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THE NBS METEOR-BURST PROPAGATION PROJECT - A PROGRESS REPORT

BY

CHARLES E. HORNBACK, LOUIS D. BREYFOGLE, AND GEORGE R. SUGAR

U. S. DEPARTMENT OF COMMERCE
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March 31, 1960

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CONTENTS

PAGE

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ABSTRACT

This report briefly describes a meteor-burst propagation-study program at NBS-Boulder Laboratories and presents some of the preliminary analysis results. Observations have been made with scaled systems over three different paths (Long Branch - Table Mesa, Norman - Fargo, and Barrow - Kenai) at frequencies of 30, 50, and 74 Mc/s. The recorded data is processed by a combination of manual and automatic methods. The preliminary results show about a 10 db diurnal variation in threshold for a constant duty-cycle. Thresholds for a constant duty-cycle were observed to have an approximate frequency dependence relative to 30 Mc/s of 15 db lower for 50 Mc/s and 30 db lower for 74 Mc/s. There was no statistically-significant difference observed in the occurrence of meteor-bursts from a Poisson distribution.

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1. INTRODUCTION

The meteor-burst propagation project described in this report was conceived during the early part of 1956. At that time, it was planned to make an extensive study of meteors to determine their communications utility. The instrumentation required for this study was elaborate - as a consequence, data taking did not begin until September 1959.

The original plan for the experiment was tc make measurements, on a routine basis, of meteor-burst signal amplitudes over several oblique paths, at several frequencies in the VHF range. Automatic data recording and reduction techniques based on the use of medium size electronic digital computer (IBM 650) were planned in order to handle the large volume of data required to obtain statistically significant results. The field recordings were to be made in such a manner as to permit the later reproduction of the amplitude fluctuations of each burst signal. This method was chosen to allow very great flexibility in data analysis. The work has been proceeding along these lines, and this report is designed to bring the reader up to date on the operation of the project.

The first portion of the report will be devoted to the equipment aspect, the second part to the data analysis and preliminary results. It is assumed that the reader is familiar with the basic concepts of meteor-burst propagation and communication [1, 2, 3].

2. EXPERIMENTAL ARRANGEMENTS

2.1. Transmission Paths

Three basic transmission-reception paths (Long Branch - Table Mesa, Norman - Fargo, and Barrow - Kenai) were established as shown in Figure 1. The details of these paths are tabulated in Table 1.

The two paths in the central United States are arranged so that they cross near their midpoints. This arrangement was chosen to simplify studies of the effects of path orientation on the meteor-burst characteristics.

The Barrow - Kenai path was established to allow a comparison of meteor-burst activity in the arctic regions with the activity in the temperate regions. This path will be used primarily to determine those characteristics of meteor-burst propagation which are peculiar to the arctic region.

2.2. Field Station Equipment

One of the primary prerequisites to data comparisons between different paths is the maintaining of "scaled systems"; that is, systems as nearly identical as possible at all locations and on all frequencies of operation. Special attention has been given to system scaling in selecting and setting up the experimental paths.

The antennas used at all field sites are horizontally-polarized five-element Yagi antennas located 2.4 wavelengths above the ground and tilted along their boom axes at an angle of 40 degrees relative to the ground. The 40 degree tilt angle suppresses the ground-reflected component and thus provides a more uniform radiation pattern than would be possible with a horizontal Yagi antenna. Figure 2 shows a comparison of the patterns of the tilted and horizontal antennas.

The transmitters at the Long Branch, Norman, and Barrow field sites are continuous-wave transmitters operated at 2 kilowatts output on each frequency (30, 50, and 74 Mc/s). (Since December 2, 1959, the 74 Mc/s transmitter at Long Branch has been operated at 10 kilowatts output.) The system scaling is maintained by correcting the data for transmitter power output differences and transmission line losses.

The receiving sites at Table Mesa, Fargo, and Kenai all utilize similar equipment. The receivers used are special NBS-designed units which have a 300 cycle bandwidth and a logarithmic amplitude response characteristic. Daily calibrations are made on all receivers. All calibrations are referred to 1 microvolt open-circuit at the antenna terminals (50 ohm impedance).

Two general types of recording media are used at the receiving sites. The meteor-burst data recordings are taken on seven-channel punched paper tapes produced by a digital recorder [5]. Each recorder has three similar but independent channels. The data for each of the three operating frequencies are sampled, digitized in a binary form, and recorded on a separate punched tape. In addition, strip-chart recordings are made at each frequency in order to provide a graphic record of the overall system performance. In order to present a clearer indication of the scatter signal, the strip-chart recorders have a 12-second time constant in their input circuits.

Two modes of operation of the digital recorder are currently being used. The first, the so called "start-stop" mode, utilizes a threshold unit (external to the recorder) to supply the start-stop pulses to control the recorder. In this mode of operation, data is punched out only when the incoming signal exceeds a manually set threshold. Since meteor-burst signals exhibit considerable fading, the threshold unit includes circuitry to keep the recorder from stopping during brief signal fades. In order to more accurately reproduce the sharp leading edge of the burst signal, the first five samples are spaced close together in time. The remaining samples are more widely spaced, the sampling continuing as long as the signal is present. The first sample of a meteor-burst record is taken within 10 milliseconds of the start of a burst. The first sample and four additional samples make up the "fast" samples that are taken at the beginning of each signal burst. These samples may be taken at a rate of 200, 100, or 50 samples per second. The remaining samples are taken at a rate of 20, 10, or 5 samples per second. At the

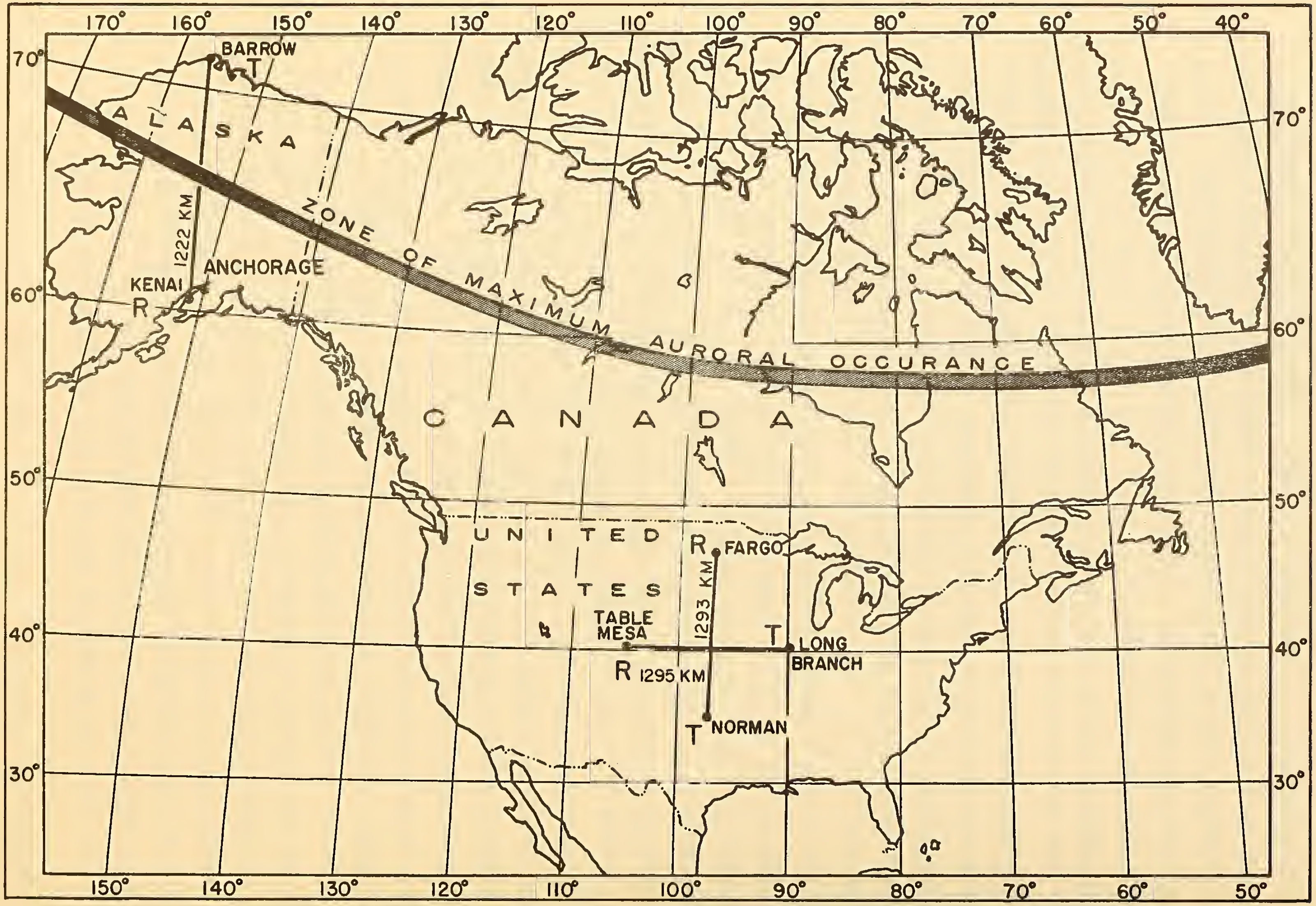

Figure 1 LOCATION OF TEST PATHS. "T" DENOTES A TRANSMITTING SITE, "R" DENOTES A RECEIVING SITE.

Table 1   DETAILS OF EXPERIMENTAL PATHS

	Table Mesa - Long Branch			Fargo - Norman			Kenai - Barrow		
Frequency, Mc/s	30.010	49.640	73.880	30.015	49.560	73.800	30.000	49.605	73.800
Date of Commencement	26 September, 1959	25 September, 1959	27 September, 1959	11 November, 1959	12 November, 1959	11 November, 1959	1 November, 1959	17 October, 1959	16 January, 1960
Date of Termination	Continues in operation	Continues in operation	Continues in operation	30 June, 1960	30 June, 1960	30 June, 1960	30 June, 1960	30 June, 1960	30 June, 1960
Transmitter location coordinates of site	Long Branch, Illinois 40°13' N; 90°01'W	← Same —	← Same —	Norman, Oklahoma 35°18'N; 97°30'W	← Same —	← Same —	Barrow, Alaska 71°18'N; 156°45'W	← Same —	← Same —
Receiver location coordinates of site	Table Mesa, Colorado 40°08'N; 105°15'W	← Same —	← Same —	Fargo, North Dakota 46°56'N; 96°52'W	← Same —	← Same —	Kenai, Alaska 60°34'N; 151°15'W	← Same —	← Same —
Surface path length (great circle)	1295 Km 805 St. Miles	← Same —	← Same —	1293 Km 804 St. Miles	← Same —	← Same —	1222 Km 759 St. Miles	← Same —	← Same —
Geographic coordinates of path midpoint	40°26'N; 97°38'W	← Same —	← Same —	41°07'N; 97°13'W	← Same —	← Same —	65°57'N; 153°25'W	← Same —	← Same —
True azimuth of receiver from transmitter	274° 30'	← Same —	← Same —	2° 10'	← Same —	← Same —	165° 39'	← Same —	← Same —
True azimuth of transmitter from receiver	84°38'	← Same —	← Same —	182° 35'	← Same —	← Same —	350° 42'	← Same —	← Same —
True azimuth of receiver from path midpoint	269° 34'	← Same —	← Same —	2° 21'	← Same —	← Same —	191° 15'	← Same —	← Same —
Geomagnetic inclination of path midpoint	70° 06'N	← Same —	← Same —	70° 06'N	← Same —	← Same —	77° 00'N	← Same —	← Same —
Type of antennas[1]	5 Element Yagi Antennas tilted 40° with respect to ground, located 2.4 λ high.								
Antenna Height in Feet	78.7	47.6	32	78.7	47.6	32	78.7	47.6	32
CW Transmitter power output	2 Kw	← Same —	10 Kw from 2 December, 1959 to 8 May, 1960 2Kw otherwise	2 Kw	← Same —	← Same —	← Same —	← Same —	← Same —
System loss[2]	176 db relative to 1 microvolt open circuit, referred to 50 Ohms. Reference transmitter power is 2 Kilowatts.								

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[1] See Figure 2.

[2] System Loss is defined as the ratio of the r.f. power input to terminals of transmitting antenna to the available power at the terminals of the receiving antenna [4].

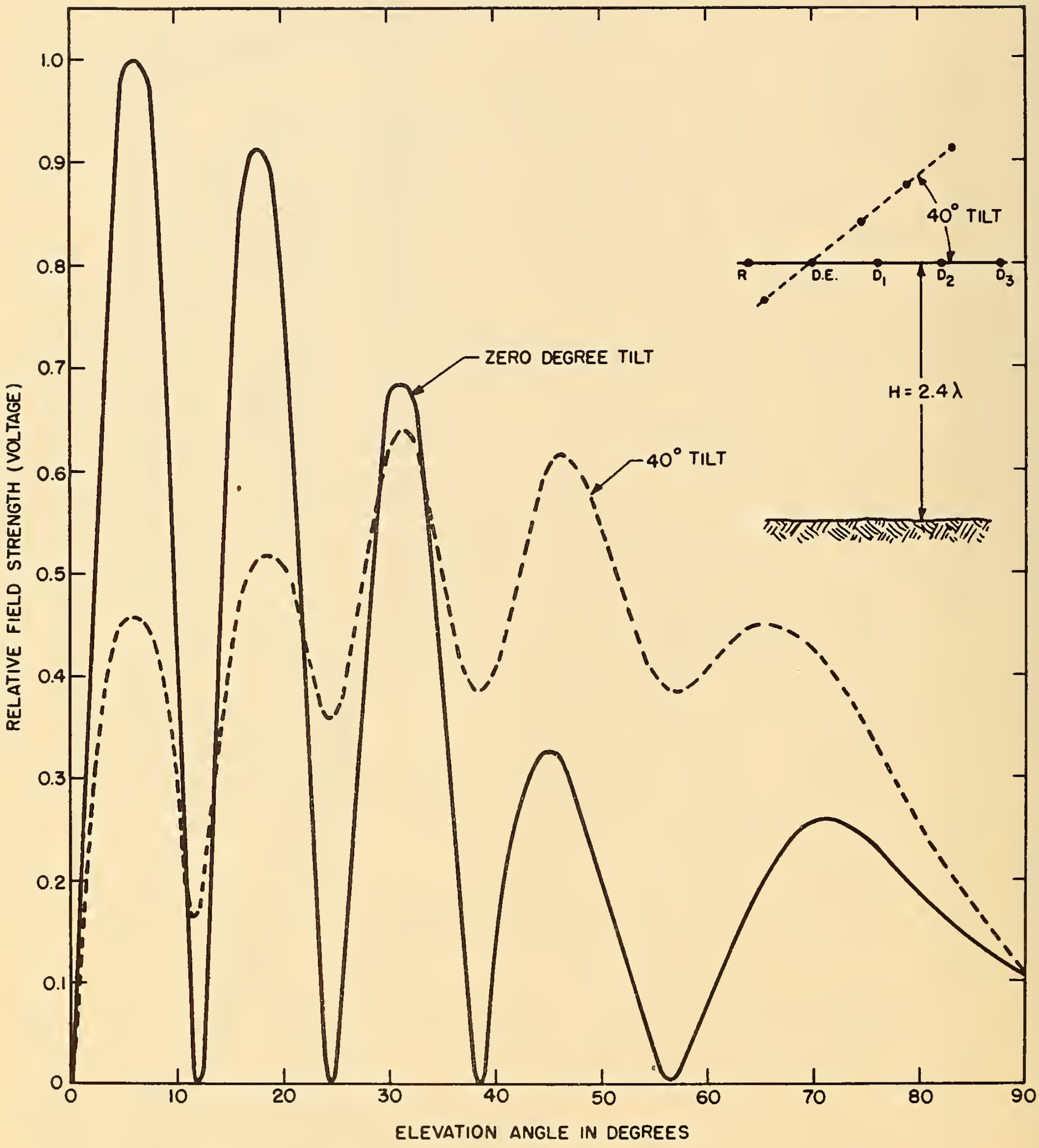


Figure 2 CALCULATED PATTERNS IN VERTICAL PLANE OF HORIZONTALLY POLARIZED 5 ELEMENT YAGI ANTENNAS WITH AXES TILTED 0° AND 40° (OVER A PERFECTLY CONDUCTING PLANE)

end of each burst record, the recorder records the time, and stops to wait for the next burst.

The second mode of operation is the "continuous sampling" mode. No threshold is used; the recorder runs continuously, recording the signal variations which are fed to it from the receivers. Continuous sampling is performed at rates of 20, 10, or 5 samples per second.

The receiving and recording equipment is calibrated daily with a standard c-w signal generator connected at the receiver input terminals. A calibration tape is punched out by the recorder as the calibrations are made. In addition, a separate "internal test" is made daily to determine the overall condition of the digital recorder.

The digital recorder is currently being operated for a period of 16 minutes of each hour. The strip-chart records are being taken for a full 24 hours per day.

3. DATA CONTROL

The flow of data from the field stations through the various stages of processing is represented by the diagram shown in Figure 3. The effective control of the data processing has required a large amount of detailed record keeping. Considerable time has been spent from October 1959, to present, in developing the processes for data control.

3.1. Logging of Records

Records received daily from the three receiving stations are:

1. station log-sheets,
2. calibration tapes,
3. recorder test tapes,
4. data tapes, and
5. strip charts.

Transmitting stations send in their station log-sheets. Norman and Barrow also send strip charts showing a continuous record of the power transmitted.

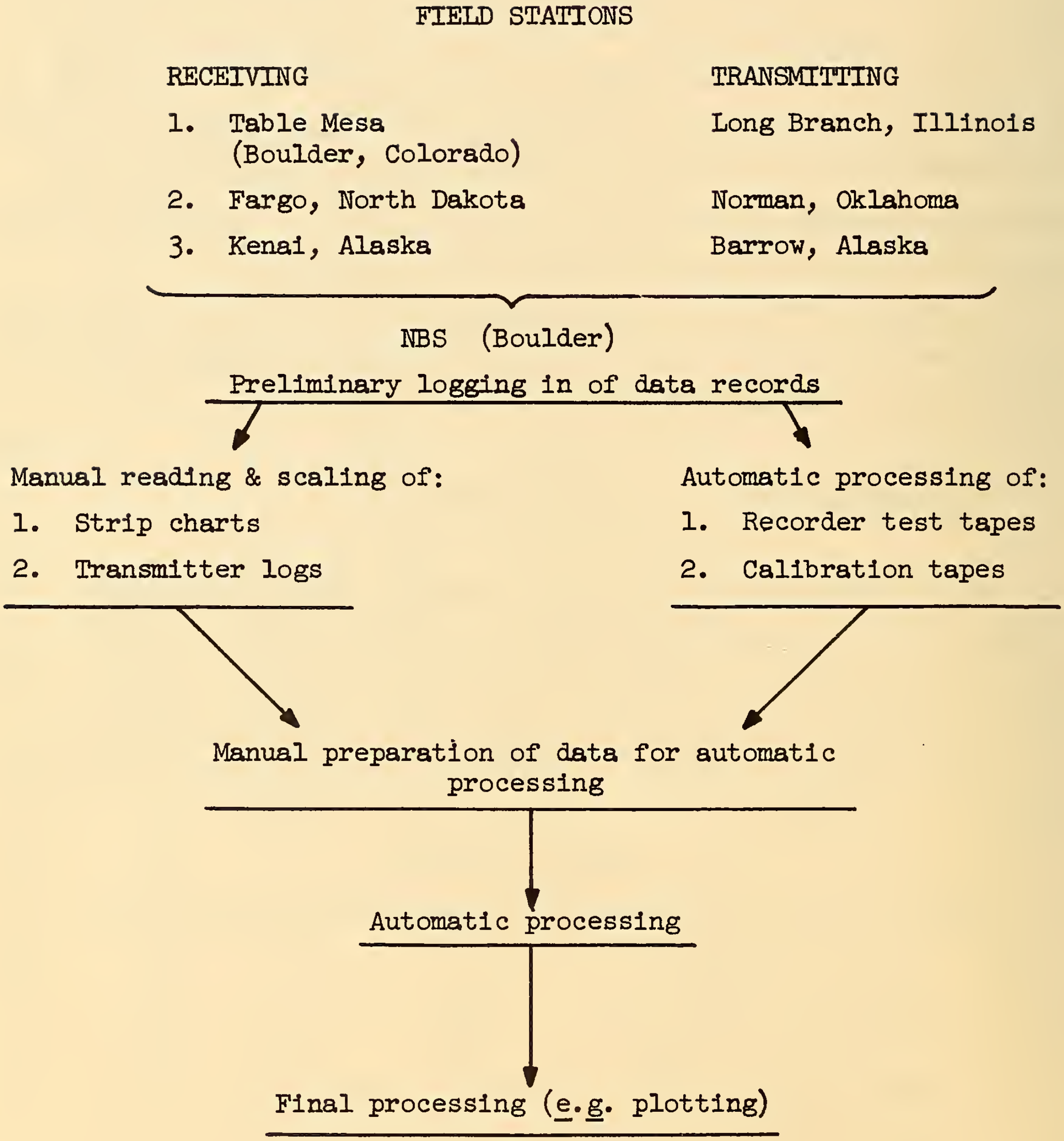


Figure 3 SEQUENCE OF METEOR-BURST DATA PROCESSING

3.2. Recorder Test and Calibration Tapes

The test and calibration tapes are processed as soon as they are received. Errors in each test tape are identified and a tape-condition report is sent to the field station. The calibration tape processing produces calibration cards (Hollerith cards) which relate recorder scale values to signal levels at 5 db intervals from -40 to +40 db.

3.3. Strip Charts

There is a strip chart made for each signal frequency recorded at each station. These charts are records of the same receiver signal which goes into the digital recorder and are used to provide a visual indication of the character of the received signal. Each chart is scaled for noise level and scatter signal level. A record is kept for all unusual (e. g. sporadic E) and unusable (e. g. transmitter off) signal data. This information is used to help determine which data tapes should be processed and how they should be edited. In essence, the strip charts are the main source of information used in the quality control of the data.

3.4. Systems Corrections

All the data are normalized relative to a 1 microvolt (open circuit) signal at the receiving antenna terminals and a power of 2 kw delivered to the transmitting antenna terminals, by correcting for transmission line losses and for the transmitter power output variations. The line losses for the field stations have been measured to within 0.1 db except at Barrow and Norman where line loss estimates have been made knowing the lengths and types of line involved. The transmitter power output variations are determined from the transmitter logs to within 0.1 db and are combined with the line losses to give a total correction which is rounded to the nearest decibel. This total correction is then used to normalize the observed signal strength values.

3.5. Preparation of Data for Automatic Processing

The preparation of data tapes for machine processing requires that all of the information from the station log-sheets, the test tapes, and the strip charts be assembled, that the tapes be edited, and that processing control cards (power corrections, identification, etc.) be prepared. The data tapes are then processed in the computer. The results, on punched cards, are further processed either by additional automatic computation, by plotting, or by some form of manual processing of the card listing.

3.6. Data Summary

A summary of the data which have been taken by the field stations from September 1959 to March 1960 is shown in Table 2. Note that the symbol F (used in Table 2) for faulty data does not always mean that useful information cannot be obtained from the tape records, but rather, that more than the ordinary processing procedures are required to obtain the information.

4. DATA INTERPRETATION

Several questions arise in attempting to reduce the recorded data to meaningful numbers which describe meteor-burst characteristics. The two principle questions are:

1. Which of the measurable characteristics are most useful for determining the communication capability of meteor-burst signals?
2. How should the values of these characteristics be presented?

Some approaches to answering these questions are discussed below.

4.1. The Nature of the Received Signals

There are at least five kinds of signals which are observed:

1. galactic noise,
2. D-scatter,
3. meteor-burst signals,
4. enhanced signals such as Es, and
5. interference.

Figure 4 shows a sample of a strip-chart taken at Table Mesa at 30 Mc/s using a 12-second recorder time-constant. This is a record of the received signal strength from 0600 to 0645 and from 0940 to 1100 on

Table 2 METEOR-BURST DATA SUMMARY

Date		Table Mesa			Fargo			Kenai		
From	To	30Mc	50Mc	74Mc	30Mc	50Mc	74Mc	30Mc	50Mc	74Mc
1959	1959									
9/25	10/8	F	F	F	None	None	None	None	None	None
10/8	10/17	F	F	F	F	F	F	None	None	None
10/17	10/23	F	F	F	F	F	F	None	F	None
10/23	10/24	MTM & HUMP	MTM & HUMP	MTM & HUMP	F	F	F	None	F	None
10/24	10/25	F	F	F	F	F	F	None	F	None
10/25	10/30	F	F	F	F	F	F	None	F	None
10/31	11/1	D & A	D & A	D & A	F	F	F	F	F	None
11/1	11/2	D & A	HUMP & D & A	D & A	F	F	F	F	F	None
11/2	11/8	D & A	D & A	D & A	F	F	F	F	F	None
11/8	11/10	T	T	T	F	F	F	F	F	None
11/11	11/16	T	T	T	F	F	F	F	F	None
11/17	11/19	BL	BL	BL	F	F	F	F	F	None
11/20	11/26	BL	BL	BL	F	F	F	D & A	D & A	None
11/26	11/27	BL	HUMP	BL	F	F	F	D & A	HUMP & D&A	None
11/27	11/30	BL	BL	BL	D & A	D & A	D & A	D & A	D & A	None
11/30	12/1	BL	BL	BL	D & A	D & A	D & A	BL	BL	None
12/1	12/2	BL	BL	BL	I & A	D & A	D & A	BL	BL	None
12/2	12/4	D & A	MTM	None	D & A	D & A	D & A	BL	BL	None
12/4	12/5	D & A	MTM	None	BL	BL	BL	BL	BL	None
12/5	12/14	D & A	MTM	None	BL	BL	BL	BL	BL	None
12/14	12/15	D & A	D & A	D & A	BL	BL	BL	BL	BL	None
12/15	12/16	D & A	D & A	D & A	BL	BL	BL	BL	BL	None
12/16	12/19	D & A	D & A	D & A	BL	T	F	BL	BL	None
12/19	12/30	D & A	D & A	D & A	F	F	F	BL	BL	None
12/30	12/31	D & A	D & A	D & A	F	F	F	BL	BL	None
1960	1960									
1/1	1/31	BL	BL	BL	BL	F	F	BL	T	None
2/1	2/7	BL	BL	BL	BL	F	F	BL	T	T
2/7	2/9	BL	BL	BL	BL	F	F	BL	T	BL
2/9	2/14	D & A	D & A	D & A	BL	F	F	BL	T	BL
2/14	2/17	D & A	D & A	D & A	BL	D & A	F	BL	T	BL
2/17	2/24	BL	BL	BL	BL	BL	F	BL	T	BL
2/24	3/2	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A
3/2	3/9	BL	BL	BL	BL	BL	BL	BL	BL	BL
3/9	3/16	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A
3/16	3/23	BL	BL	BL	BL	BL	BL	BL	BL	BL
3/23	3/30	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A	D & A

Legend: F = Faulty data due to receiver malfunction or interfering signals.
T = Faulty data due to transmitter malfunction.
BL = Backlog of data (probably about 60% usable).
MTM, HUMP, and D & A = Analysis programs; see the appendix.

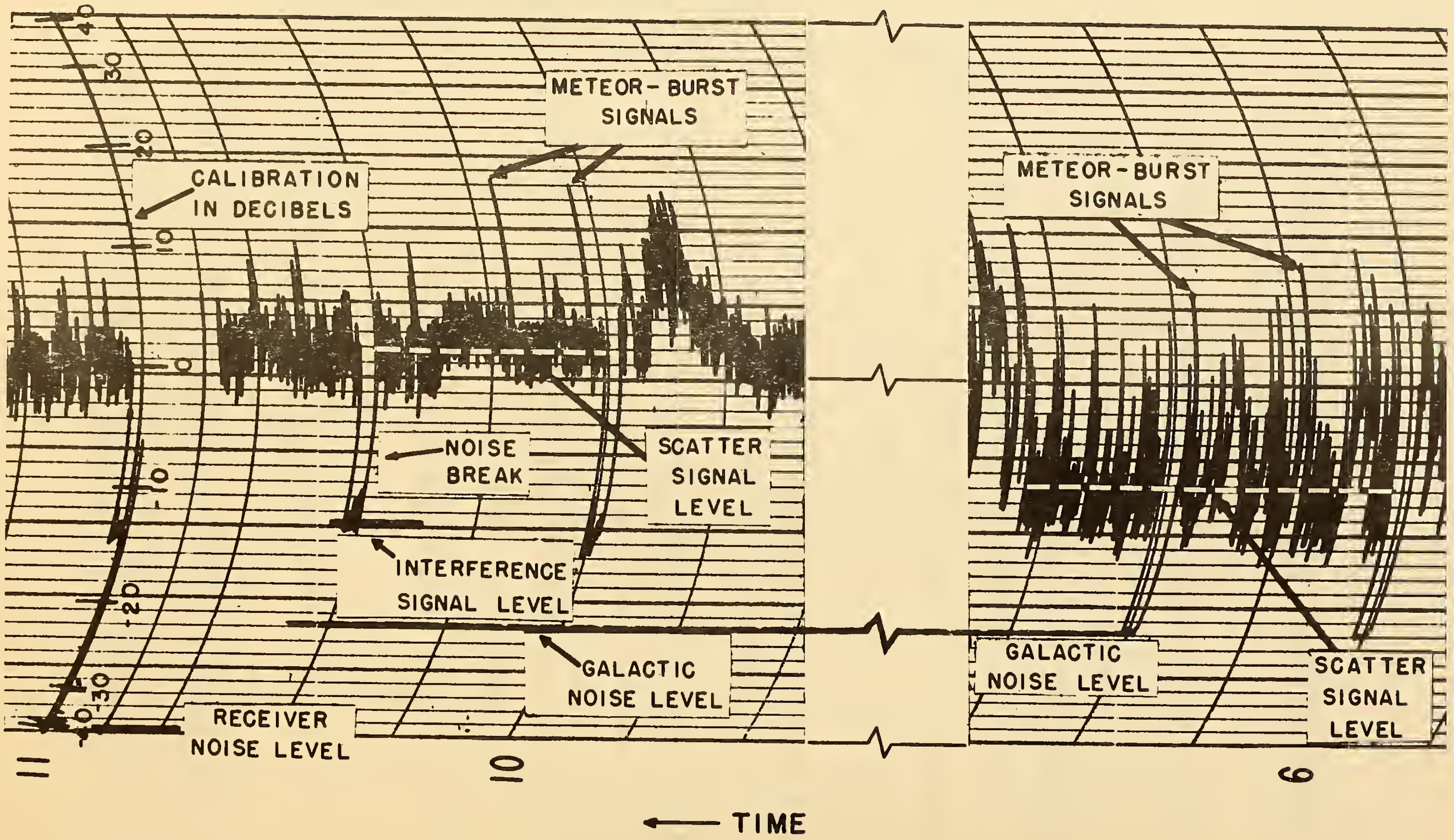


Figure 4 SAMPLE STRIP-CHART RECORD

October 28, 1959. The two-minute "noise breaks" at each hour and half hour show the levels of galactic noise (at 0600 and 0630) or an interfering signal (at 1000 and 1030) if present. In this example, the scatter-signal level is 10 to 20 db above the galactic-noise level. The relatively large meteor-burst signals appear as the spikes which show above the scatter level. The interference-signal level is about 10 db above the galactic-noise level. (In this case, the interference is not strong enough to affect the desired data.) Other kinds of signals appear on the strip-charts, such as sporadic-E signals which appear as a very high continuous signal level or aurorally reflected signals which often appear as a thin trace on the chart. Examples of these signal records are not shown in this report but are similar to those shown in Figures 24 and 32 of Bailey _et al_. [6].

Since various modes of propagation are observed, one problem is to decide where to set the system threshold in order to observe relatively pure meteor-burst signals. The criterion for establishing the observing threshold level has been obtained by studying the probability distribution of the received signal strengths. Figure 5 shows an example of a Rayleigh plot made for Table Mesa data taken on October 31, 1959 at 1200 hours. The plot shows the cumulative distribution of signal strength for each of the three observing frequencies. Scatter signals are known to have a Rayleigh distribution [7]. In Figure 5 these would be represented by a straight line with a slope of -1. The straight lines in Figure 5 labelled 30, 50, and 74 Mc/s represent Rayleigh distributed signals having the same median values as the observed signals. If there were no meteor-burst signals, the curves of Figure 5 would represent the scatter only and would follow the straight lines in the upper direction and bend away from the straight line in the lower direction, as the example curves do because of noise contamination. The fact that the actual curves bend away from the straight line in the upper direction is attributed to the presence of meteor-burst signals since meteor-burst signals are not Rayleigh distributed.

This difference in distribution provides the method for selecting meteor-burst signals for analysis. The duty cycle of a Rayleigh distributed signal is 0.1% at 10 db above its median (0.01% at 11 db above the median). Therefore, if the observing threshold for meteor-burst signals is set 10 db above the signal median there will be very little contamination of the burst data by scatter signals. Hence, in the example of Figure 5, the threshold levels for observing meteor signals at 30, 50, and 74 Mc/s should be 5 + 10 = 15 db, -17.5 + 10 = -7.5 db, and -26.5 + 10 = -16.5 db respectively.

The diurnal variation in the median signal is illustrated in Figure 6 which shows the weekly medians of the hourly-median signal levels for some Fargo data. (These should not be interpreted as representing scatter propagation since there is substantial noise and meteor-burst contamination of some of the values.) There appears to be more diurnal variation in the median signals for Fargo than for either Table Mesa or Kenai.

Thresholds used for the start-stop mode of operation on 50 and 74 Mc/s are set to be 10 db above the highest scatter-signal levels. (The 74 Mc/s signal medians are primarily noise.) Similarly chosen thresholds are used when analysing the continuous mode data. By using these fixed thresholds, results such as the long-term variation of meteor rates can most readily be obtained. At 30 Mc/s, the presence of relatively strong signals having a non-meteoric propagation mode has interfered with the normal operation of the recording system in the start-stop mode. As a result, only continuous-mode data is taken at 30 Mc/s and a floating threshold is used by the analysis program.

4.2. Duty Cycle

Duty cycle is the percentage of time that the observed signal strength is greater than a given signal level. To a first approximation, the duty cycle is a measure of the time available for communicating by means of meteor-burst propagation, and is therefore, a useful parameter to obtain. The actual useful time is, of course, dependent

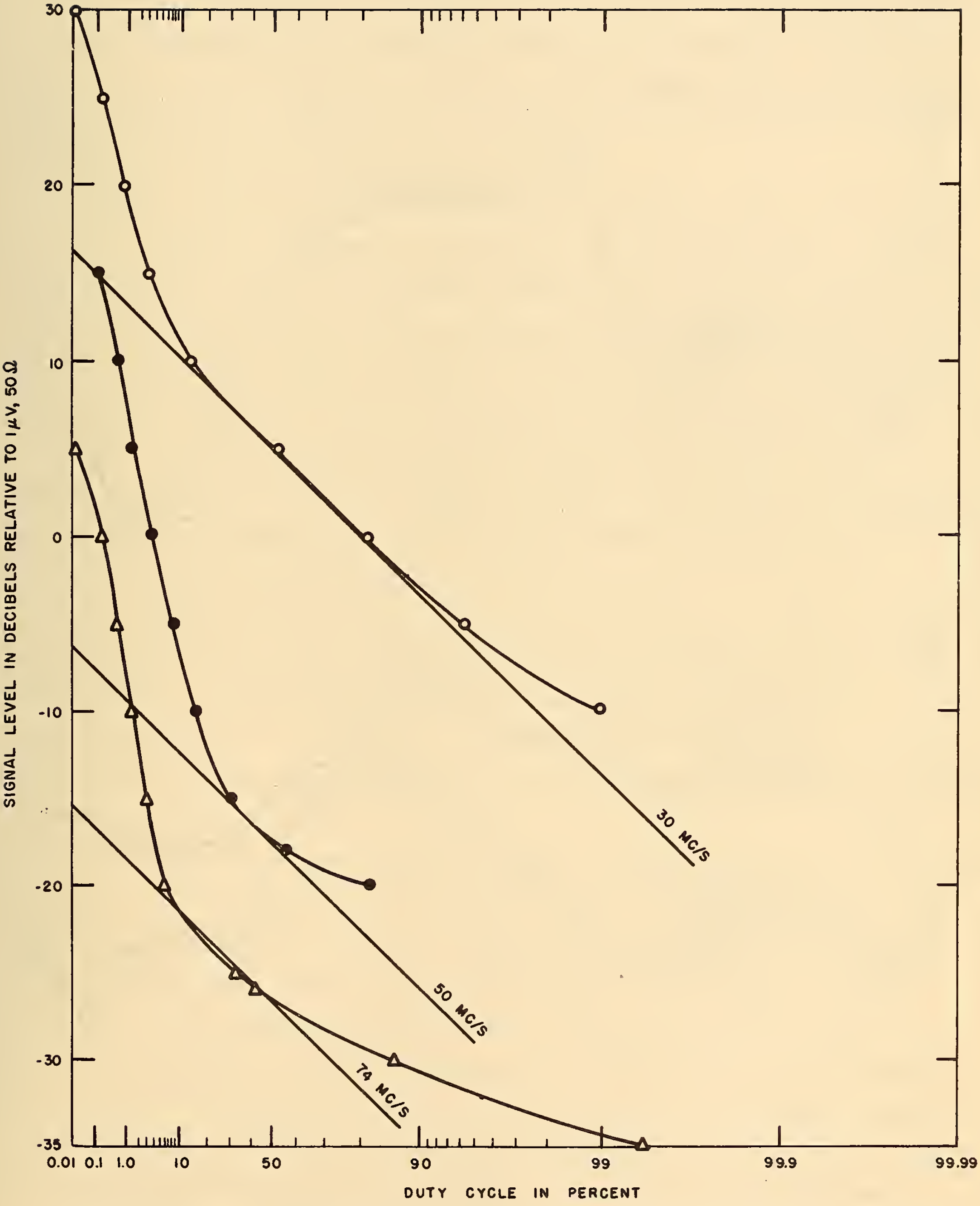


Figure 5 RAYLEIGH PLOT OF SIGNAL LEVEL VERSUS DUTY CYCLE

Figure 6 MEDIANS OF THE HOURLY-MEDIAN SIGNAL LEVELS, FARGO, NOVEMBER 27 THROUGH DECEMBER 4, 1959

on equipment parameters as well as propagation characteristics.

Figure 7 through 11 illustrate the variations in the weekly medians of duty cycle observed for various levels and frequencies. Figure 8 shows the diurnal variation quite well with a maximum near 0600 hours and a minimum near 1800 hours. The times of maxima and minima generally agree with previous observations [3].

Several features should be pointed out in these duty-cycle curves.

1. Figures 7 through 9 are for one set of data taken at Table Mesa. Each plot is for a different frequency, and the differences between duty cycles at the various frequencies are apparent. These data indicate that at a given duty cycle the signal level is 15 db lower at 74 Mc/s than at 50 Mc/s and 15 db higher at 30 Mc/s than at 50 Mc/s.

2. Figure 7 shows the effect of high mid-day scatter signals on the 30 Mc/s duty cycles. The duty cycle data for 5, 10, and 15 db signal levels are missing here since the high scatter levels have obscured the meteor-burst observations.

3. Figure 10 shows the duty cycles observed on 50 Mc/s at Fargo. If these data are compared with the corresponding data from Table Mesa (Figure 8), it is apparent that there are distinct differences in their diurnal variations. The extent to which these differences are associated with path orientation is not known since the two sets of data were taken at different times.

4. Figure 11 shows the duty cycles observed on 50 Mc/s at Kenai. The most interesting feature of these data is the absence of the pronounced morning maximum which is apparent in the Fargo and Table Mesa data. Further data should demonstrate whether this kind of diurnal variation is a permanent characteristic of the Barrow-Kenai path.

5. It can be seen from Figures 7 through 11 that rather large hour-to-hour variations in duty cycle are present. Other data indicate a variation in duty cycle, at a given hour of the day corresponding to about a 10 db range of threshold levels. Figure 12 is a mass plot illustrating the spread of hourly values.

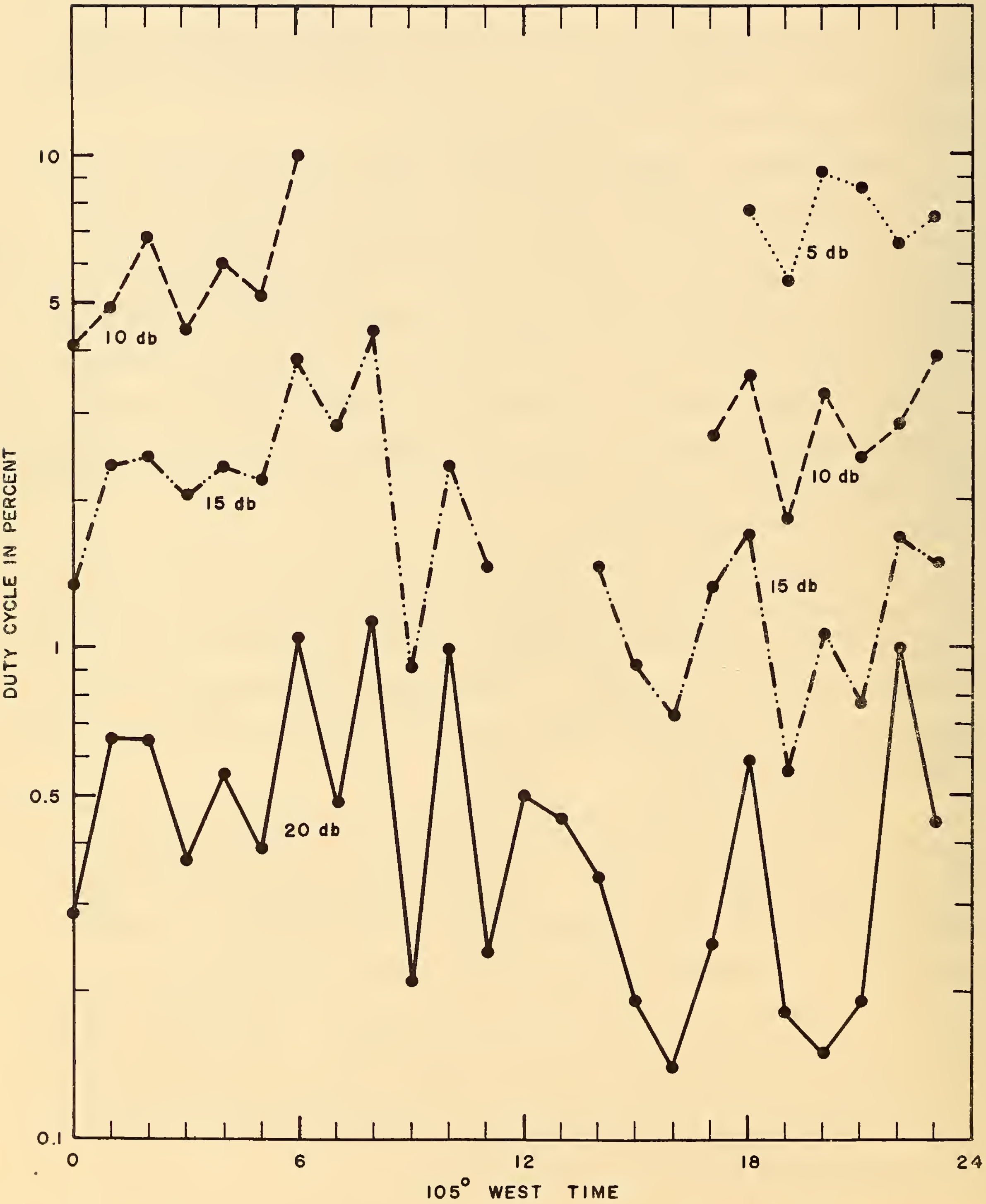


Figure 7 MEDIANS OF THE HOURLY DUTY-CYCLE VALUES FOR INDICATED THRESHOLDS RELATIVE TO 1 MICROVOLT (50 OHMS), TABLE MESA, OCTOBER 31 THROUGH NOVEMBER 8, 1959, 30 MC/S.

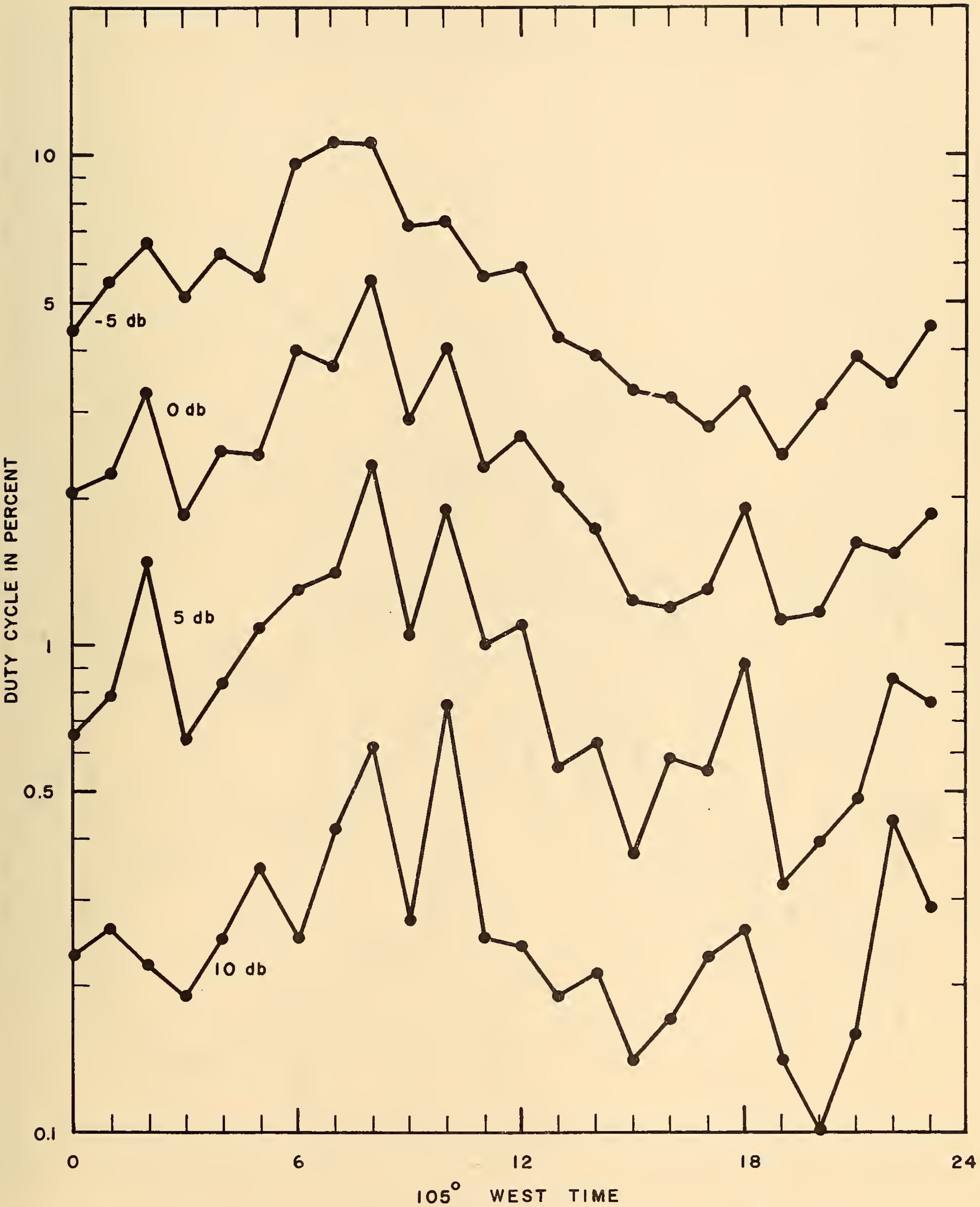


Figure 8 MEDIANS OF THE HOURLY DUTY-CYCLE VALUES FOR INDICATED THRESHOLDS RELATIVE TO 1 MICROVOLT (50 OHMS), TABLE MESA, OCTOBER 31 THROUGH NOVEMBER 8, 1959, 50 MC/S.

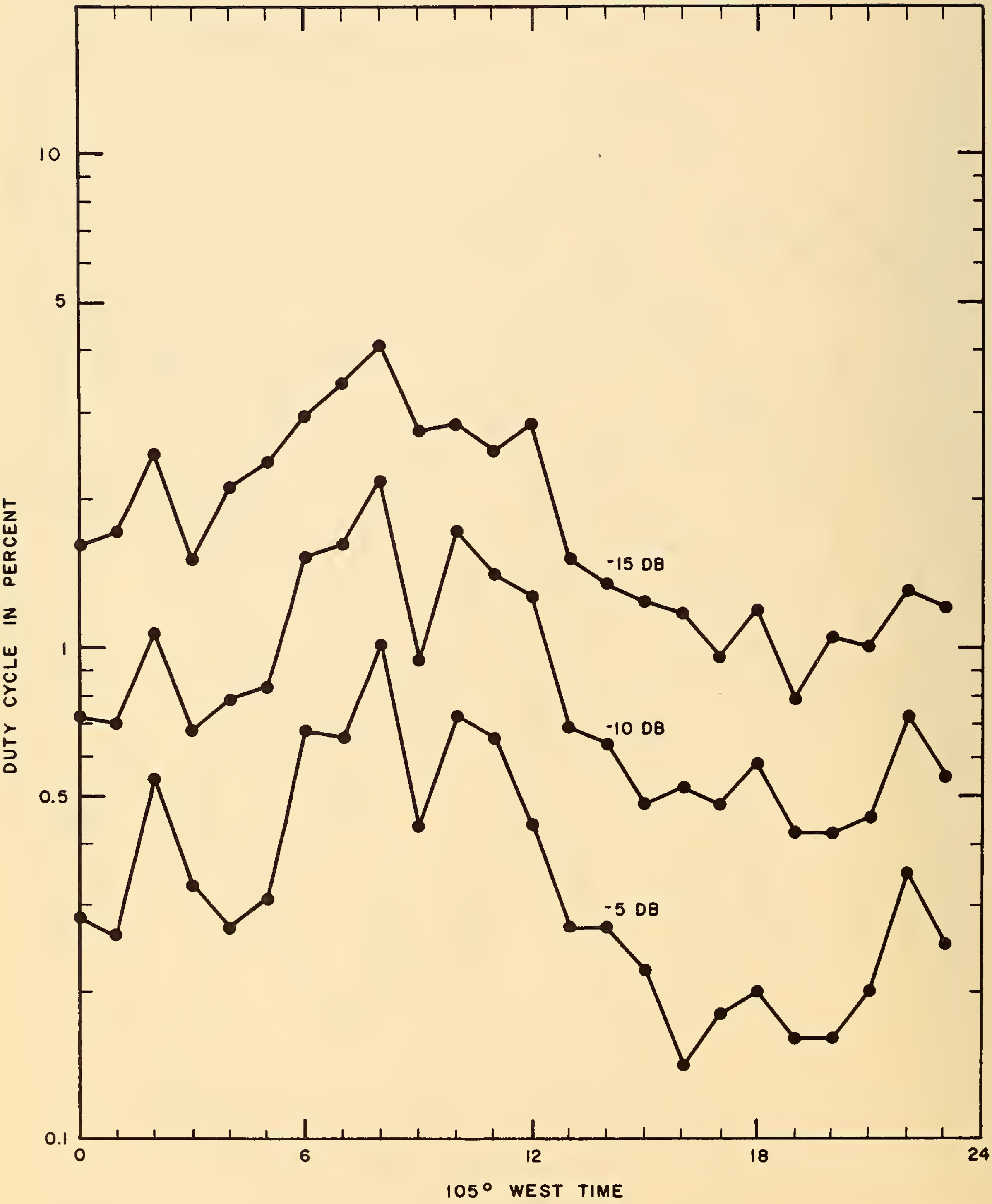


Figure 9 MEDIANS OF THE HOURLY DUTY-CYCLE VALUES FOR INDICATED THRESHOLDS RELATIVE TO 1 MICROVOLT (50 OHMS), TABLE MESA, OCTOBER 31 THROUGH NOVEMBER 8, 1959, 74 MC/S.

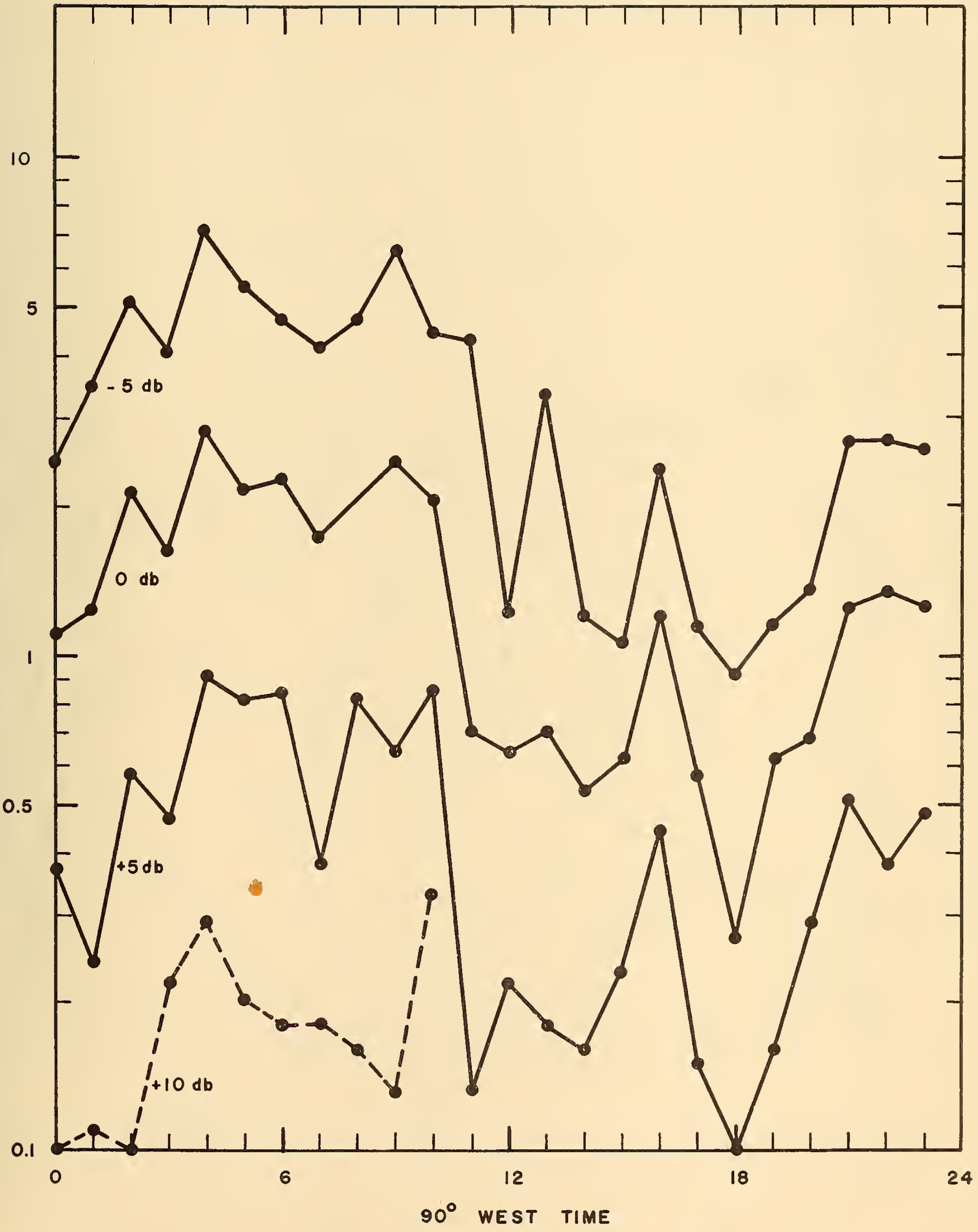


Figure 10 MEDIANS OF THE HOURLY DUTY-CYCLE VALUES FOR INDICATED THRESHOLDS RELATIVE TO 1 MICROVOLT (50 OHMS), FARGO, NOVEMBER 27 THROUGH DECEMBER 4, 1959, 50 MC/S.

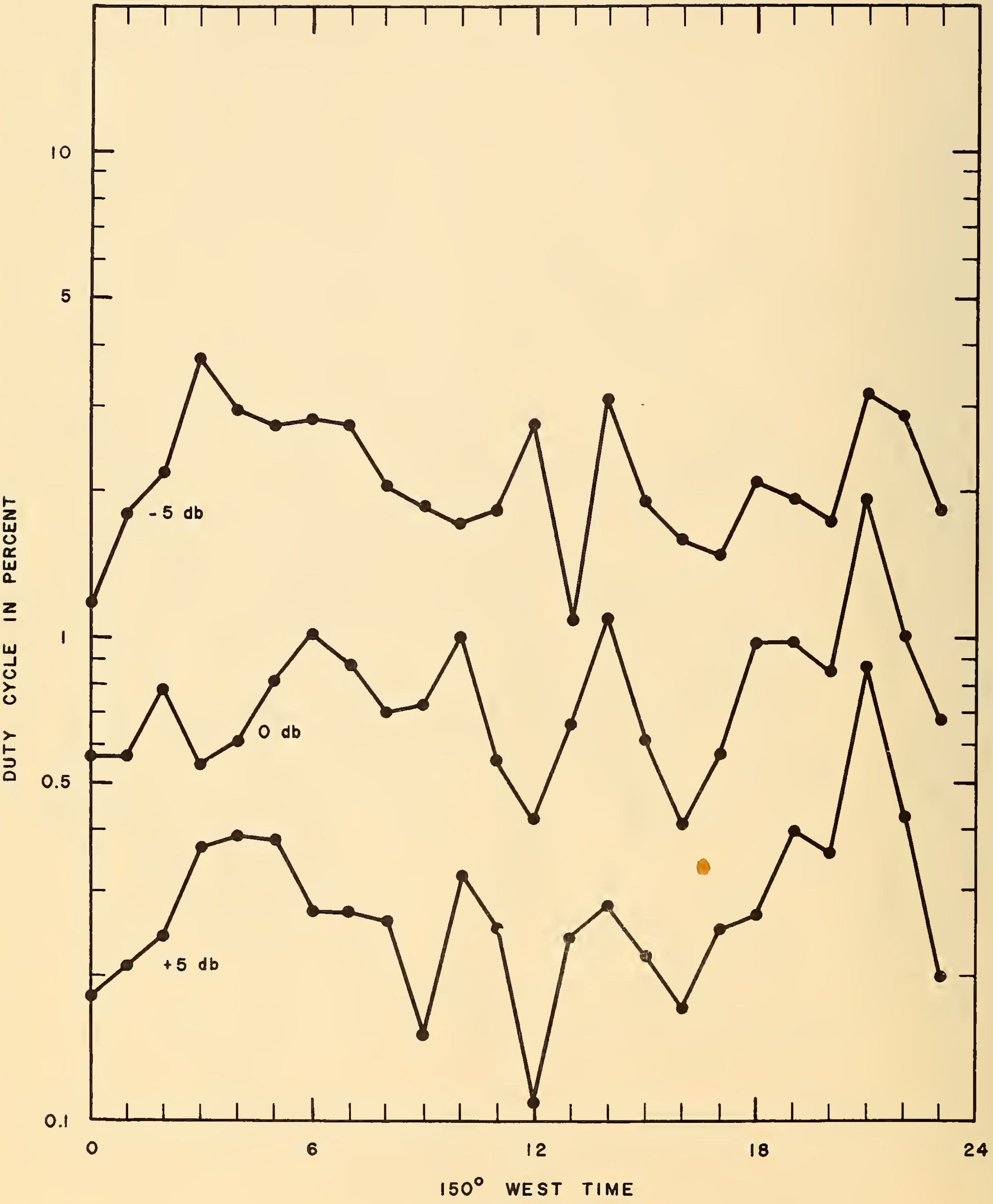


Figure 11 MEDIANS OF THE HOURLY DUTY-CYCLE VALUES FOR INDICATED THRESHOLDS RELATIVE TO 1 MICROVOLT (50 OHMS), KENAI, NOVEMBER 23 THROUGH DECEMBER 1, 1959, 50 MC/S.

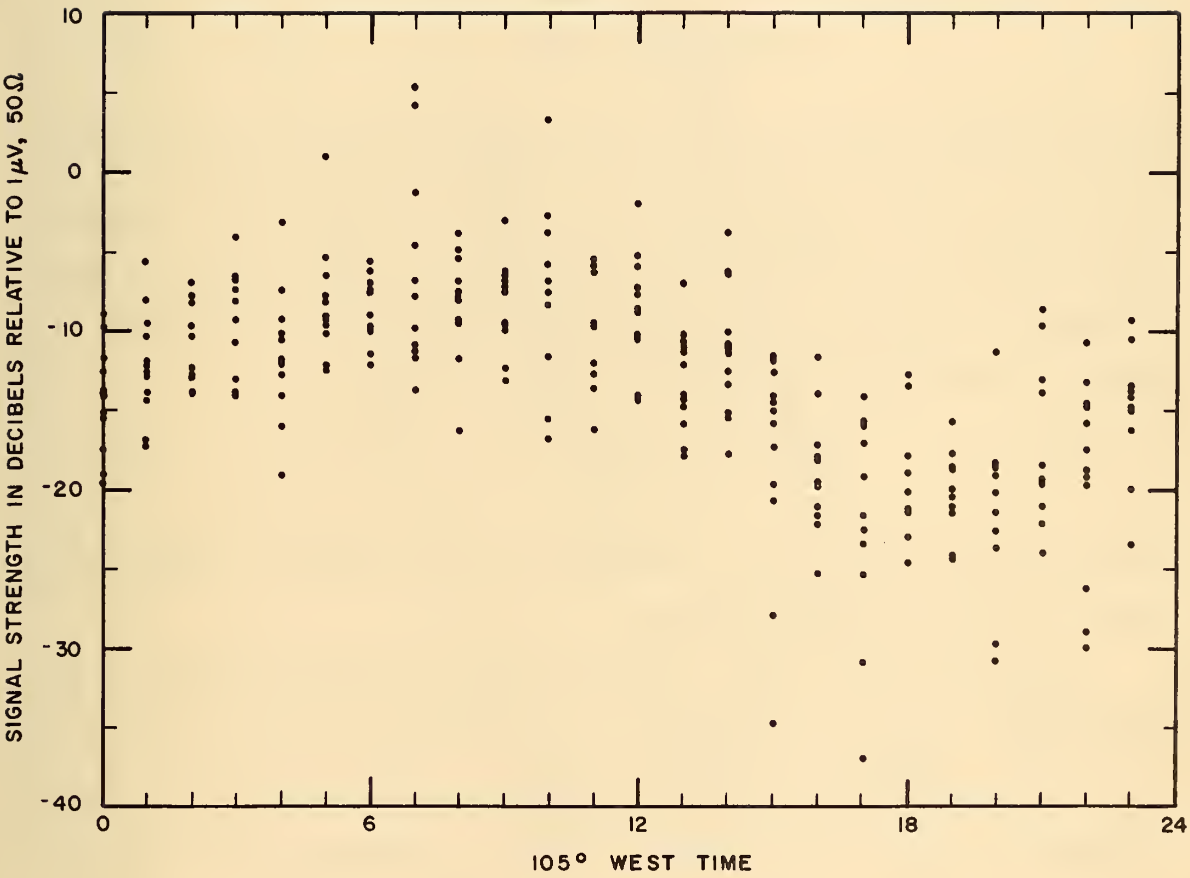


Figure 12 MASS PLOT OF 100%-INTERCEPT VALUES, TABLE MESA, DECEMBER 15 THROUGH 30, 1959, 50 MC/S

The variation of duty cycle *versus* threshold for one observing period at Table Mesa is illustrated in Figure 13. It can be seen that, for duty cycles less than 50%, this relation between duty cycle and threshold can be approximated by a straight line. These lines can be represented by the equation

$$D = m\,(S_1/20 - S/20) \qquad (1)$$

where D is the logarithm of the fractional duty cycle, m is the magnitude of the slope of the line, S_1 is a reference signal level in decibels, and S is the signal level in decibels. The slope m and reference signal level S_1 define the line. S_1 is the 100%-intercept, *i. e.* when S equals S_1, the duty cycle equals 100%. Equation (1) corresponds to the more conventional duty cycle relation [8]

$$d/100 = (s_1/s)^m \qquad (2)$$

where d is the duty cycle in percent, s_1 is the reference signal voltage, and s is the signal voltage.

Hourly slope and 100%-intercept values have been computed for several weeks of data by performing a least squares fit of a straight line to the data for each hour. The data points used were only those in the range from 10 db above the median signal strength to the signal strength corresponding to 0.05% duty cycle. Figures 14 through 16 show plots of weekly medians of hourly-slope values for Table Mesa, Fargo, and Kenai. Most of the 50 and 74 Mc/s slope values are in the range of 1.5 to 2.0 and show little diurnal variation. The 30 Mc/s slope values show considerable diurnal variation and are usually greater than 2.0. This result indicates [8] that these 30 Mc/s test circuits are poorly suited for a meteor-burst communication system.

It appears that the observed values of the 30 Mc/s slopes are strongly influenced by the scatter signal levels. The relatively high

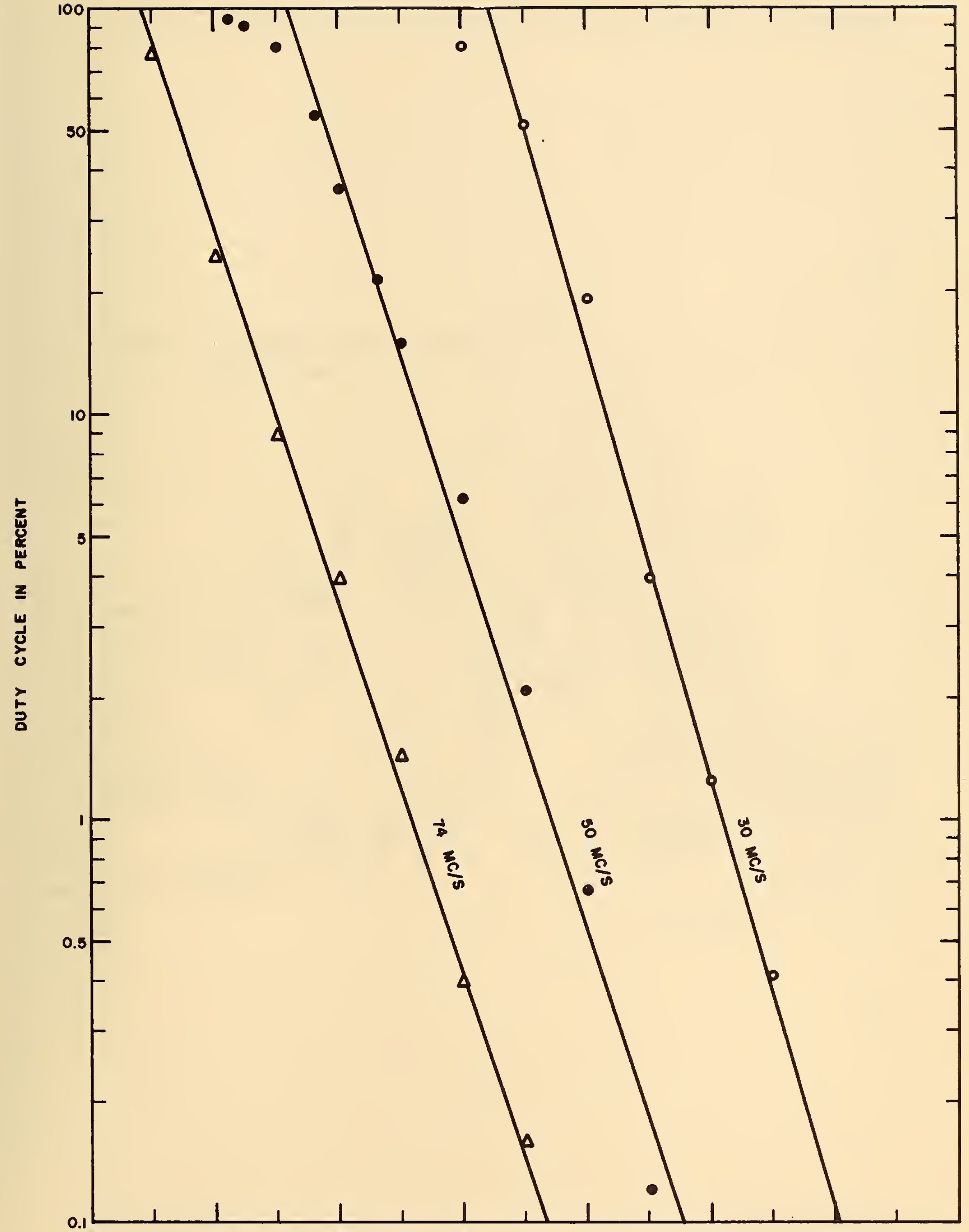


Figure 13 DUTY CYCLE <u>VERSUS</u> SIGNAL STRENGTH

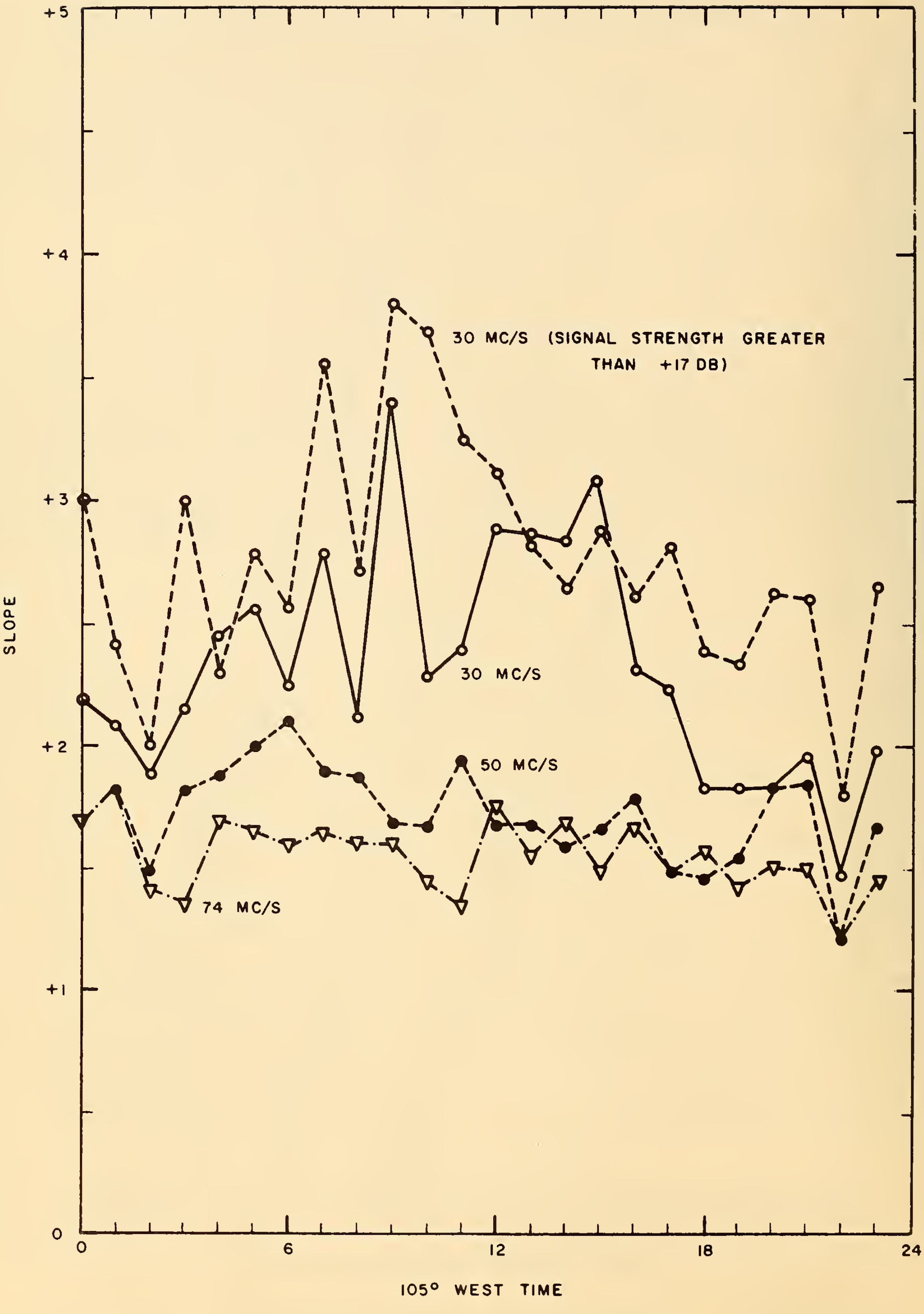


Figure 14 MEDIANS OF THE HOURLY-SLOPE VALUES, TABLE MESA, OCTOBER 31 THROUGH NOVEMBER 8, 1959

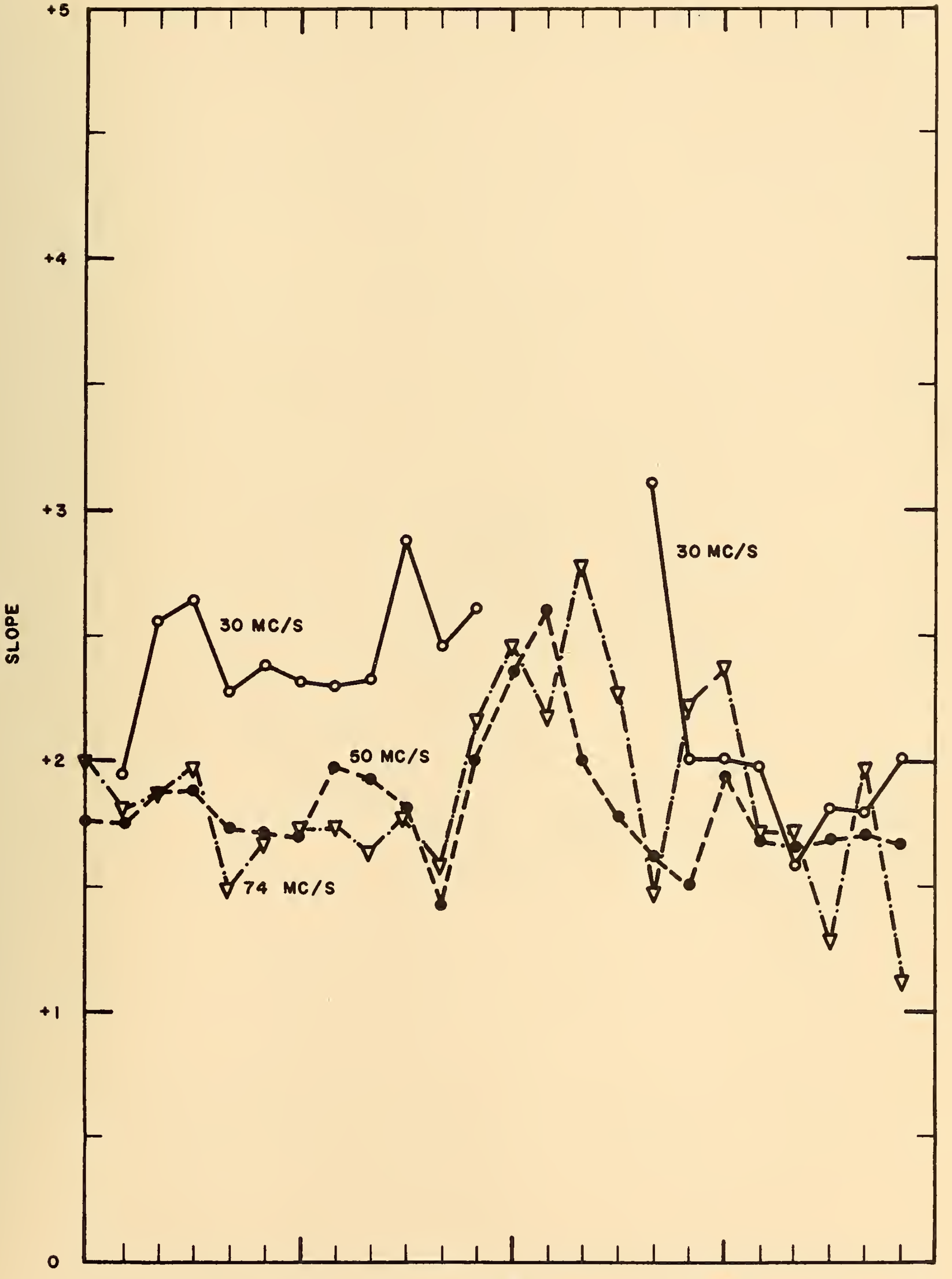


Figure 15 MEDIANS OF THE HOURLY-SLOPE VALUES, FARGO, NOVEMBER 27 THROUGH DECEMBER 4, 1959

Figure 16 MEDIANS OF THE HOURLY-SLOPE VALUES, KENAI, NOVEMBER 23 THROUGH DECEMBER 1, 1959

scatter levels at 30 Mc/s obscure the weaker meteor-burst signals and thus increase the proportion of signals received from overdense trails. To check this point, slopes were computed using only those data points which fell above a high and constant threshold (+17 db). These slopes are shown in Figure 14 and are consistent with the above hypothesis.

Figure 17 shows medians of hourly 100%-intercept values for 30, 50, and 74 Mc/s observations at Table Mesa. The diurnal variation here is apparent. The day-to-day variability of the intercept is illustrated by the mass plot shown in Figure 12. (It has recently been found that the 1%-intercept value is a more reliable measure of meteor activity, and therefore in future work it will be computed and used in place of the 100%-intercept.)

4.3. Meteor-Burst Rates and Durations

Meteor arrival rates vary from hour to hour and day to day with a short-term variation in rate which is thought to be Poisson distributed; *i. e.* if the time intervals between meteor arrivals are measured, the probability density function of these time intervals will be given by

$$p(n) = \bar{n} \exp(-\bar{n}t) \tag{3}$$

where $\bar{n}$ is the average rate of the meteor occurrences and t is the time interval. The distribution function is obtained by integrating equation (3), and is

$$P(t \geq T) = \bar{n} \int_T^{\infty} \exp(-\bar{n}t) \quad dt = \exp(-\bar{n}t) \tag{4}$$

where T is the minimum time-interval being considered. This is the probability that the time interval between bursts will be greater than or equal to a given time T. Note that a plot of the logarithm of $P(t \geq T)$ *versus* T results in a straight line.

Before proceeding, it is useful to define some terms used in the analysis of meteor-burst rate and duration data. These are defined

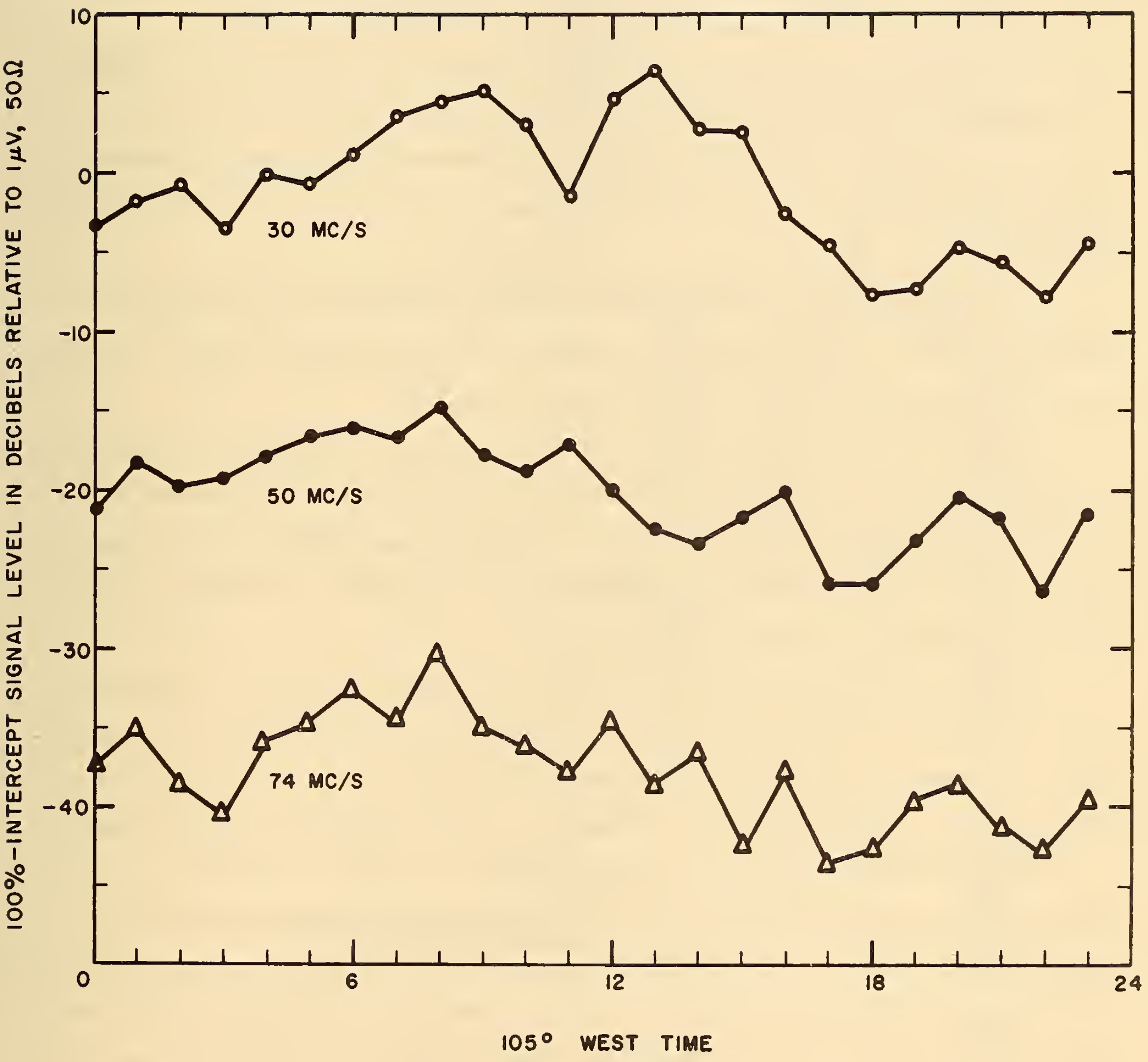


Figure 17 MEDIANS OF THE HOURLY 100%-INTERCEPT VALUES, TABLE MESA, OCTOBER 31 THROUGH NOVEMBER 8, 1959

with reference to a threshold which is at least 10 db above the median signal level. The definitions are as follows:

1. Hump - An excursion of the signal above the threshold level. For example, in Figure 18, the signal excursions between times t_1 and t_2, t_3 and t_4, t_5 and t_6, and t_8 and t_9 are called "humps".

2. On-Time - The time interval spanned by a hump. For example, in Figure 18, the time interval t_2 minus t_1 is the "on-time" for hump A.

3. Off-Time - The time interval between two adjacent humps. For example, in Figure 18, the time interval t_3 minus t_2 is the "off-time" between humps A and B.

4. Elapsed-Time - The time interval between the beginning of adjacent humps. For example, in Figure 18, the time interval t_3 minus t_1 is the "elapsed-time" between humps A and B.

Several hours of data have been processed to obtain an indication of elapsed-time, on-time, and off-time distributions. Figures 19 and 20 show examples of these results. The data used were from 50 Mc/s observations at Table Mesa and appeared to be similar to data for other hours, frequencies, and stations.

On-time distributions are similar in shape from hour to hour, however, the number of on-times greater than a given on-time can vary over a 10 to 1 range. This variation must be due in part to variations in meteor-rates, meteor-trail orientations, and ionospheric wind-shears.

Elapsed-time distribution curves show two main features: 1. for elapsed-time intervals less than 3 seconds, the elapsed-time curve bends sharply upward; and 2. for elapsed-time intervals greater than 3 or 4 seconds, the elapsed-time curve is nearly a straight line. The upward bend of the curve appears to result from the multiple humps of fading meteor-burst signals such as shown for burst B of Figure 18. If all bursts were non-fading, then the upward bend of the curve would probably not be present. The straight-line portion of the curve appears to be associated with the time intervals between the meteor-bursts themselves.

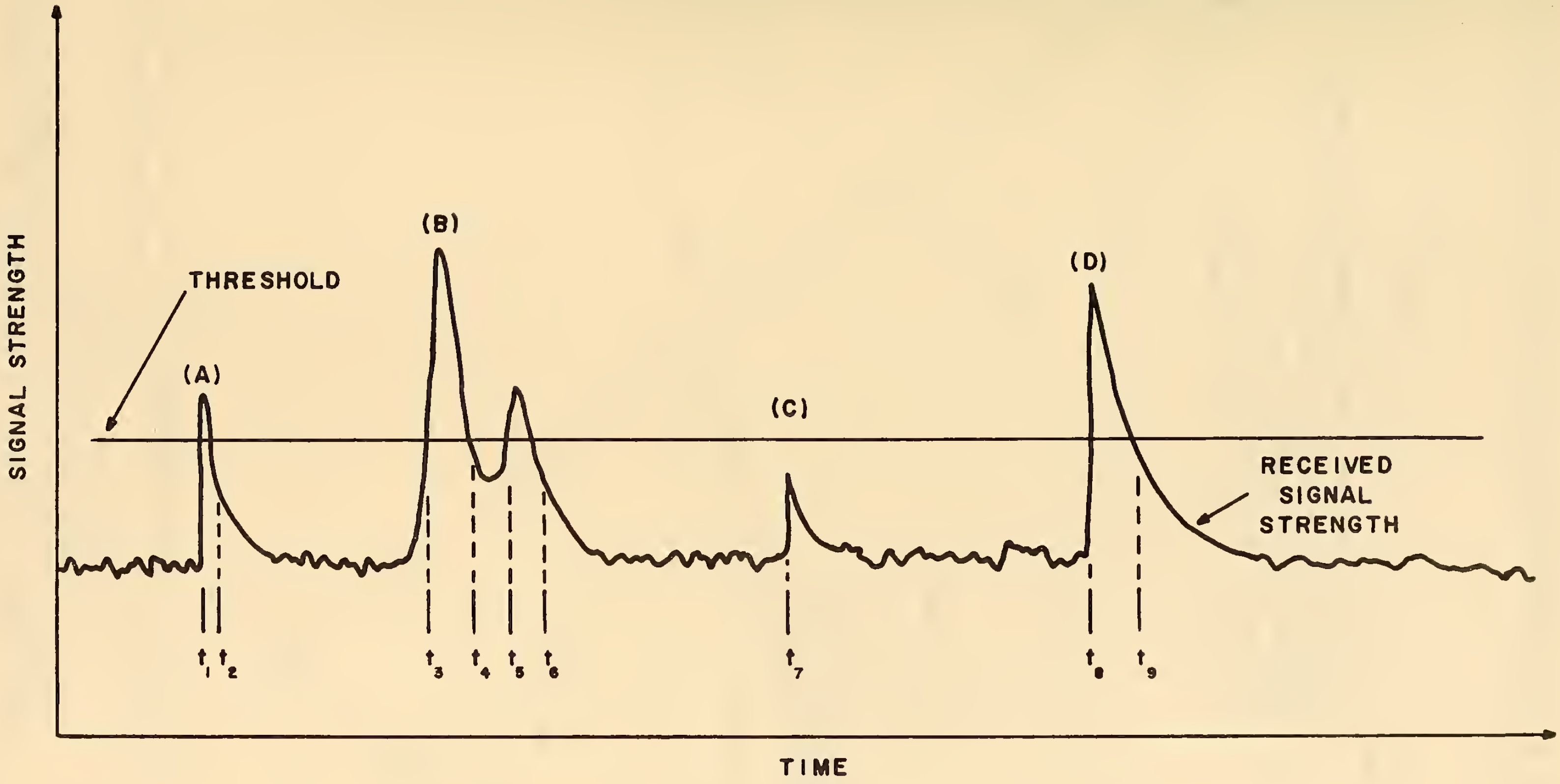


Figure 18 ILLUSTRATION OF METEOR-BURSTS USED IN DEFINING SIGNAL PARAMETERS

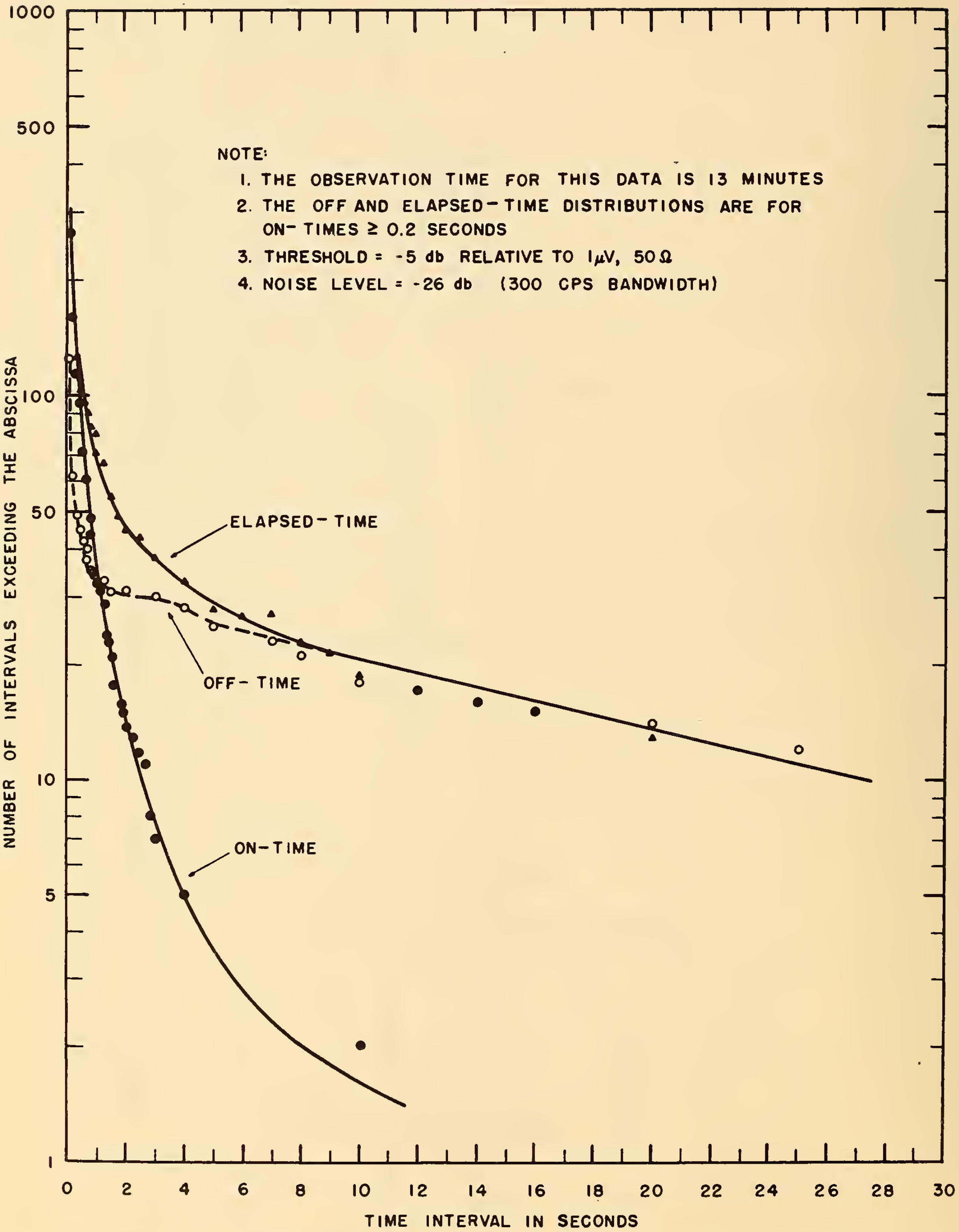
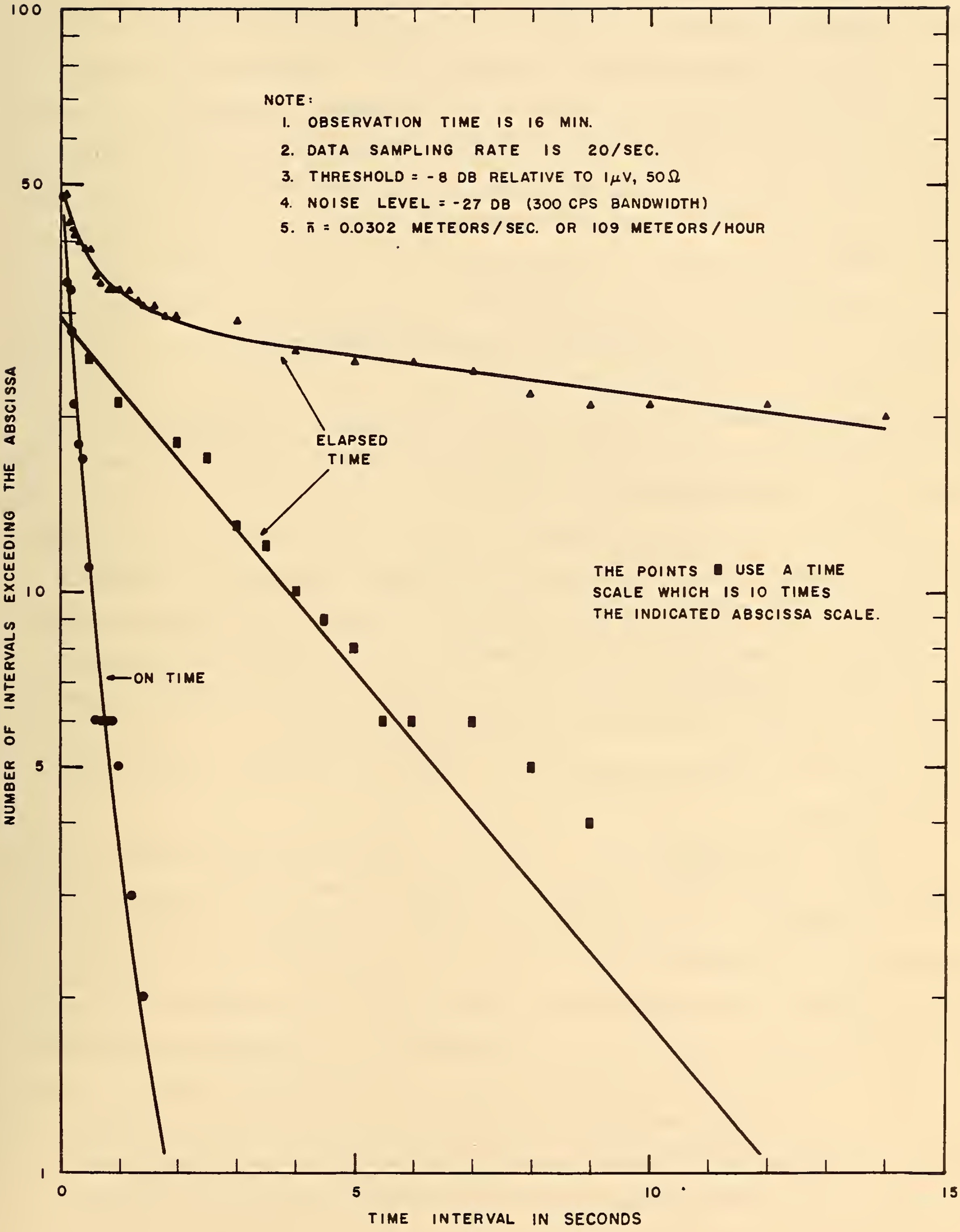


Figure 19 ON-TIME, OFF-TIME, AND ELAPSED-TIME DISTRIBUTIONS, TABLE MESA, OCTOBER 24, 1959, 0400 HOURS, 50 MC/S



NOTE:
1. OBSERVATION TIME IS 16 MIN.
2. DATA SAMPLING RATE IS 20/SEC.
3. THRESHOLD = -8 DB RELATIVE TO 1 μV, 50 Ω
4. NOISE LEVEL = -27 DB (300 CPS BANDWIDTH)
5. $\bar{n}$ = 0.0302 METEORS/SEC. OR 109 METEORS/HOUR

THE POINTS ▮ USE A TIME SCALE WHICH IS 10 TIMES THE INDICATED ABSCISSA SCALE.

Figure 20 ON-TIME AND ELAPSED-TIME DISTRIBUTIONS, TABLE MESA, FEBRUARY 24, 1960, 2000 HOURS, 50 MC/S

An estimate of meteor rate, based on the elapsed time distributions, may be made if it is assumed that the intervals between bursts are Poisson distributed and that the inclusion of data for fading bursts does not seriously alter the slope of the basic Poisson distribution. (The validity of these assumptions is being investigated.) The following procedure is used. The elapsed-time data for intervals greater than 3 seconds are fitted by a straight line. The slope, $\bar{n}$, of this line is then taken to represent the meteor-burst rate, using the relation

$$\bar{n} = - \frac{\ln P(t \geq T)}{T} = -2.30 \frac{\log P(t \geq T)}{T} \qquad (5)$$

which was obtained from equation (4). By applying this procedure to the data of Figure 20, it is found that the meteor rate was 109 per hour for an observing threshold of -8 db.

The off-time curve of Figure 19 shows the distribution of time intervals between humps rather than the intervals between the beginnings of humps (elapsed-times). The off-time and elapsed-time curves are essentially the same for interval times greater than about 10 seconds. The sharp upward bend of the curve at intervals less than 2 seconds emphasizes the fact that the intervals between the humps of a burst are quite brief. These data suggest that typical fading rates are between 2 and 10 cps.

One of the problems which concern the users of a meteor-burst communication system is how long must one wait in order to be able to make a single transmission of a specified length. Such waiting-time information is being evaluated in detail. One can obtain a rough estimate of the probability of successful transmission by using information such as that given in Figure 20. As an illustration, consider the following example: Suppose that the system uses a 50 Mc/s frequency and a threshold of -8 db, and one wishes to know what the probability is of obtaining a 0.2 second transmission interval while waiting no longer than 60 seconds. Assume that the on-time and elapsed-time distributions are independent. Then the desired probability is just the product of the probabilities that there will be a meteor-burst within 60 seconds and the probability that the on-time will be at least 0.2 seconds. From Figure 20, it is found that the former probability is 0.81 and the latter 0.48. Thus the probability of a successful transmission is 0.39.

5. SUMMARY

Meteor-burst data have been recorded digitally on paper tape and continuously on strip charts for three frequencies (30, 50, and 74 Mc/s) over three paths (Long Branch - Table Mesa, Norman - Fargo, and Barrow - Kenai). By means of the strip-chart recordings, station log-sheets, and calibrations, the digital data tapes are prepared for automatic processing. The results of the duty cycle and meteor-burst elapsed-time analyses are punched on Hollerith cards.

Meteor-burst duty-cycle data, when plotted in a coordinate system of logarithm of duty cycle versus signal strength in decibels, lie along a straight line which may be described by two parameters, slope and 100%-intercept. Slope and 100%-intercept values have been obtained by the method of least squares fitting of a straight line to the data. The slope values for 50 Mc/s and 74 Mc/s are usually between 1.5 and 2.0, while for 30 Mc/s, values are usually greater than 2.0. Therefore, 30 Mc/s systems are considered to be poor choices for meteor-burst communication purposes [8]. The Table Mesa and Fargo 100%-intercept data show about a 10 db diurnal variation in the observing threshold which has a maximum in the morning and a minimum in the afternoon. Kenai data do not show a significant diurnal variation. The threshold for observing a fixed duty cycle shows a frequency dependence such that a 15 db higher threshold should be used to observe 30 Mc/s signals than for 50 Mc/s and 30 db higher threshold for 30 Mc/s than for 74 Mc/s.

Meteor-burst elapsed-time data (elapsed-times are the time intervals between meteor bursts) are presented for signal bursts whose durations above a given threshold are greater than 0.2 seconds. Plots of the logarithm of the number of elapsed time-intervals which exceed a given time interval versus the time interval show that the data lie along a straight line and, therefore, fit a Poisson distribution. If one assumes the data are Poisson distributed, the slope of the distribution line is the meteor rate for the observing period.

The authors wish to acknowledge the help and guidance of Kenneth L. Bowles and Ralph J. Slutz, and also, the work of the many people at the various field stations and the NBS-Boulder Laboratories who have obtained and analyzed the data.

6. APPENDIX. COMPUTER PROGRAMS FOR DATA ANALYSIS

Data, calibration, and test tapes are analyzed by means of computer programs. The computer is equipped with a paper-tape reader which reads the tape characters under control of the computer program. The calibration program produces a calibration card which has signal scale values (0-99) corresponding to every 5 db level from -40 db to +40 db. The test-tape program produces error cards whenever an error is detected in the test-tape.

6.1. Kinds of Programs

There are several kinds of data-analysis programs which may be grouped into "basic" reduction programs and "secondary" reduction programs.

The basic-reduction programs are used to process the data tapes and give intermediate results in the form of punched cards. Three of these programs which have been developed are:

1. HUMP (Detects the maxima and minima of the signal-strength data). This program reads the characters from either start-stop or continuous data tapes and punches a card for each time a maximum or minimum is detected in the sequence of data samples. Each card punched at a maximum indicates the interval of time during which the signal strength was lower than a threshold value; there are ten such intervals on each card corresponding to ten thresholds. These span a 50 db range in signal strength in five decibel steps. Each card punched at a minimum indicates the interval of time (measured from the previous card) during which the signal was greater than the threshold value; there are ten such values on each card corresponding to the same thresholds used for the maximum card.

2. MTM (Produces a card for each recorded meteor-burst signal). This program is used primarily to analyze the start-stop data tapes. A card is punched for each meteor-burst signal as defined by the recording equipment. Information punched on the card includes:

(1) the time at the beginning of the meteor-burst to the nearest second,

(2) the elapsed-time to the beginning of this burst since the beginning of the previous burst,

(3) the maximum value of the signal during the burst, and

(4) the total amount of time the signal was above a given level for ten different signal levels which span a 50 db range in 5 db steps.

At the end of each hour of data, a set of three cards is punched which shows the total time that the signal was greater than the various thresholds and gives the total number of meteor-bursts counted for the hour.

3. DIST (Forms cumulative distribution of the signal-strength values, of the elapsed-times, and of the on-times). Only continuous data tapes are processed by this program. Three distributions are formed:

(1) the number of signal-strength samples which are equal to or exceed a given scale value versus the scale values,

(2) the number of elapsed-time intervals which exceed a given time interval versus the time intervals, and

(3) the number of on-time intervals which exceed a given time interval versus the time intervals.

The time intervals are measured by means of a threshold, i. e. referring to Figure 18, burst (C) does not exceed the threshold, therefore, time t_7 would not be measured, but all the other times indicated in the Figure would be measured. For each hour of data, the values of the three distribution tables are punched on 16 cards.

The secondary reduction programs are used to process the cards from the basic reduction programs. Several of these programs have been developed:

1. ANALYSIS OF DIST (Produces an hourly value card for signal median, slope, intercept, and six duty cycles). This program reads a

set of hourly cards into the computer for the distribution of the signal-strength values and performs the following computations:

(1) determines the median of these signal values and converts this to a normalized decibel value,

(2) computes six duty cycles for six decibel levels which are separated by 5 db steps, and

(3) computes by least-squares fit, the slope and 100% or 1% intercept of the line which describes equation (2), i. e.

$$d/100 = (s_1/s)^m .$$

These values are assembled and punched on one card for each hour of data. There are two modifications of this program:

(a) Sectional Slopes - This program computes slopes and intercepts by least-squares fit of a straight line for two sections of the signal strength range. The answers are punched on one card for each hour of data.

(b) Hourly Cards from MTM Cards - This program processes the three hourly summary cards from the MTM program and produces an hourly output card which has the same information as the output card from the ANALYSIS OF DIST program.

2. MEDIAN (Finds the medians of the various values on the hourly cards from the ANALYSIS OF DIST program). This program reads in a set of cards (up to 90 cards) and determines the median values of the various parameters on the cards. One output median card is punched for each set of cards read in.

6.2. Processing Data

Many problems have arisen since we started to process some of the data in October 1959. For example, a great deal more handwork is required in order to prepare data for the computer than had originally been expected. Also, some programs are too slow to use if an appreciable amount of data is to be processed. Processing techniques are being improved so that less handwork is required and processing rates are increased.

One of the big problems is the slowness of the present computer system. Running times for the basic-reduction programs are:

1. HUMP - requires real time to run, i. e. 16 minutes of recorded data requires 16 minutes of computer time.
2. MTM - requires 3 to 4 minutes per 16 minutes of recorded data.
3. DIST - requires 1.75 minutes per 16 minutes of recorded data (recorded at 5 samples per second).

Running times for the secondary-reduction programs are considerably faster and present no immediate problems.

Because of the slow running time, only about two days of data on three frequencies have been run on the HUMP program. However, this program produces the most detailed description of the received signals.

About one week of data was run on the MTM program; however, without the angle information, this program produces very little more than the DIST program. Most of the data has, therefore, been reduced by the DIST program. About 12 weeks of data have been processed.

Obviously all of the recorded data has not been run. There is a back-log of data building up and with the present computer installation, it seems improbable that little more than half of the data can be processed as fast as it is taken. The computer situation should be greatly improved during the summer or early next fall when a much faster computer is to be installed at the NBS-Boulder Laboratories.

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