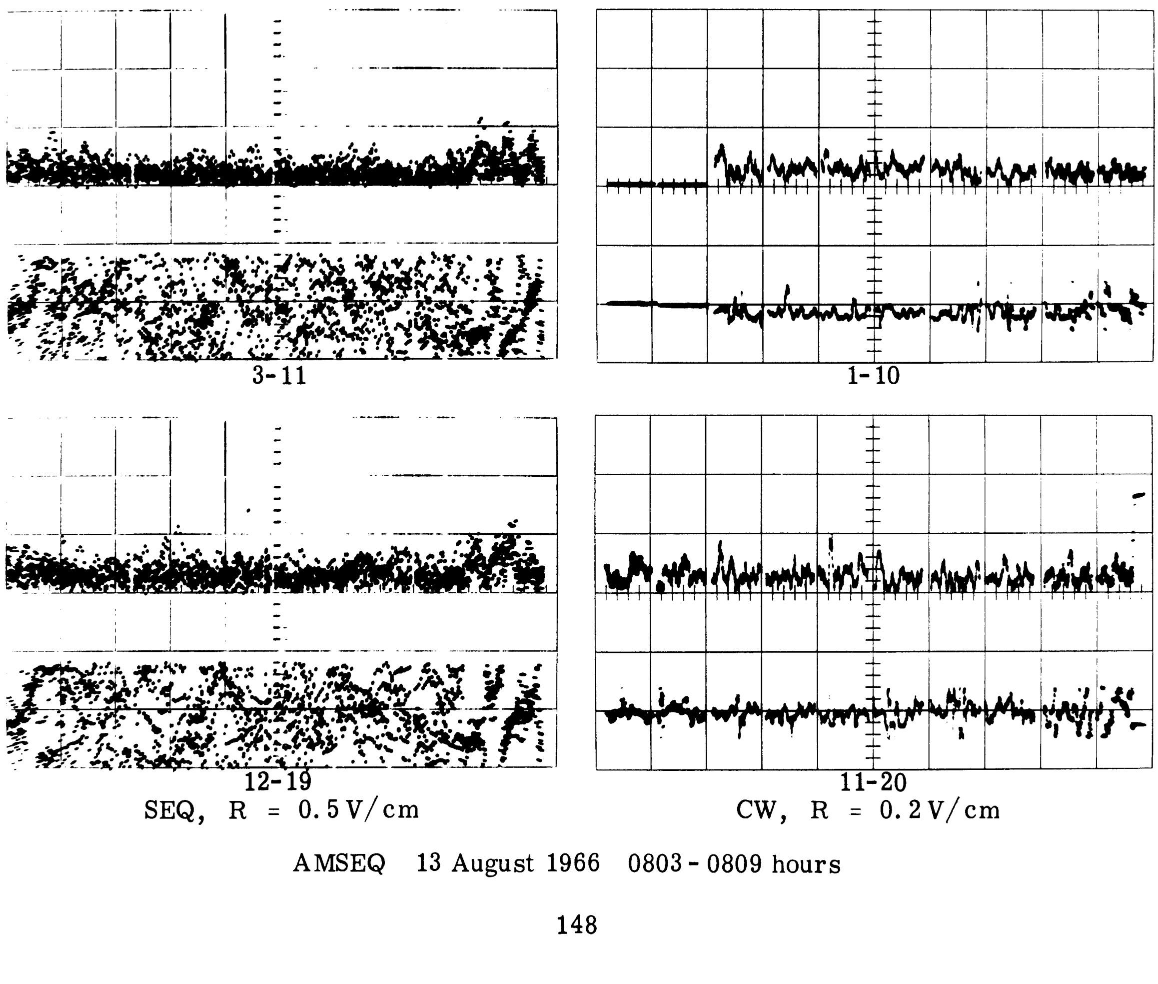
SEQ, R = 0.5 V/cm　　CW, R = 0.2 V/cm

AMSEQ 13 August 1966 0403 - 0409 hours



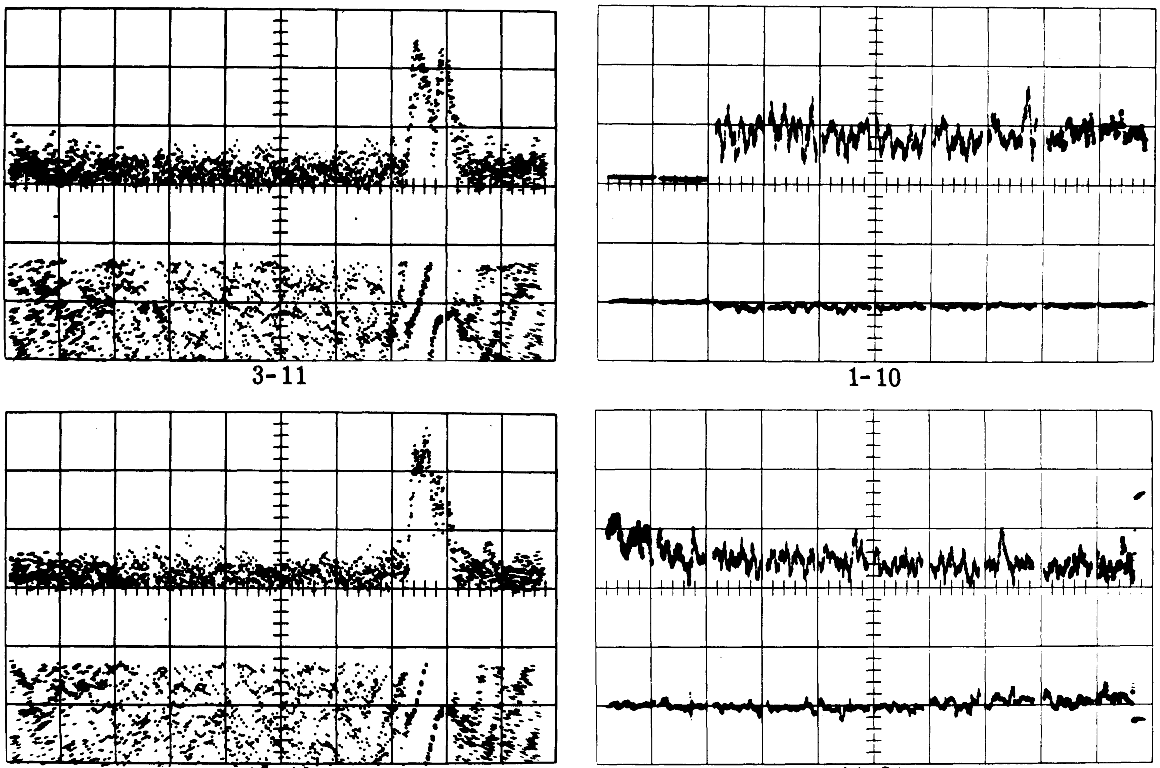
SEQ, R = 0.5 V/cm   CW, R = 0.2 V/cm

AMSEQ 13 August 1966 0603 - 0609 hours



SEQ, R = 0.5 V/cm   CW, R = 0.2 V/cm

AMSEQ 13 August 1966 0803 - 0809 hours

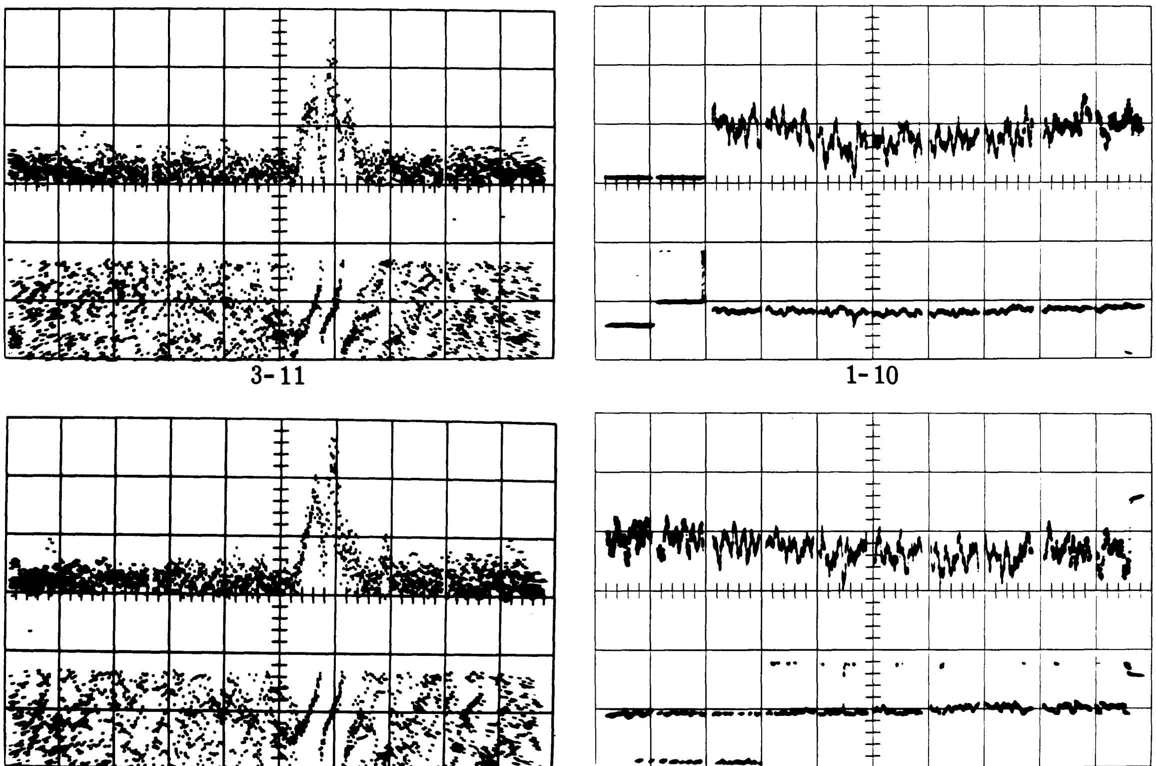


3-11 1-10

12-19 11-20

SEQ, R = 0.5 V/cm CW, R = 0.2 V/cm

AMSEQ 13 August 1966 1003 - 1009 hours



3-11 1-10

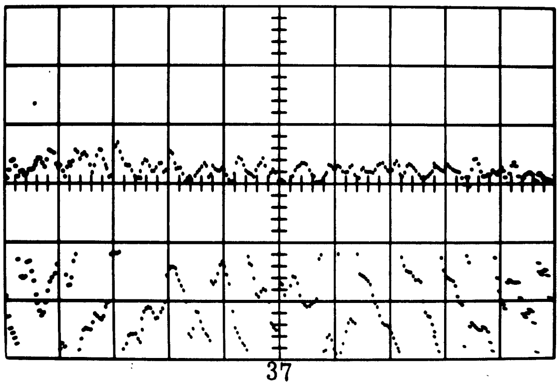
12-19 11-20

SEQ, R = 0.5 V/cm CW, R = 0.2 V/cm

AMSEQ 13 August 1966 1203 - 1209 hours

APPENDIX C

SELECTION OF SINGLE SEQUENCE EXPOSURES RESULTING FROM HIGH NOISE DATA



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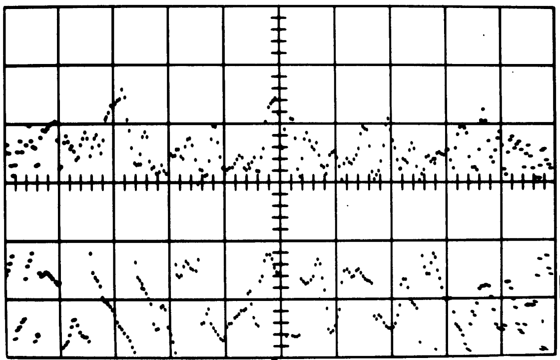

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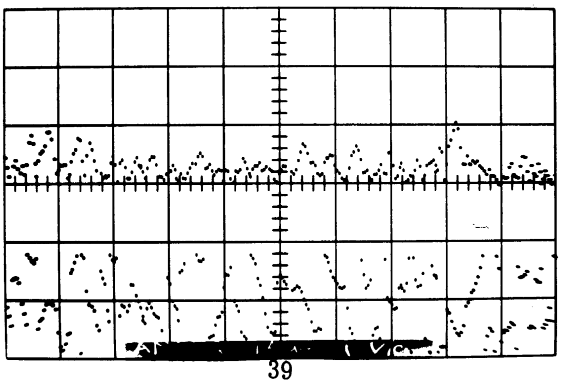

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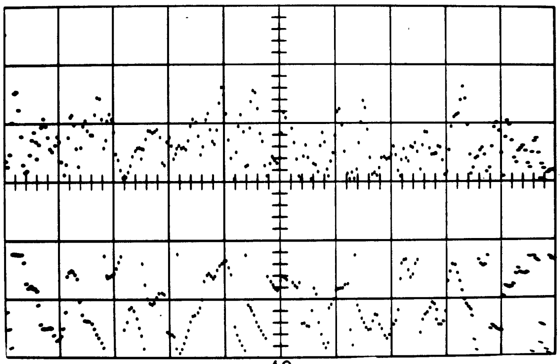
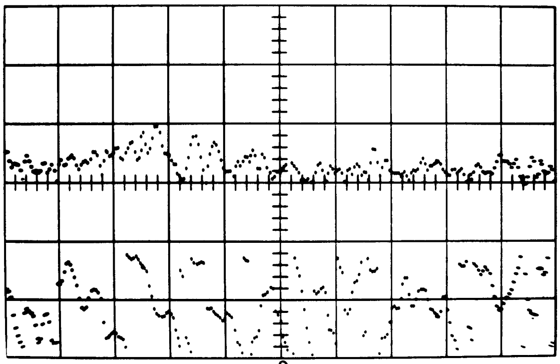


40

1357 - 1409 hours



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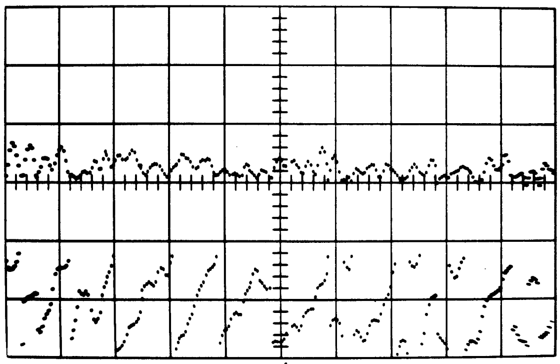

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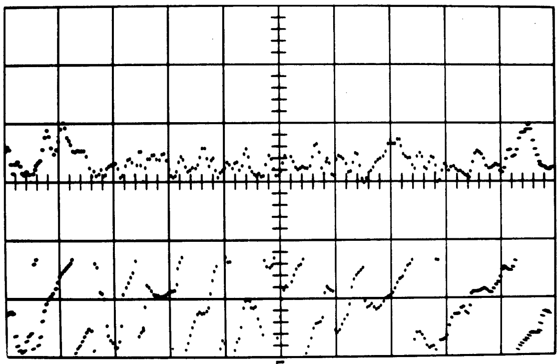

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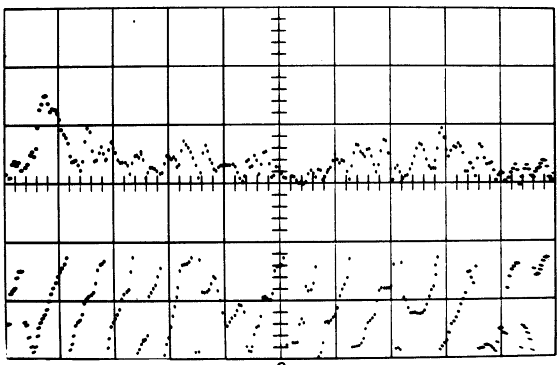
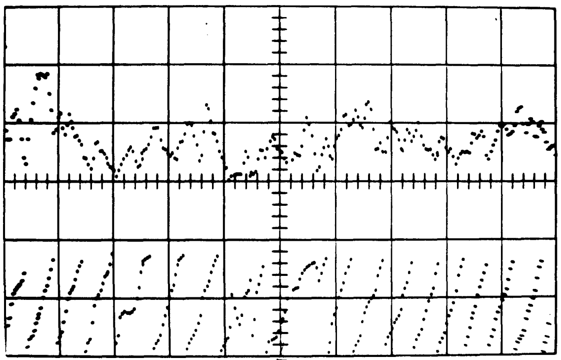


6

1409 - 1421 hours

AMSEQ 11 August 1966



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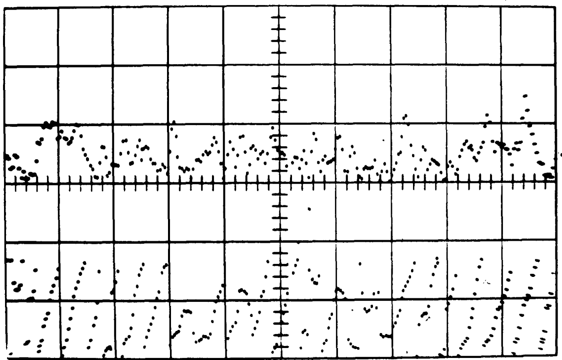

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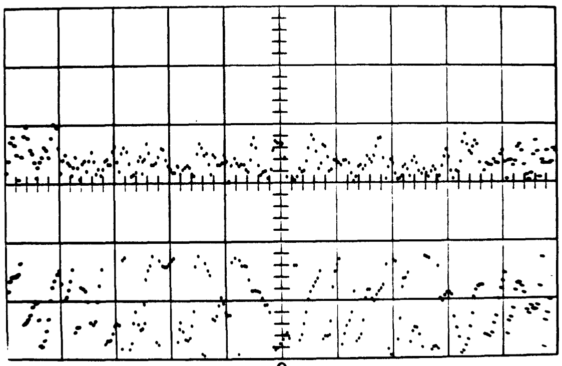

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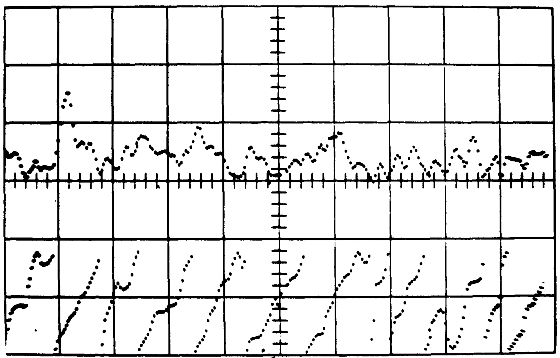
1409 - 1421 hours



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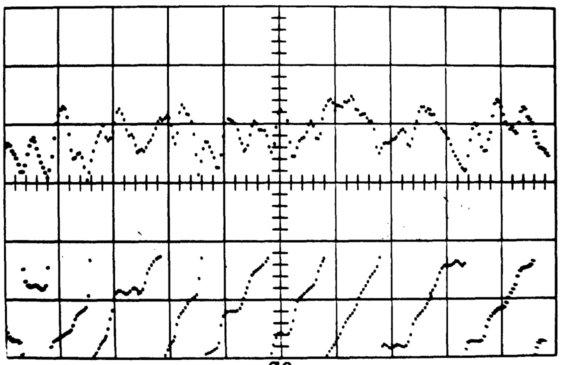
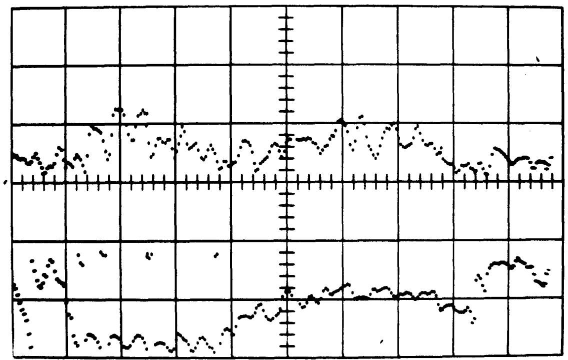


26

1700 - 1712 hours



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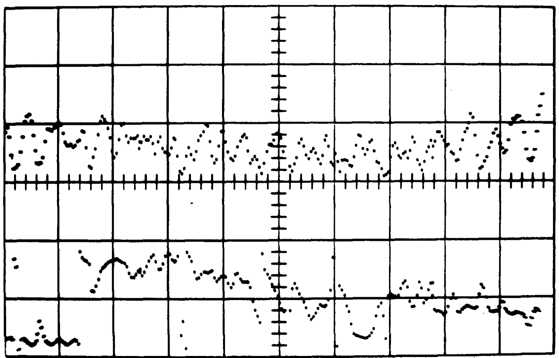
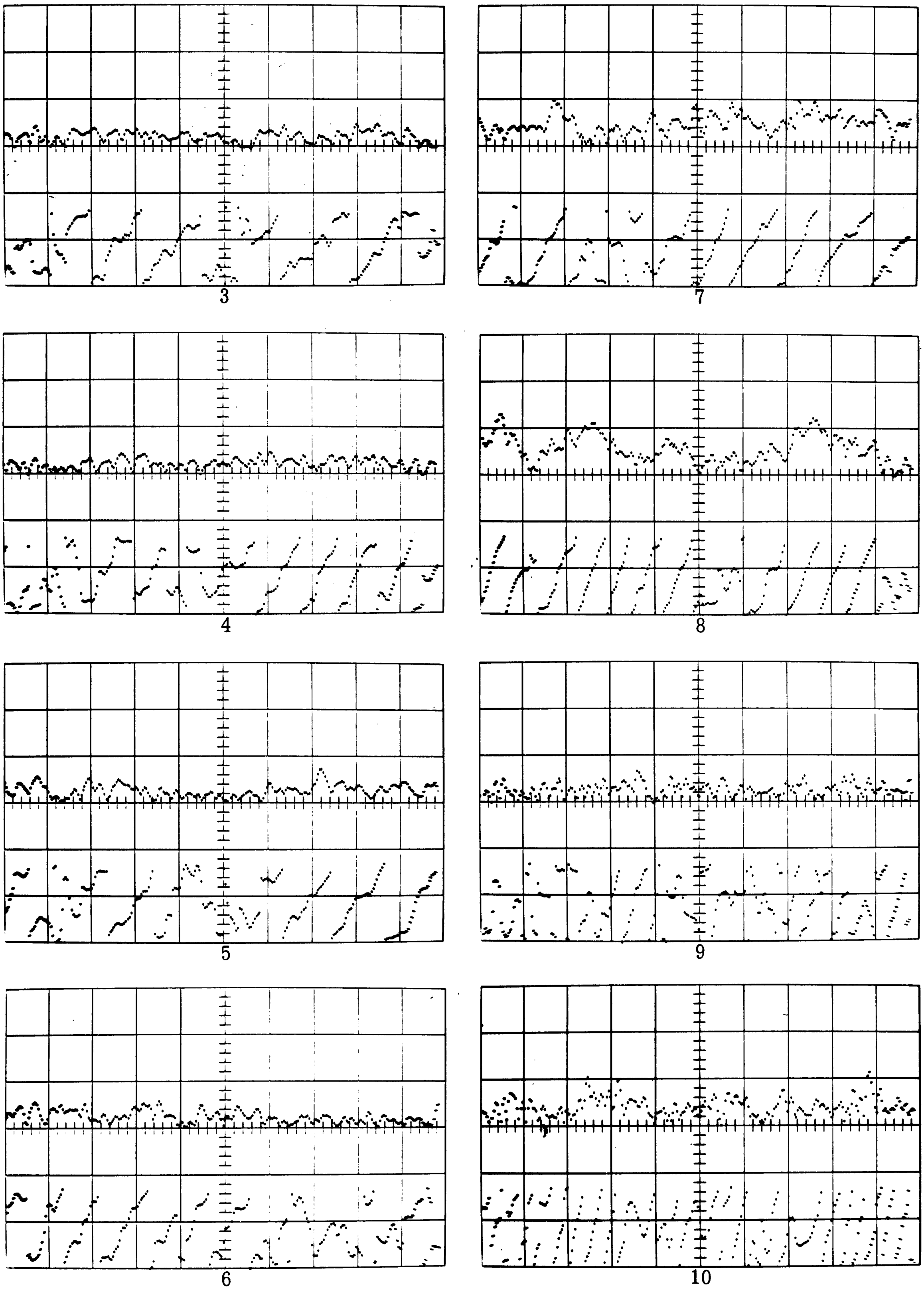


12

1748 - 1800 hours



0927 - 0939 hours

AMSEQ 12 August 1966

APPENDIX D

CORRELATION AND FOURIER TRANSFORMATION ON SIMULATED DATA

The signals BMSEQ and AMSEQ were simulated in the IBM 7090 at the University of Michigan Computing Center (C. C.). The signals were correlated with the stored version of BMSEQ by means of the CEL subroutine MCOR1. Fourier transformation was applied to these AMSEQ and BMSEQ signals and to the MCOR1 results by means of the CEL program FAST using Tukey's method for Fast Fourier Series Analysis (Ref. 5).

The Cartesian results obtained from MCOR and from FAST were, by means of square root and arctangest routines, converted into the polar amplitude and phase values R and θ. These values were plotted by the Computing Center CALCOMP plotter; the correlation results as functions of the time displacement τ, and the Fourier analysis results as functions of the frequency f. The figures on the R-axis do not have any absolute value but enable a comparison of magnitudes.

The explanation and description of the features in these results are given in Section 4.

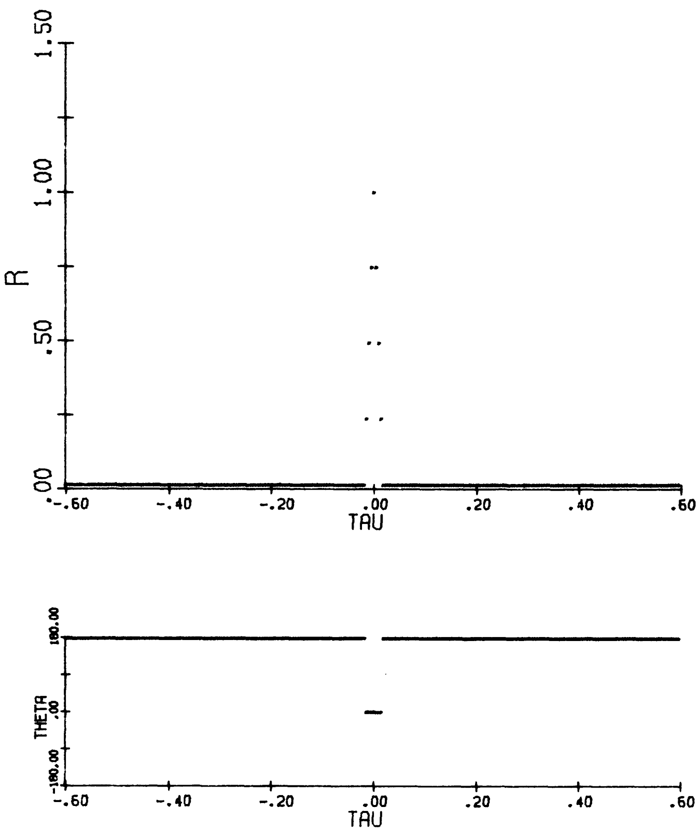


Fig. D.1. BMSEQ
autocorrelation function

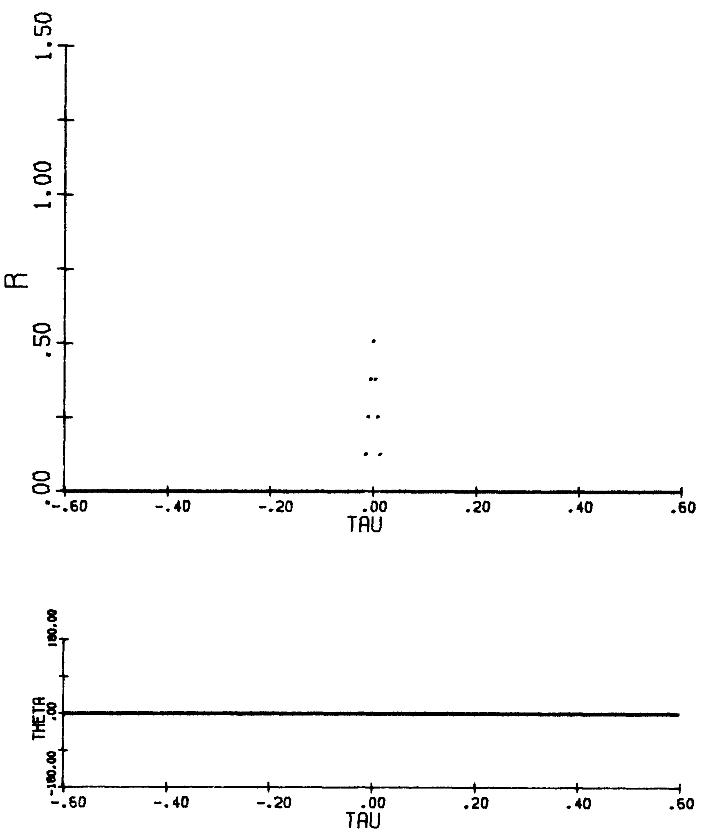


Fig. D.2. AMSEQ - BMSEQ
cross-correlation function

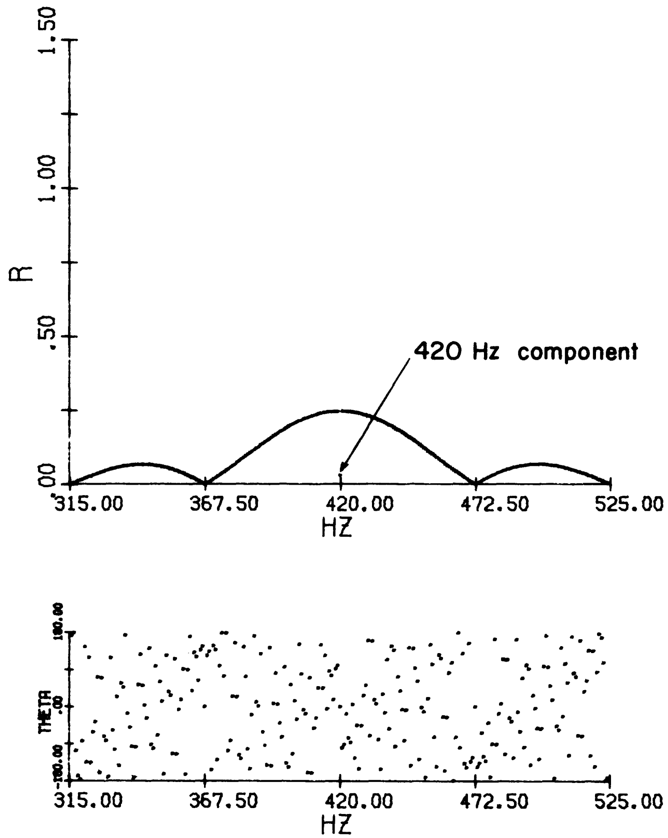


Fig. D.3. BMSEQ spectrum
(Fourier series)

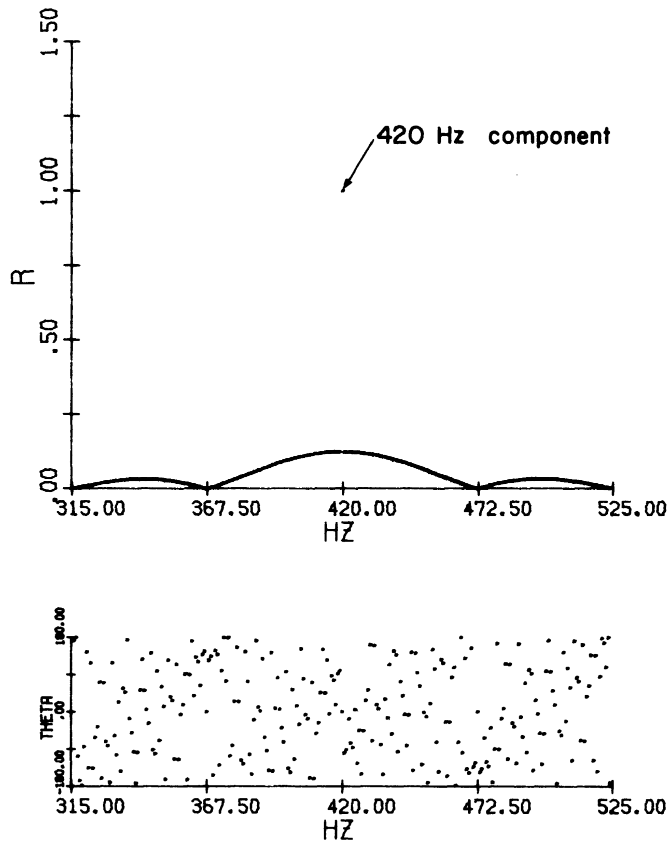


Fig. D.4. AMSEQ spectrum
(Fourier series)

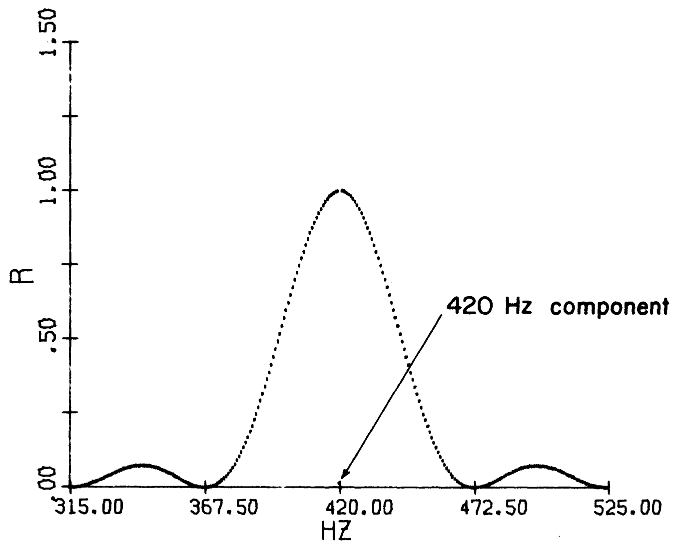


Fig. D. 5. BMSEQ
power spectrum

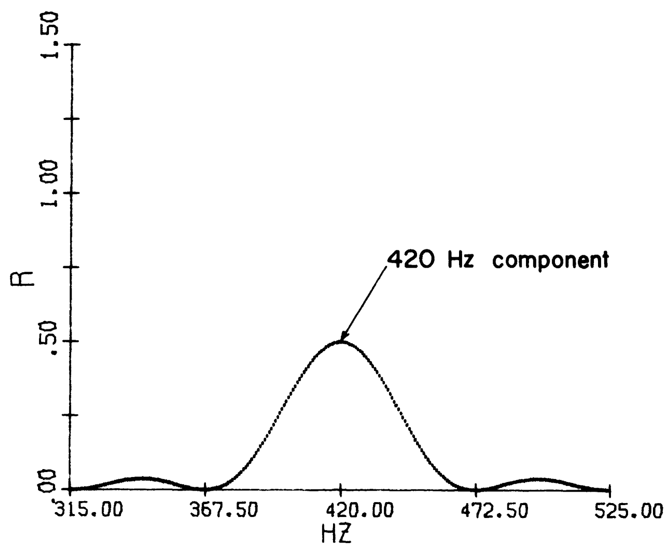


Fig. D. 6. AMSEQ - BMSEQ
cross spectrum

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4. S. W. Colomb, L. D. Baumert, M. F. Easterling, J. J. Stifler, A. J. Viterbi, Digital Communications, Prentice-Hall, New Jersey 1964.

5. J. W. Cooley and J. W. Tukey, "An Algorithm for the Machine Calculation of Fourier Series," Math. Comput., Vol. 19, April 1965, pp. 297-301.

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13. ABSTRACT
As a part of a study of underwater sound propagation in the Straits of Florida, called Project MIMI, 24-hour continuous and sampled receptions were taken on 11, 12, and 13 August 1966. The amplitude modulation of the 420-Hz carrier wave by a maximal pseudo-random sequence (AMSEQ) simultaneously yields information about the oceanic modulation of the carrier (continuous wave analysis), and the multipath sound propagation (sequence analysis). This report describes the experiment and the data processing and presents the results in photographic form as amplitude and phase versus time displays.

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