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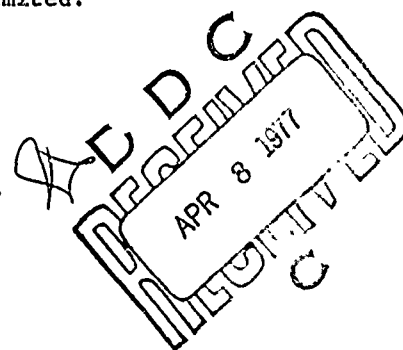
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February 1977



VLF/LF ATMOSPHERIC NOISE STATISTICS RECORDED AT VIENNA, NEW YORK

Wayne Bonser  
Lt Anthony J. Mlinar  
George A. Pfeiffer

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ROME AIR DEVELOPMENT CENTER  
AIR FORCE SYSTEMS COMMAND  
GRIFFISS AIR FORCE BASE, NEW YORK 13441

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## PREFACE

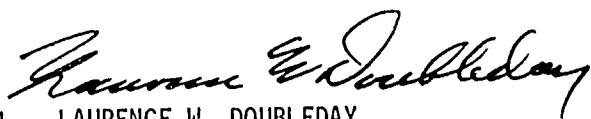
This report details the preliminary work performed in the field of VLF Atmospheric Noise Analysis by RADC for the Defense Communications Agency (DCA). This work was accomplished under the Tri Service Propagation Measurement Program, also known as RADC project 97530001 (R184). The program manager is Mr. Alfred D. Paoni.

Megatek Corporation, Harbor City, CA developed the original design and built three Statistical Noise Analyzers by which atmospheric noise is measured and its characteristics recorded.

Mr. George Pfeiffer (RADC) has been instrumental in the acquisition of the Statistical Noise Analyzers and the collection of atmospheric noise data. Mr. Pfeiffer has management responsibility for the installation, operation, and maintenance of the three collection sites.

This report has been reviewed by the RADC Office of Information and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

This report has been reviewed and is approved for publication. Any further details can be obtained by contacting RADC/DCCL (Mr. Alfred D. Paoni/315-330-3077).

  
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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number)<br>This report documents the preliminary work performed in the field of Atmospheric Noise Analysis. The data presented in this report characterizes the "real-world" atmospheric noise conditions as were observed during the first half of 1975 at Vienna, New York, and gives the VLF communication community an opportunity to become familiar with the equipment, the methods, and the statistics collected. |                       |                                                                          |

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## LIST OF ABBREVIATIONS

|        |                                         |
|--------|-----------------------------------------|
| ADEN   | Amplitude Density Function              |
| ACUM   | Amplitude Cumulative Distribution       |
| APD    | Amplitude Probability Distribution      |
| bpi    | bits per inch                           |
| dB     | decibels                                |
| EAVE   | Envelope Voltage Average Value          |
| ERMS   | Envelope Voltage Root-Mean-Square Value |
| EVD    | Envelope Voltage Deviation              |
| Hrs    | Hours                                   |
| Hz     | Hertz                                   |
| ips    | inches per second                       |
| KHz    | Kilo Hertz                              |
| SAVE   | Space Moment (Average)                  |
| SCUM   | Space - Cumulative Distribution         |
| SDEN   | Space Density                           |
| SMSQ   | Space Moment (Squared)                  |
| SNA    | Statistical Noise Analyzer              |
| SVAR   | Space Variance                          |
| VLF/LF | Very Low Frequency and Low Frequency    |
| WAVE   | Width Moment (Average)                  |
| WCUM   | Width-Cumulative Distribution           |
| WDEN   | Width Density                           |
| WMSQ   | Width Moment (Squared)                  |
| WVAR   | Width Variance                          |

## CHAPTER I

### INTRODUCTION

#### 1.0 GENERAL

An important segment of the Department of Defense's Minimal Essential Emergency Communications Network (MEECN) is the Very Low Frequency and Low Frequency (VLF/LF) communications. Assurance of reliable communications requires the knowledge of transmission amplitudes, propagation characteristics, receiver characteristics, noise levels and time distributions. Determination of character-error-rates, and the minimal levels required for satisfactory VLF reception, in the absence of interfering transmissions, requires detailed knowledge of the VLF noise environment.

The measurement of atmospheric noise is accomplished by the utilization of specialized VLF receive and analysis systems. The receiver/analyzer known as a Statistical Noise Analyzer (SNA) is controlled by a mini-computer. These receivers measure noise amplitude, pulse width, and pulse spacings on ten channels within the 10-60 KHz spectrum. The data collected by one of these analyzers, at RADC's Vienna Test Annex and the subsequent analysis, is the subject of this report.

#### 1.1 THE REPORT

The recently developed ten channel, automatic Statistical Noise Analyzers have been installed at sites around the world (North Dakota USA; Greenland; and Sweden). The data gathered at these sites will be analyzed and correlated to give the VLF noise characteristics in the Northern Area.

Data was collected by one Statistical Noise Analyzer at a site near Rome, N.Y., before installation of the receivers at distant sites, to allow a "burn-in" period for one such unit and enable RADC engineers to develop collection schedules and analysis programs. The data analyzed for the Spring (March, April, May) period and the characteristics of the analyzers are presented here to give the VLF communications community an opportunity to familiarize themselves with the equipment, the methods, and the statistics collected.



## 1.2 SIGNIFICANCE OF THE EFFORT

The use of a specialized measurement system which automatically collects atmospheric noise measurements on a multiple of frequencies in the VLF spectrum, is a relatively new concept. The types of statistics now being studied have never been available before and will lead to a more thorough understanding of atmospheric noise characteristics. Pulse width and pulse spacing, of atmospheric noise spikes, are some of the statistics now being collected which have never before been the subject of investigation. CCIR curves have never been adjusted to real-world data, at these frequencies. A histogram of data, taken over a number of years, will allow the seasonal trends to be determined without extrapolation. All the information derived from this data will be useful in upgrading computer propagation models and possibly for adjustment of the CCIR curves for the High Latitudes and low frequencies.

## 1.3 BACKGROUND

The noise environment can be divided into two broad categories: internal noise, and externally emitted interference. The internal noise originates either as thermal noise from within electronic devices, or as power line or power supply fluctuations which develop from increasing (decreasing) loads, or are residual components of filtering networks. This type of noise can be easily measured, is consistent, and is predictable.

External noise can be separated into several definitive groups: Electrostatic, Atmospheric, and Man-made.

Precise measurements of propagation statics and atmospheric noise properties have been insufficient in quantity to permit accurate determination of message reception reliability at VLF. To augment available propagation data, both the Air Force and the Navy have developed sophisticated mathematical models.

Sufficient geophysical data has been gathered in the Temperate Zone to substantiate the accuracy of the models there. However, the quantity of data collected in the Northern Regions has been too limited to validate these prediction models for areas above the 50th parallel. In order to obtain the necessary information on propagation characteristics and atmospheric noise properties, the Defense Communications Agency has organized the Tri-Service Propagation Measurement Program.

There are two integral portions of this program: the collection of geophysical parameters of VLF/LF transverse magnetic waves, over long paths at high altitudes; and the collection and analysis of atmospheric noise data. The latter is being accomplished through the

utilization of Statistical Noise Analyzers positioned along a straight line across the Northern Hemisphere (above the 50th parallel).

#### 1.4 ORGANIZATION

This report is organized as follows:

Chapter 2 describes the equipment used in the collection and analysis of the atmospheric noise data.

Chapter 3 explains which parameters are measured, what statistics are calculated, and what the correlation of data provides.

Chapter 4 describes the data collected at RADC's Vienna Test annex and the subsequent analysis.

Chapter 5 contains all the graphs which were drawn from the Vienna data.

Chapter 6 summarizes the results of the analysis of the Vienna data and the plan for the actual collection of atmospheric noise data in the Northern Area.

## CHAPTER 2

### EQUIPMENT CONFIGURATION

#### 2.0 MINI-COMPUTER

The Nova 1200 minicomputer has 16K (16 bit) of core memory, and a processor cycle time of 2.6 microseconds. This Nova is equipped with hardware multiply/divide circuitry and a "program-load" option which allows the automatic loading of absolute binary programs. The Nova controls all the peripheral devices, including the Statistical Noise Analyzer. The Nova also computes (on a real-time basis) the statistics which can be calculated from the measured data.

#### 2.1 PAPERTAPE READER

The high speed papertape reader can be adapted to read 5, 6, 7 or 8 channel punched papertape. This unit can read at a speed of 100-600 characters per second and is the secondary input device..

#### 2.2 MAGNETIC TAPE

A magnetic tape drive is used to record digital data for further analysis and correlation. The tape speed is 12.5 ips (inches per second) with a recording density of 800 bpi (bits per inch). This is the primary output device.

#### 2.3 DIGITAL CLOCK

This clock is used for time-of-day information and for the control of system functions dependent on time. This clock is resettable (24 Hrs) and transfers data (Hrs, Mins, Secs, 10th Secs) back to the Nova via the Statistical Noise Analyzer.

#### 2.4 TELETYPE

An ASR 33 Teletype sends and receives messages at 100 words per minute and is the primary input device and operator interface.

#### 2.5 STATISTICAL NOISE ANALYZER

The Statistical Noise Analyzer (SNA) receives, through its own crossed-loop antenna, noise and signal voltages which, after detection, are categorized into 42 amplitude levels. The SNA simultaneously measures pulse width and pulse spacing. The data is transmitted to the Nova computer at a 10KHz rate. The receiver bandwidths are selectable at 2KHz, 1KHz, 600Hz, and 200Hz. The frequency range of the

Statistical Noise Analyzer is 10KHz to 100KHz. The antenna patterns are either a "figure-eight" pattern oriented in any one of four directions, or an omnidirectional pattern. The SNA has a dynamic range of over 120dB.

## 2.6 REDUCTION/CORRELATION SYSTEM

The final analysis center is located at RADC and is comprised of a Nova 1200 Jumbo computer equipped with 32k of memory, hardware multiply/divide circuitry, floating point arithmetic circuitry, real-time clock, and program load option. This system is presently configured with the following peripheral devices: a teletype, a papertape reader, a flat-bed plotter, a 1.25 million word disk, and two 9 track magnetic tape drives. This system is utilized to correlate the statistical data recorded on digital tape by the SNA's, plot graphs, and tabulate seasonal statistics.

## CHAPTER 3

### PARAMETERS

#### 3.0 MEASUREMENTS & STATISTICS

The Statistical Noise Analyzer compiles data by measuring the highest amplitude level (threshold) which was exceeded by a noise sample. There are 42 threshold levels that are set at 3dB increments. The fraction of time a sample remains above a certain level (set by the operator) is also measured. The following statistics are then calculated by the Nova 1200 minicomputer:

##### AMPLITUDE STATISTICS:

- a. The Density Function (ADEN)
- b. The Cumulative Distribution (ACUM)
- c. The Amplitude Probability Distribution (APD)
- d. The Envelopes Average Value (EAVE)
- e. The Envelopes RMS Value (ERMS)
- f. The Envelope Voltage Deviation (APD)

##### TIME STATISTICS:

- a. Width & Space Density (WDEN/SDEN)
- b. Width & Space Cumulative Distribution (WCUM/SCUM)
- c. First Spacing Moments (WAVE/SAVE)
- d. Second Spacing Moments (WMSQ/SMSQ)
- e. Width & Space Variance (HVAR/SVAR)

#### 3.1 CORRELATION

These statistics, when compared month to month, will display seasonal trends and the differences between receiver site locations. When enough data is gathered and statistics calculated, a comparison between predicted noise values and measured values can be made to determine the validity of CCIR predictions.

## CHAPTER IV

### VIENNA COLLECTION & ANALYSIS

#### 4.0 DATA COLLECTED

From January 1975 through June 1975 one Statistical Noise Analyzer was operated on these ten frequencies: 10.7, 14.0, 17.0, 20.0, 27.0, 40.0, 43.0, 47.0, 50.0, and 55.0 Kilo Hertz. The statistics on Amplitude were of major interest and are the only statistics which are presented in this report. The specific items of concern were the behavior of EVD and ERMS values over time and frequency.

#### 4.1 ANALYSIS

During the first two months at Vienna many adjustments and equipment tests were performed. For this reason, the months with the largest atmospheric noise data-base were March, April, May, and June. However, the data tabulated over all six months (Jan-June) was plotted, via a HIOVA 1200/DPI plotter, as Amplitude versus Time for each of the ten frequencies monitored. Then, after careful examination, the three-month period, March, April, May, was selected as the most comprehensive time span to be used in further analysis. This is the same time block used by CCIR as the "Spring Season."

The data from this time period was averaged, and the standard deviations were calculated. These averages (EVD & RMS) and their limits ( $\pm$  standard deviation) were plotted on an hour-by-hour scale, as a continuous Bargraph, for each of the ten frequencies. These graphs display the effects of time-of-day on EVD and ERMS. The mean values were plotted by hand on a scale of Amplitude versus Frequency. These graphs display the frequency characteristics of EVD and ERMS at VLF. These plots, and others, are presented in the following chapter.

5.0 - PLOTTED DATA

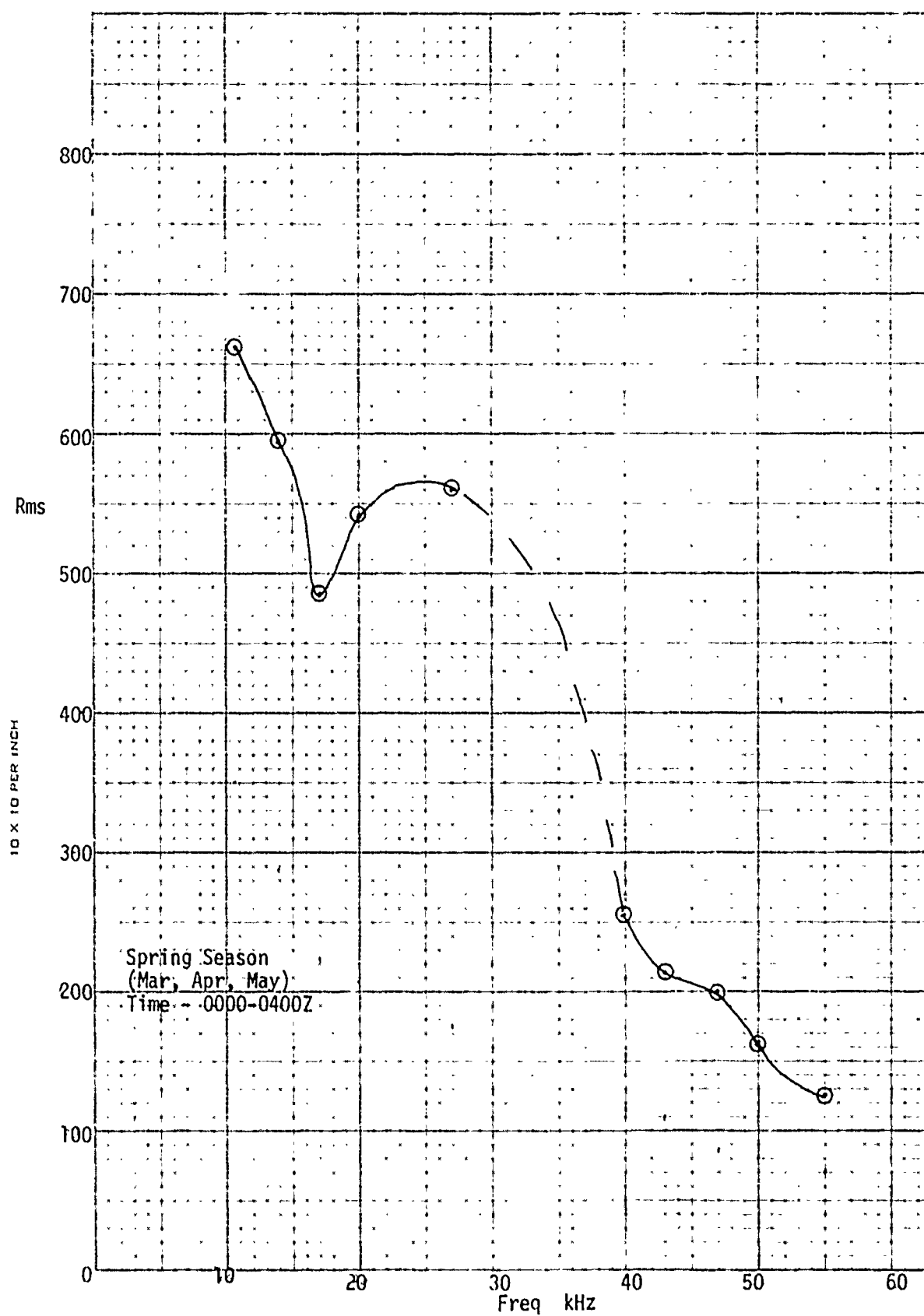
## CHAPTER V

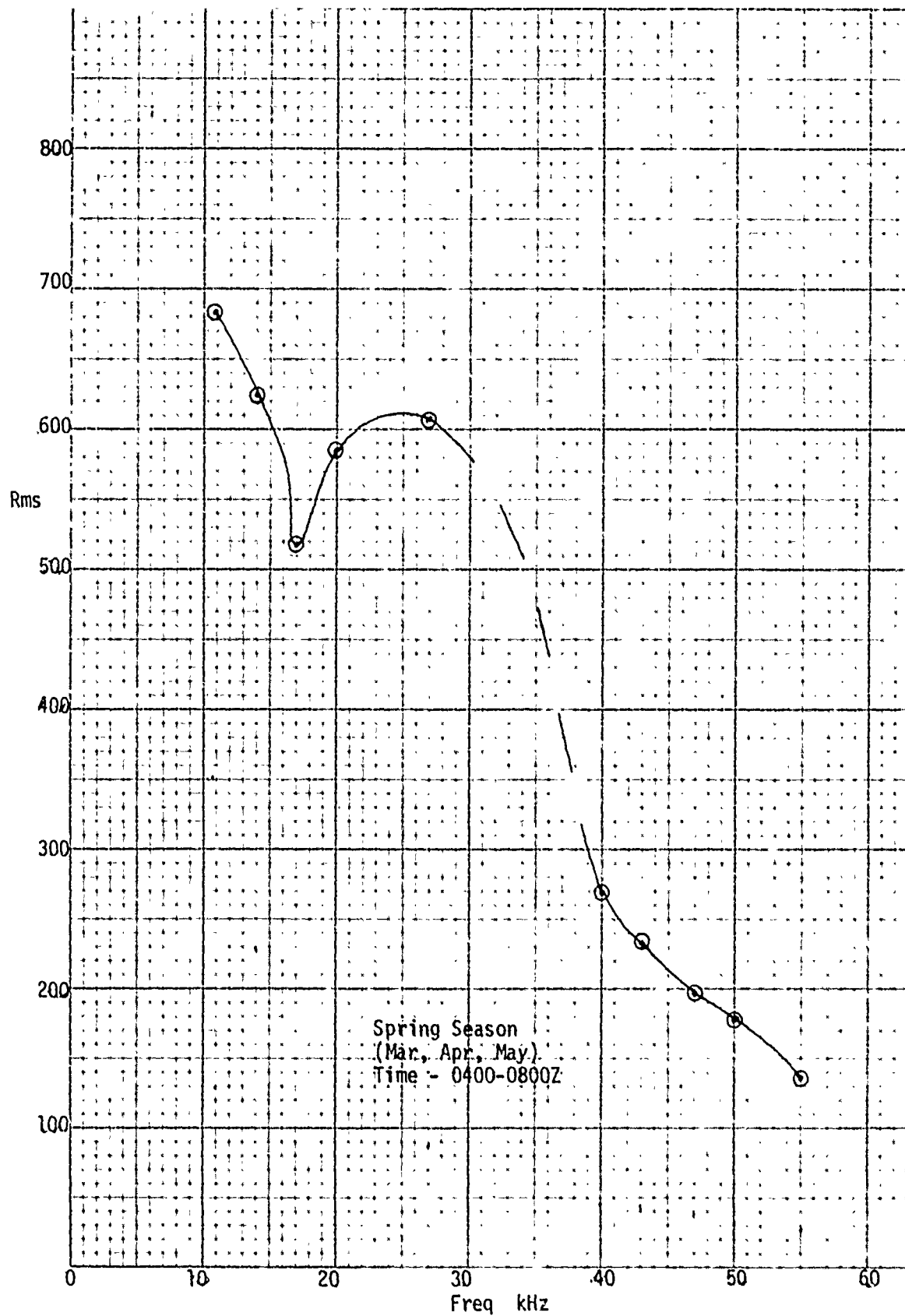
### GRAPHS

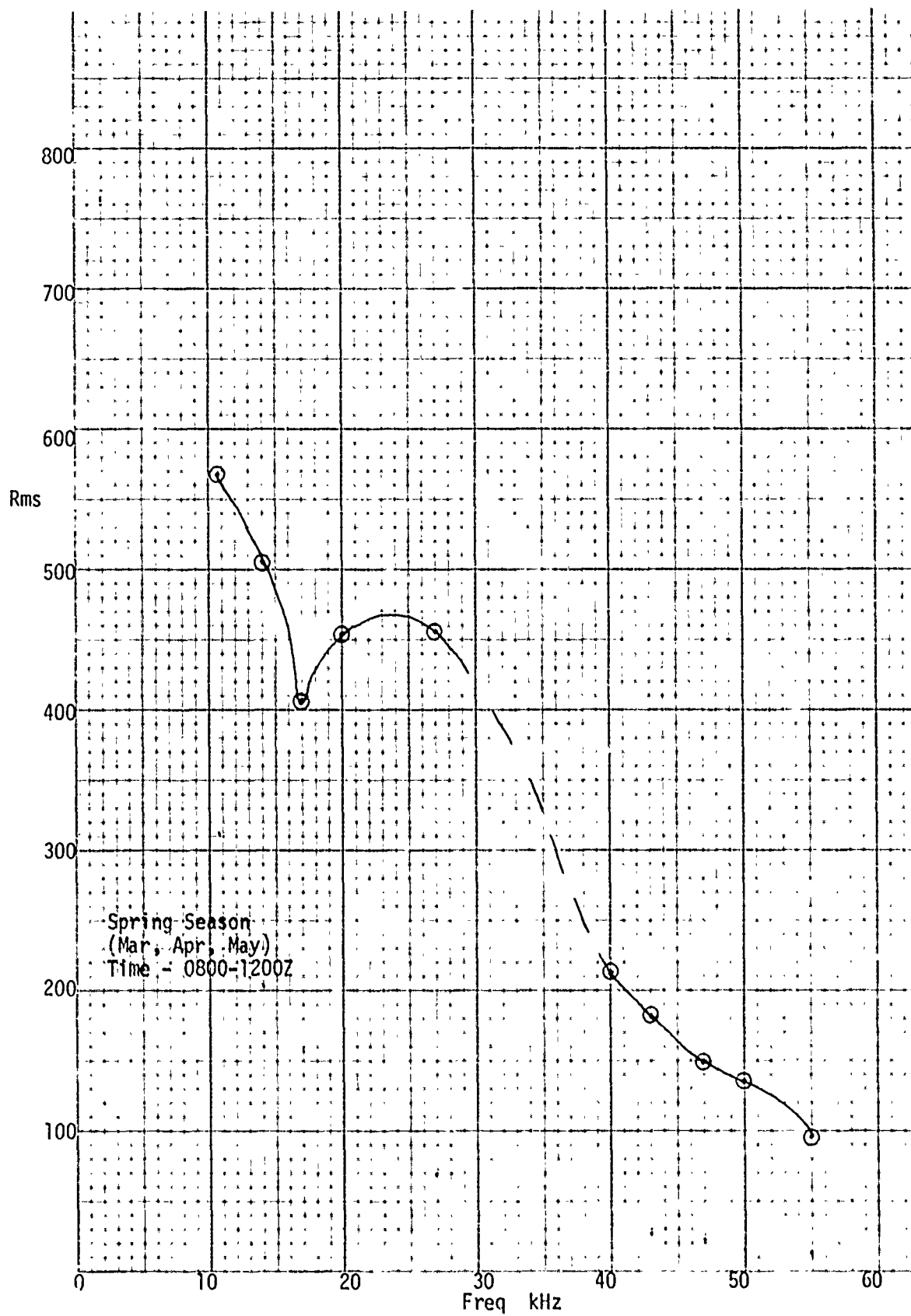
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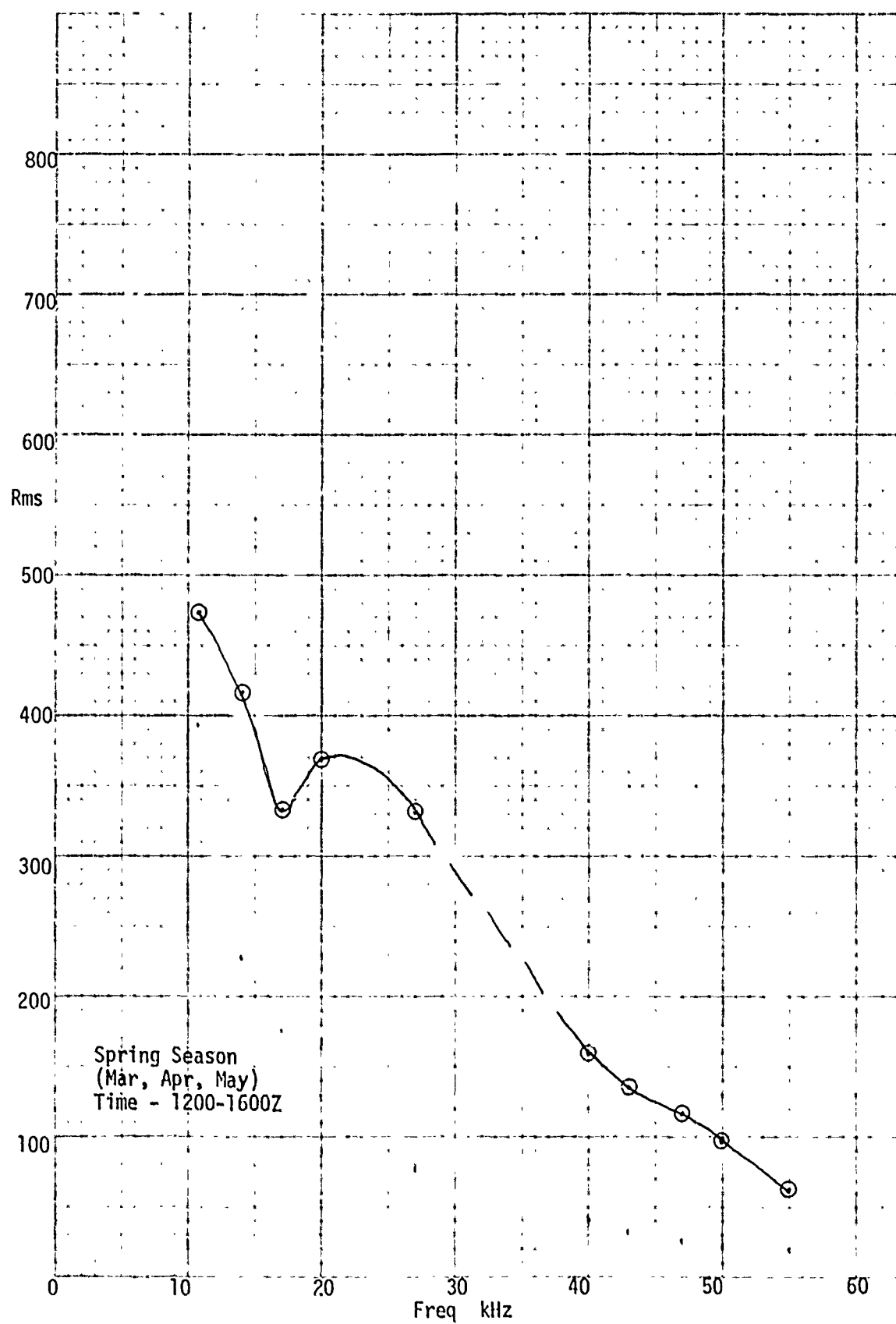


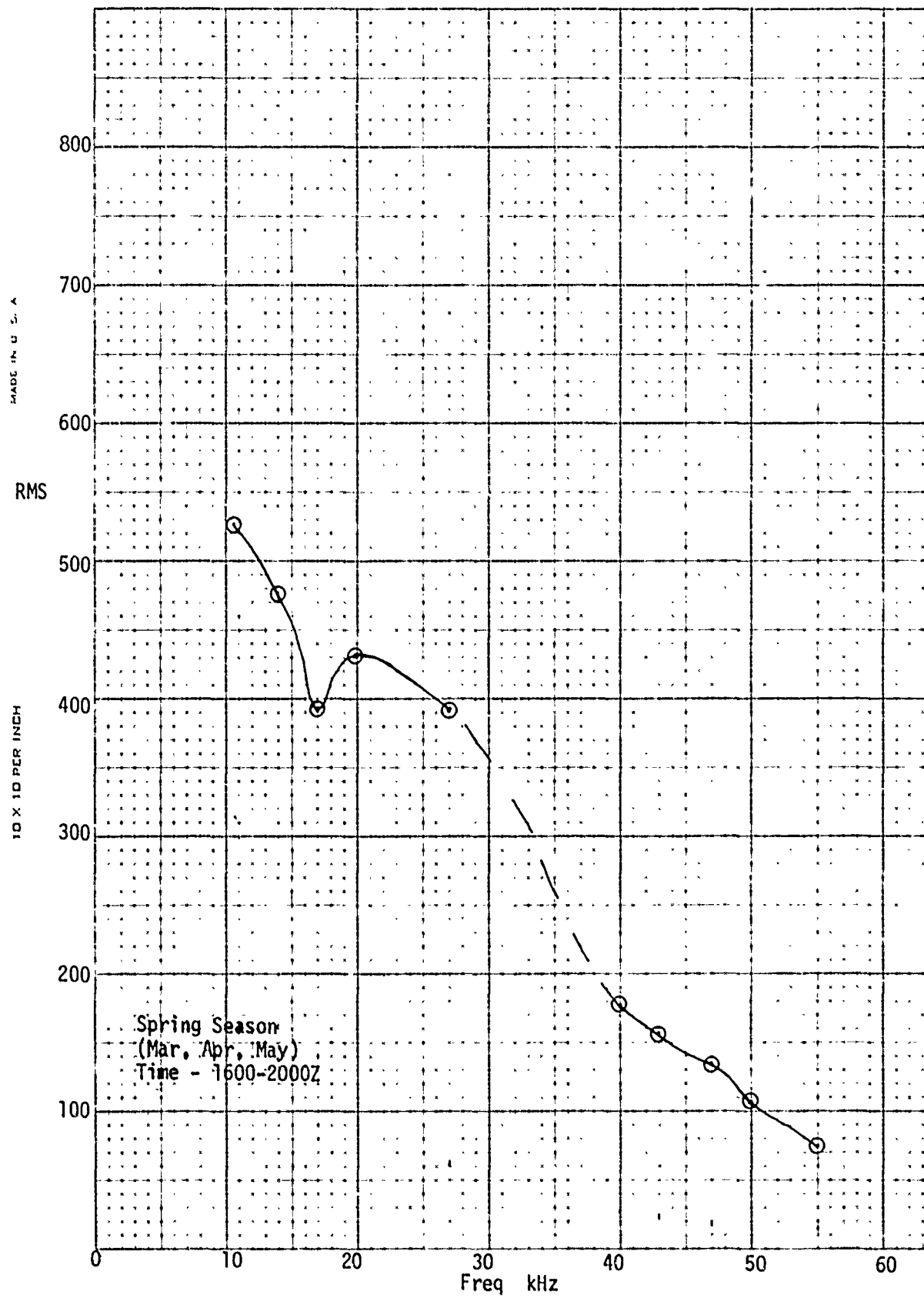
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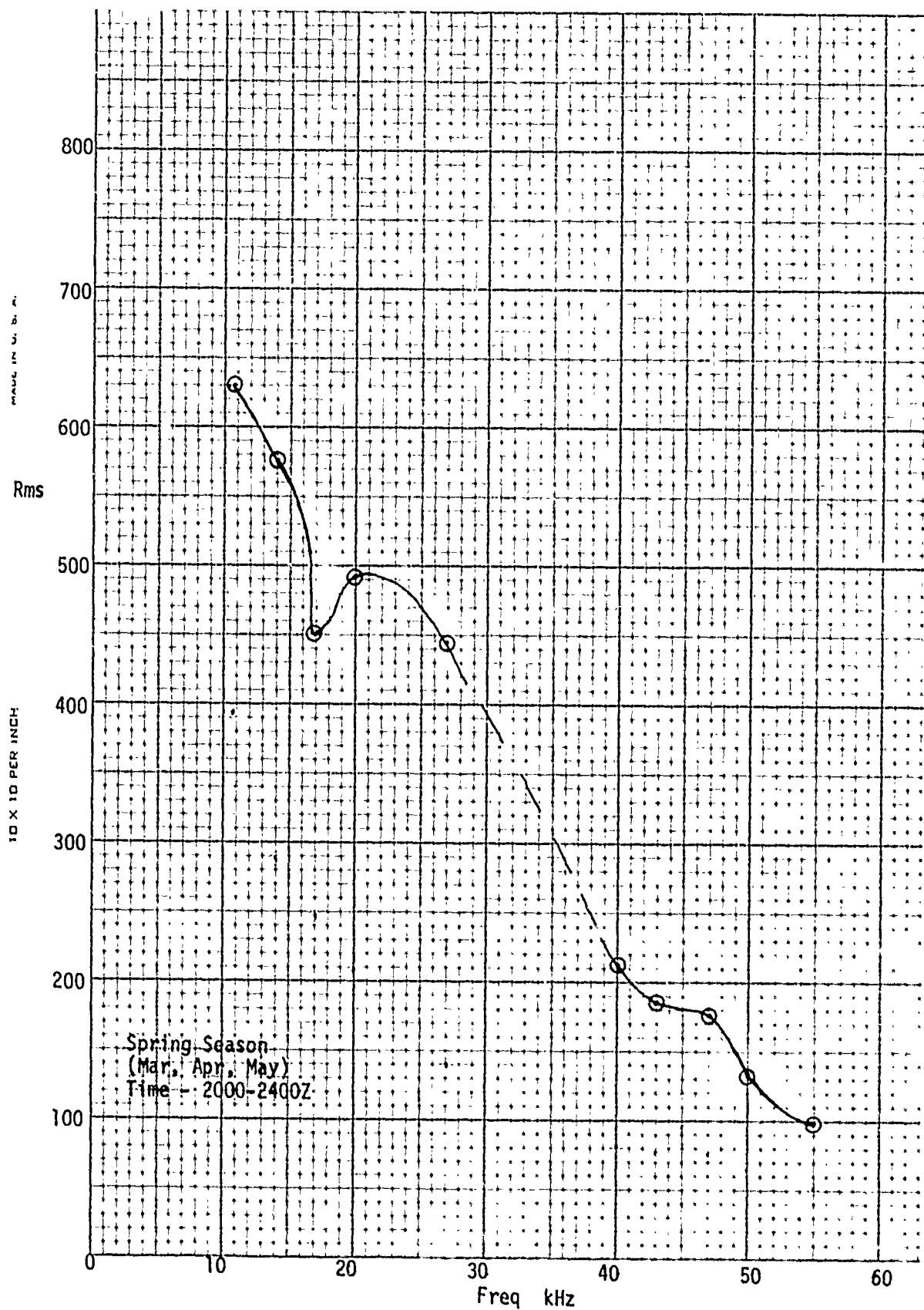






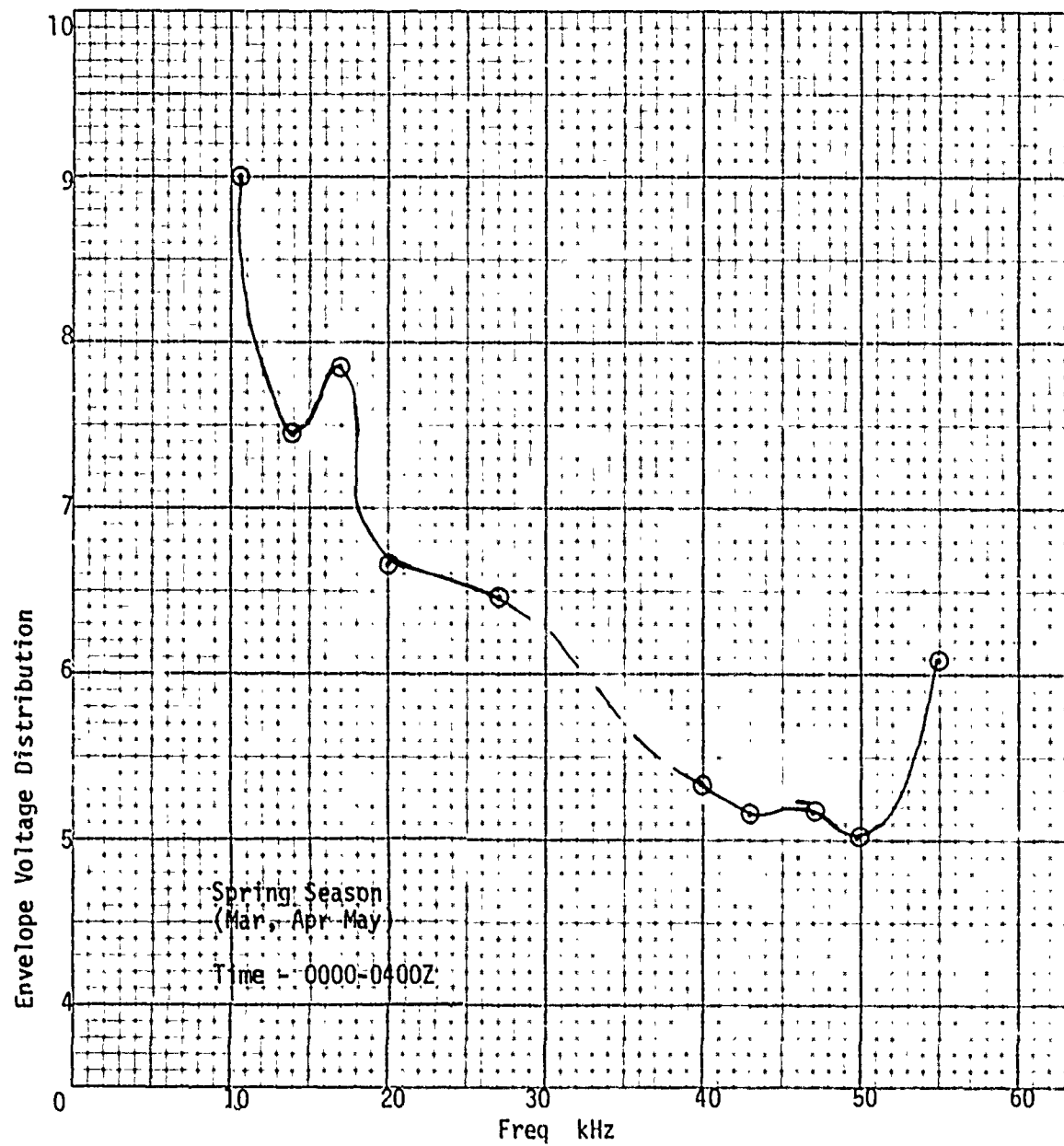


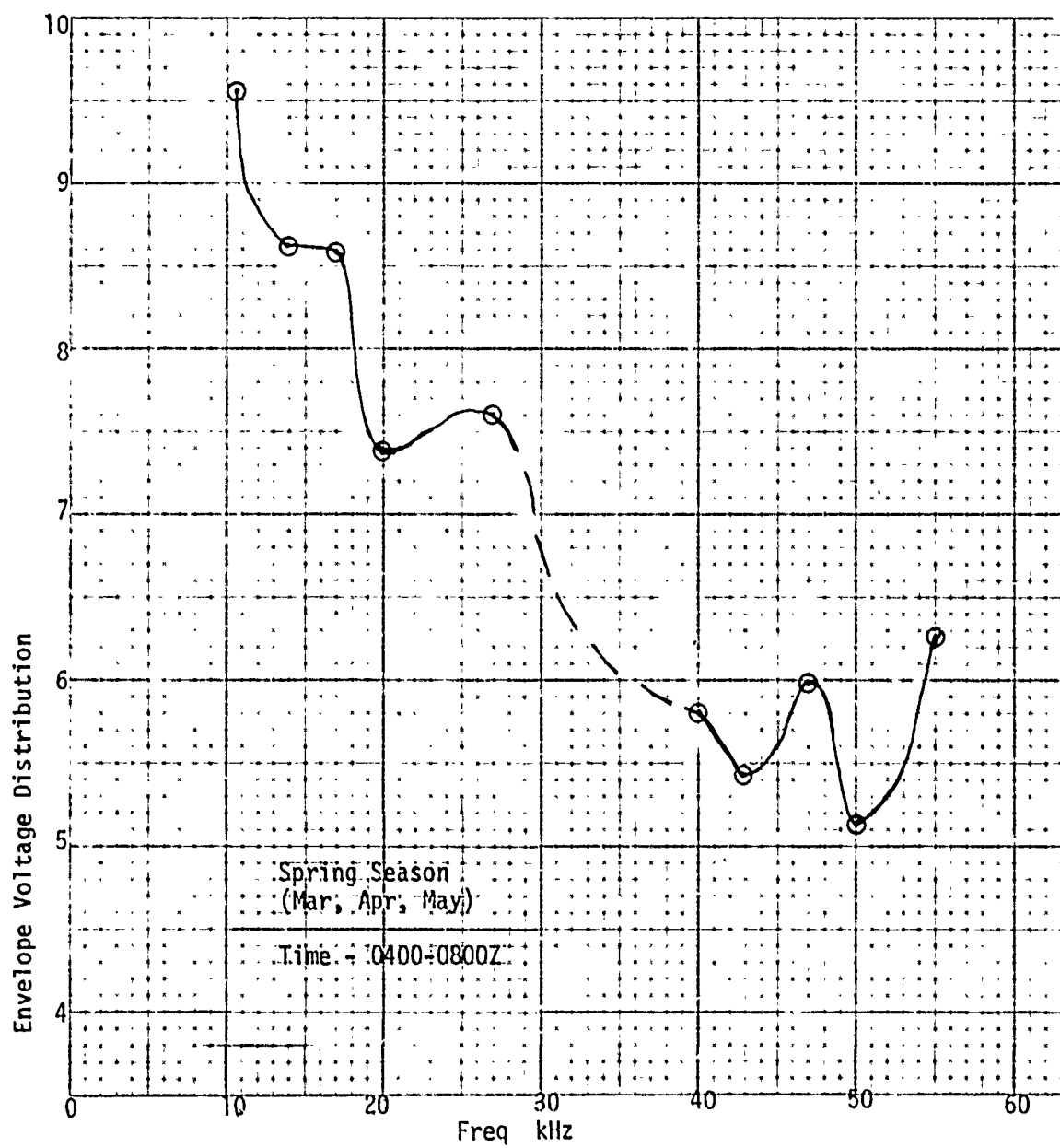


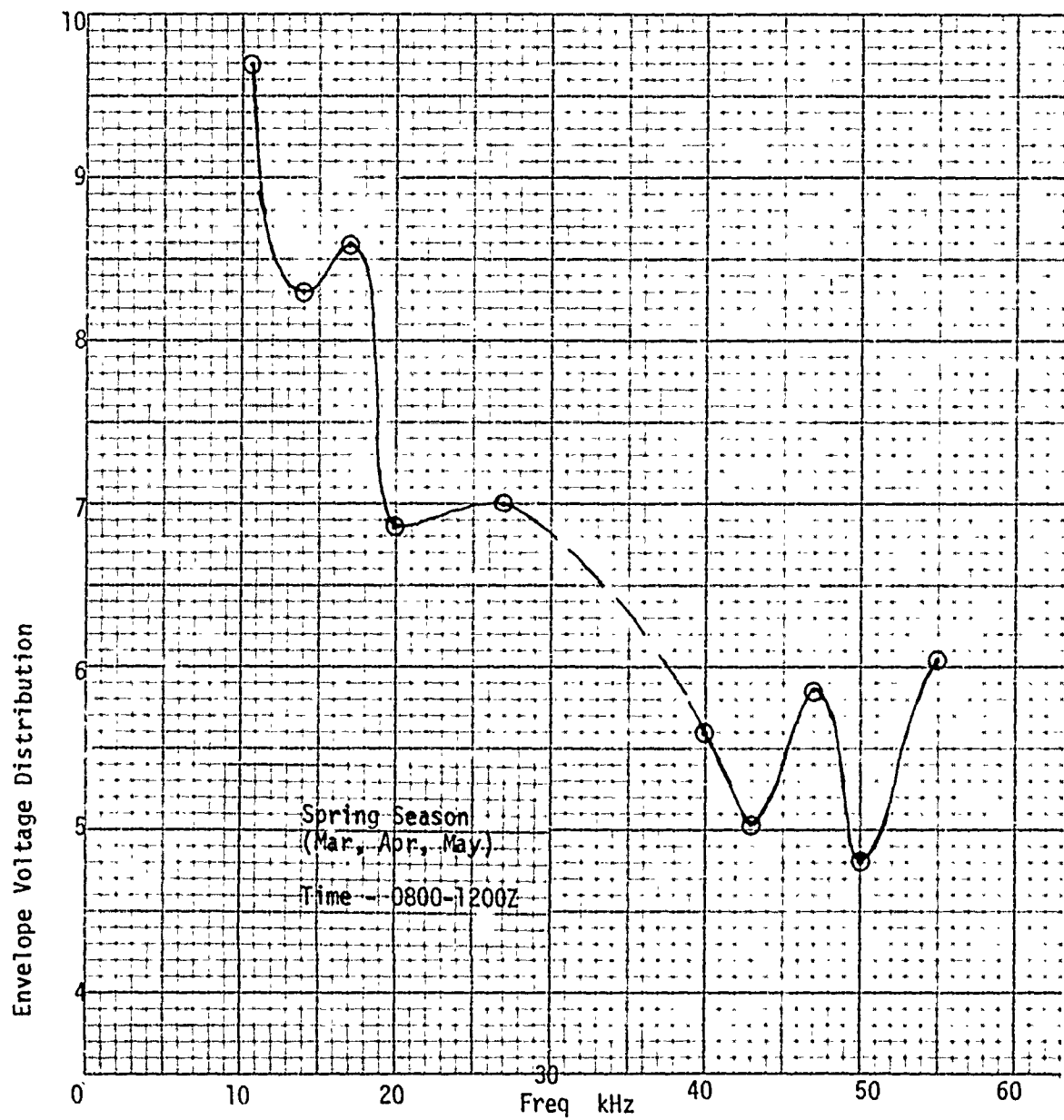


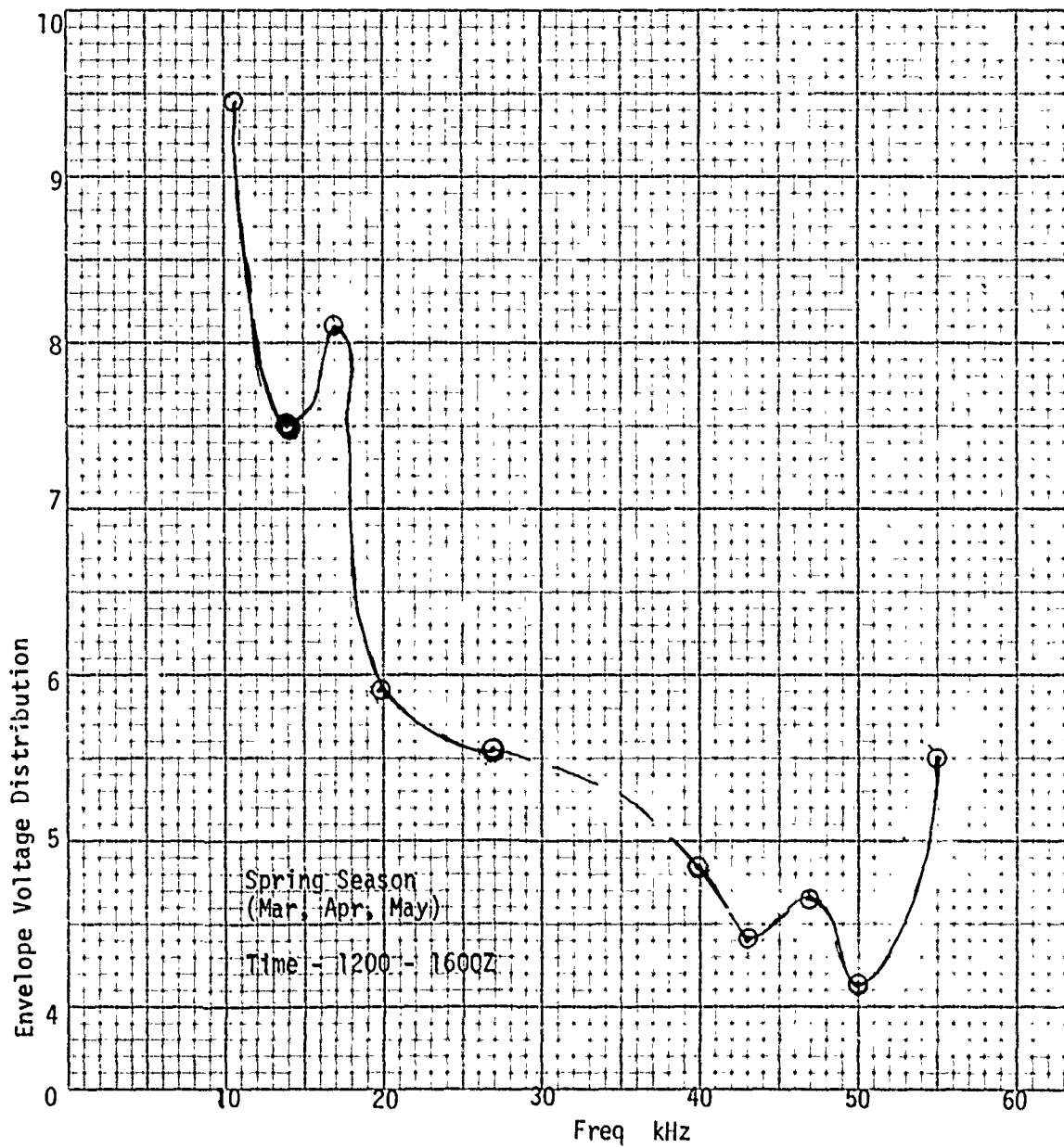
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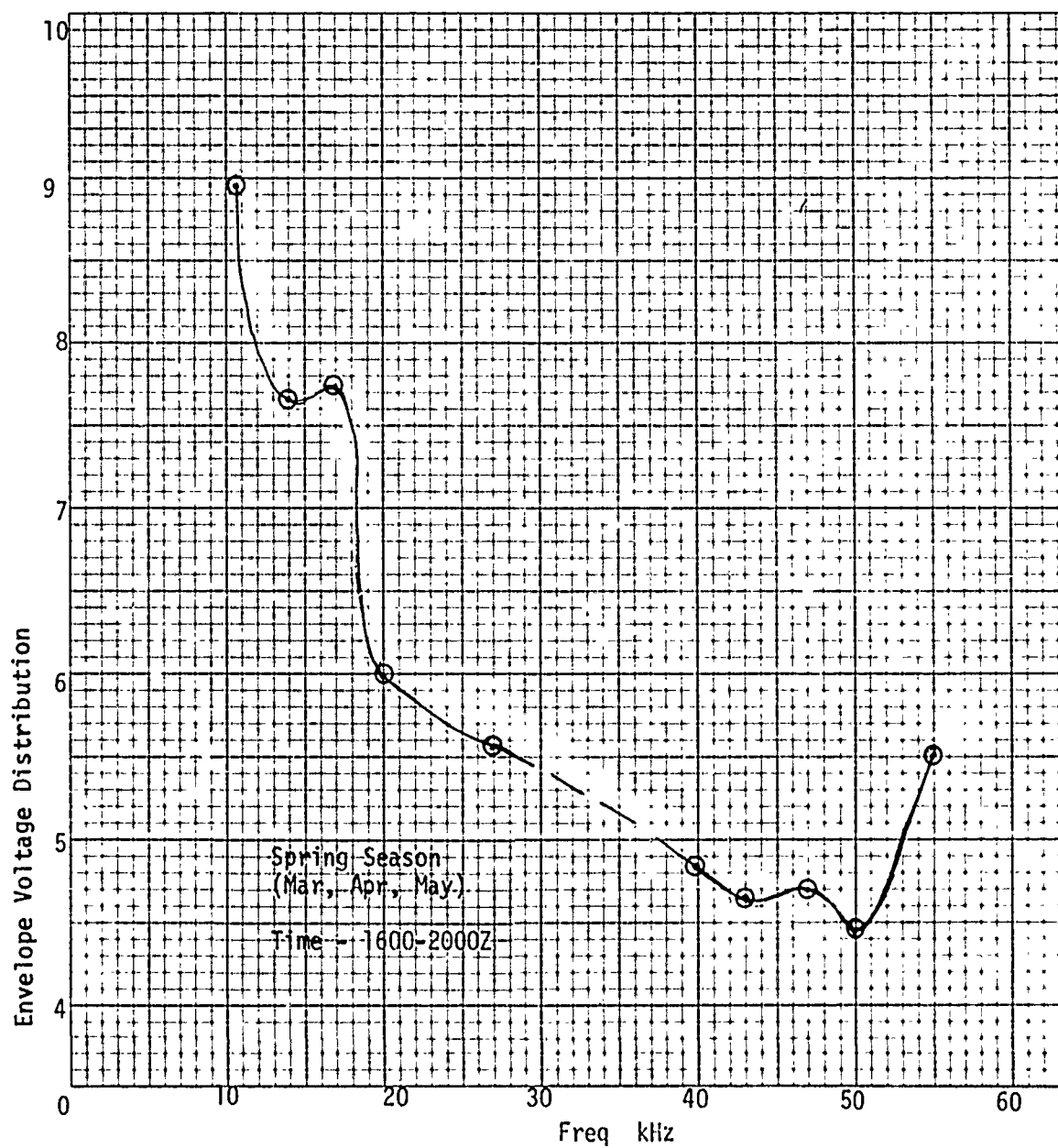


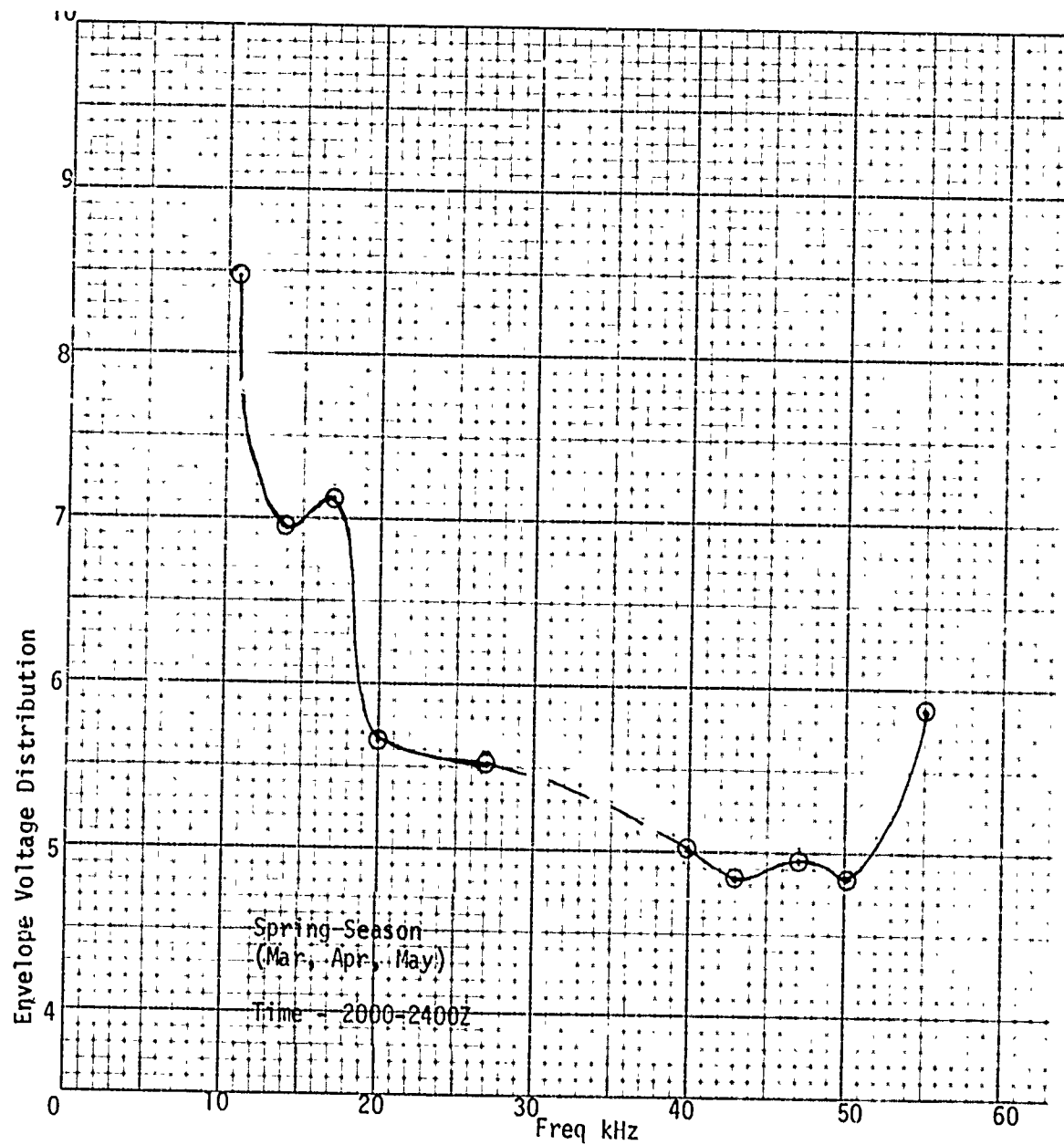




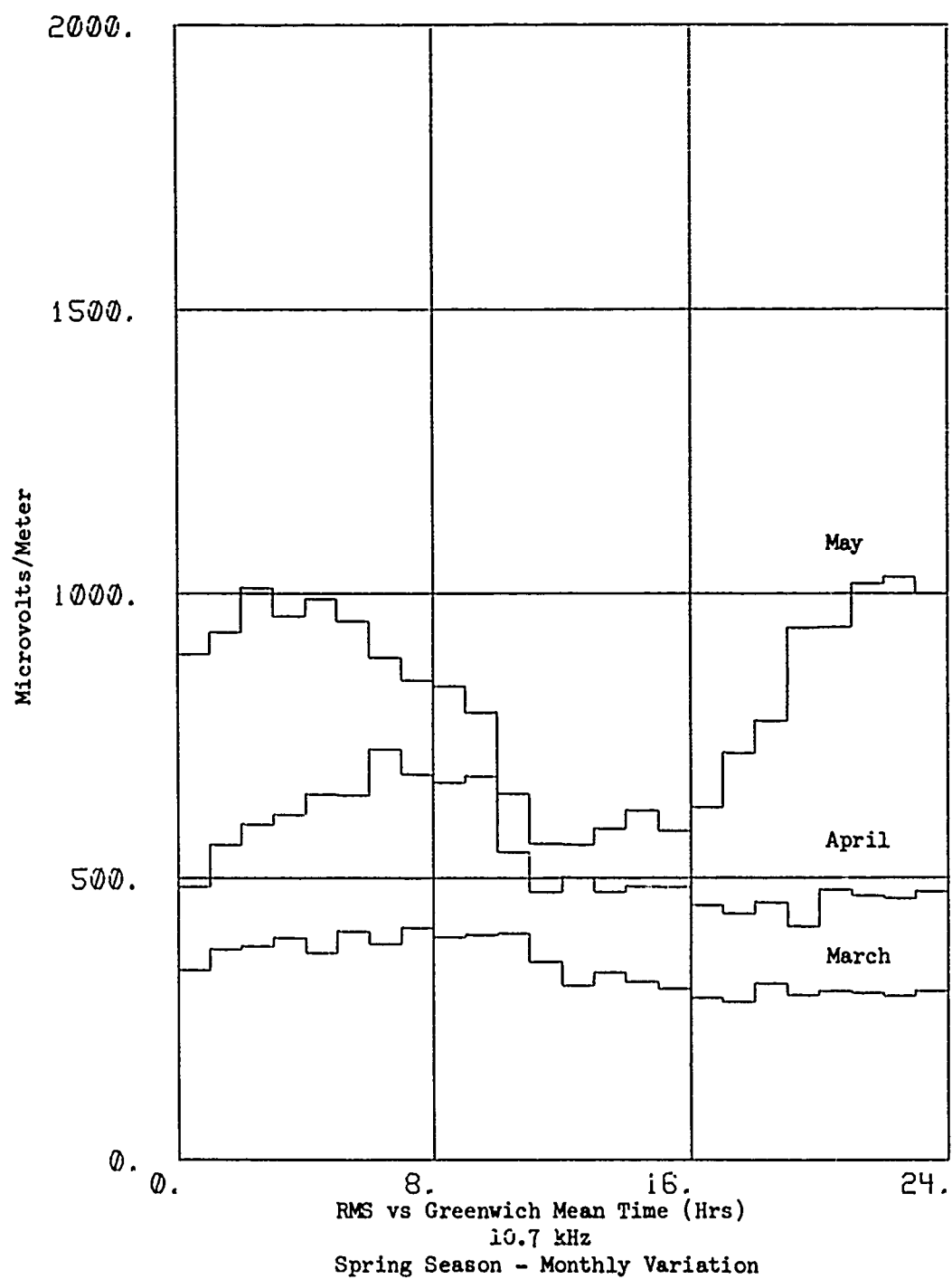




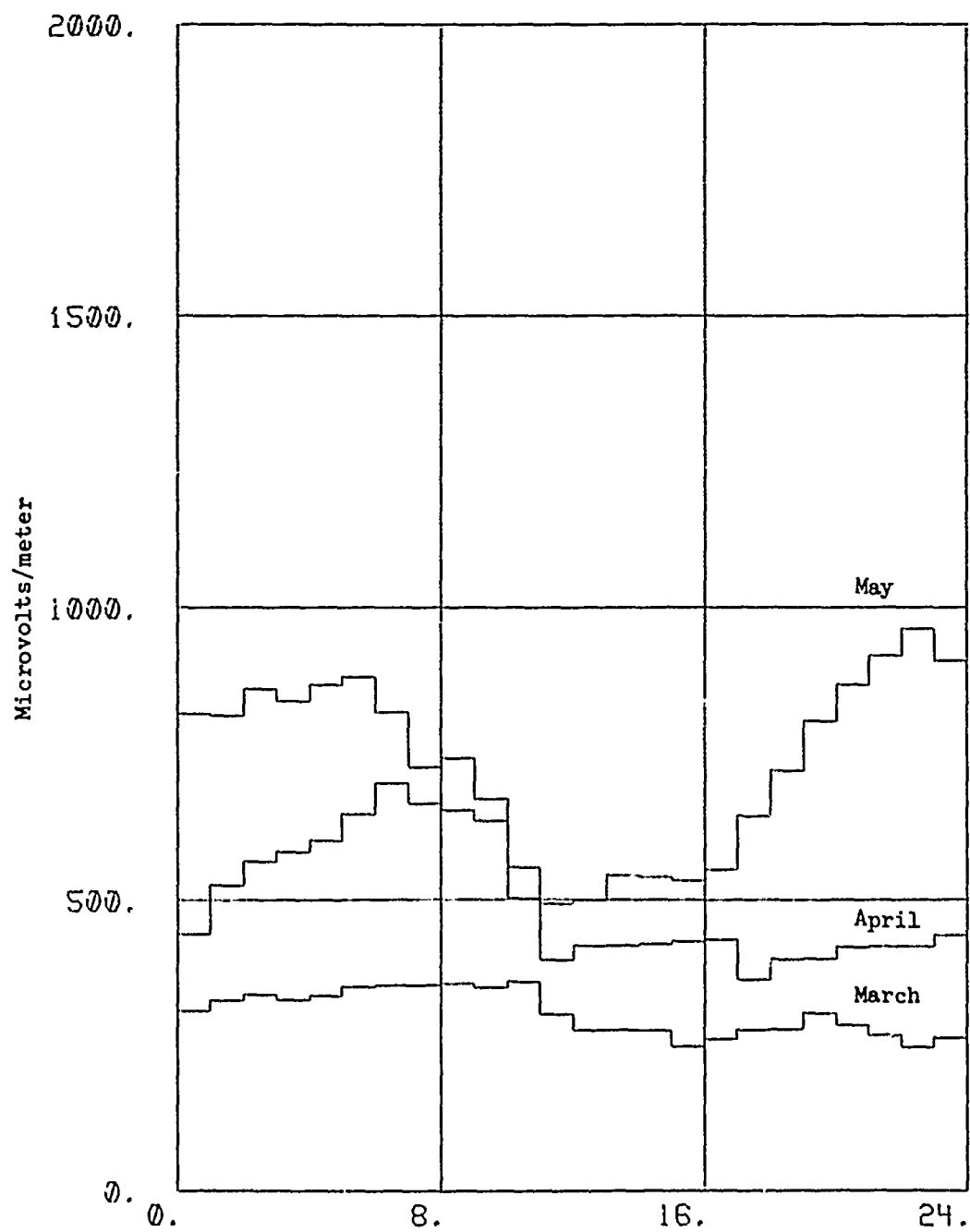




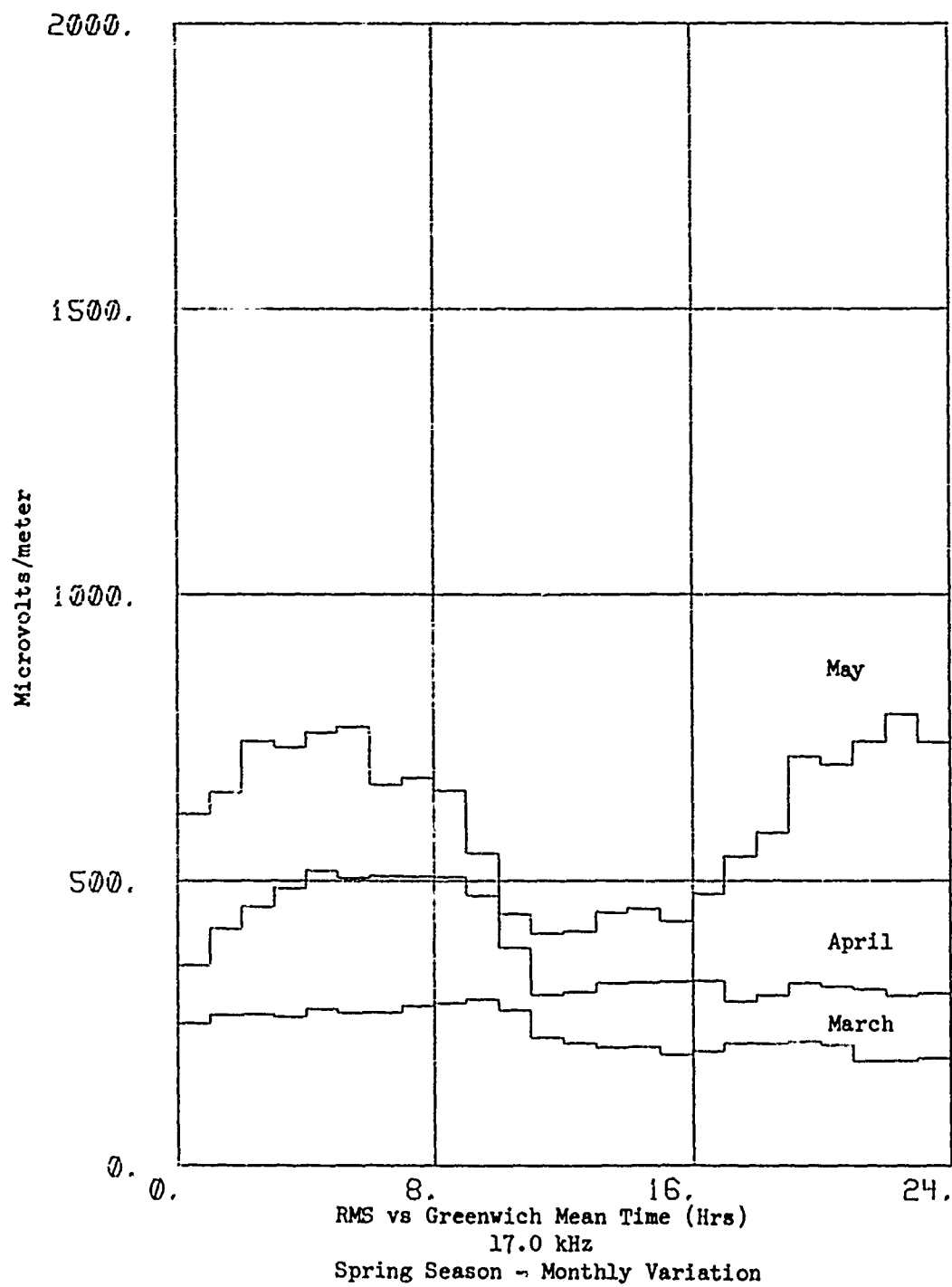
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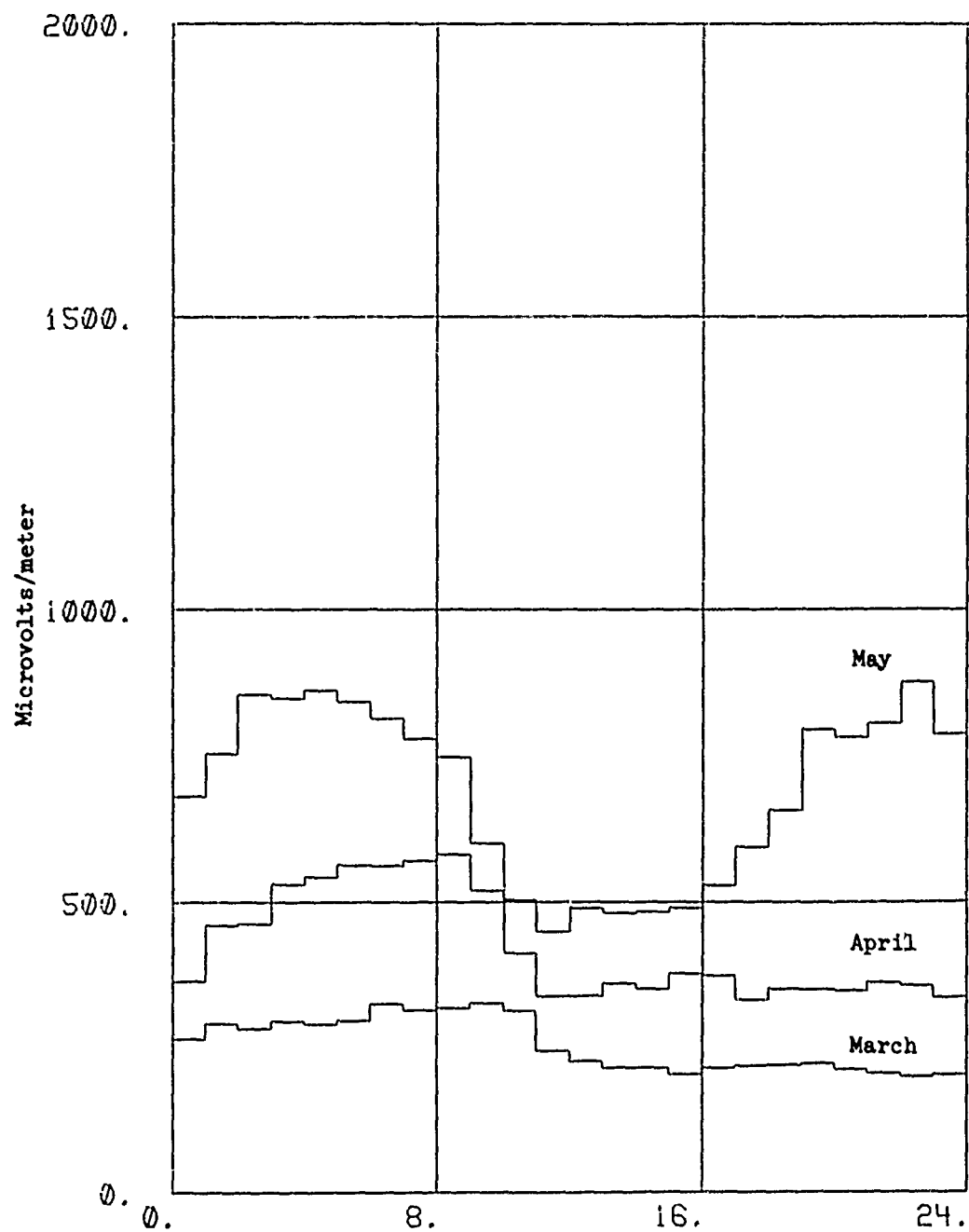




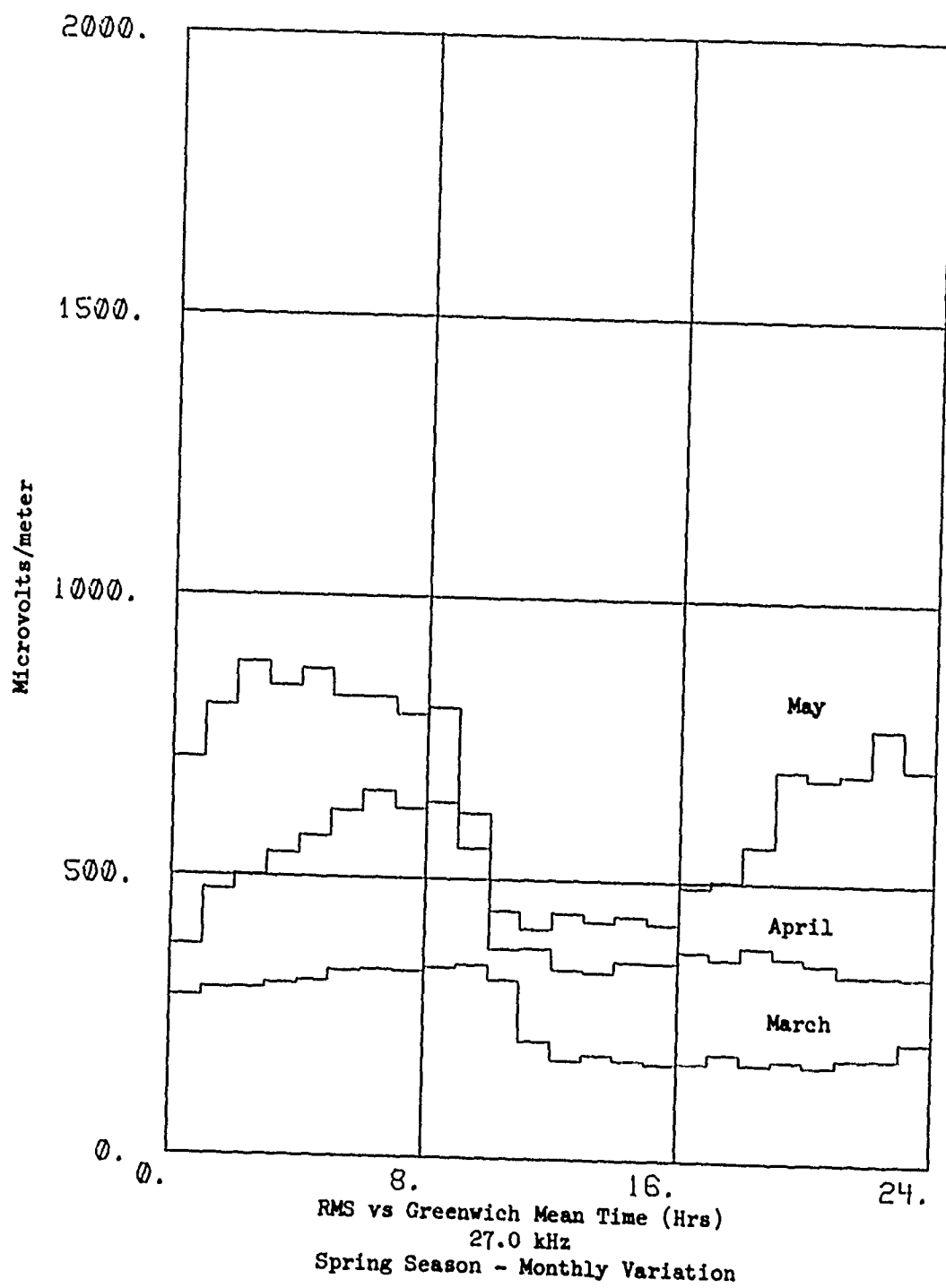


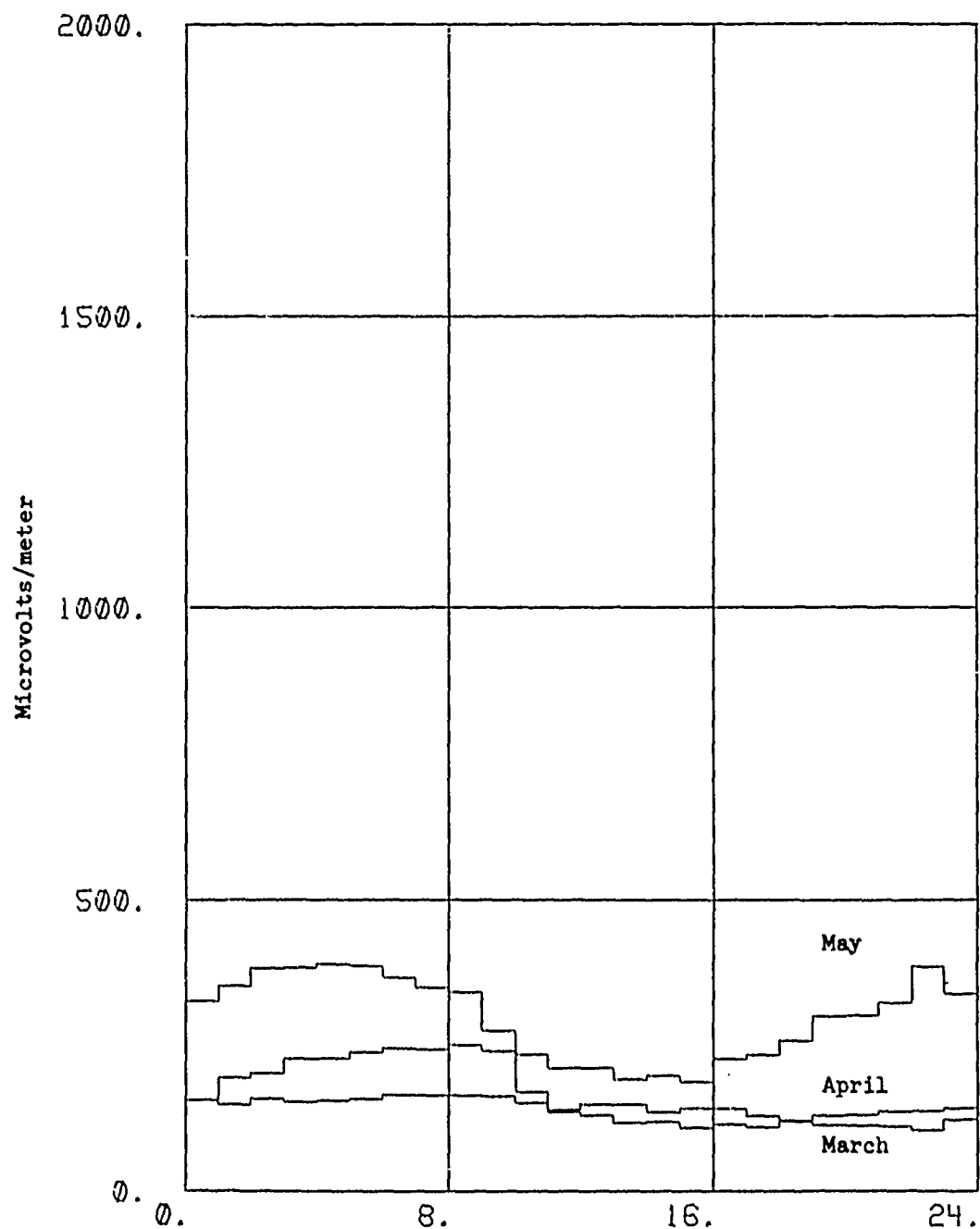
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Spring Season - Monthly Variation



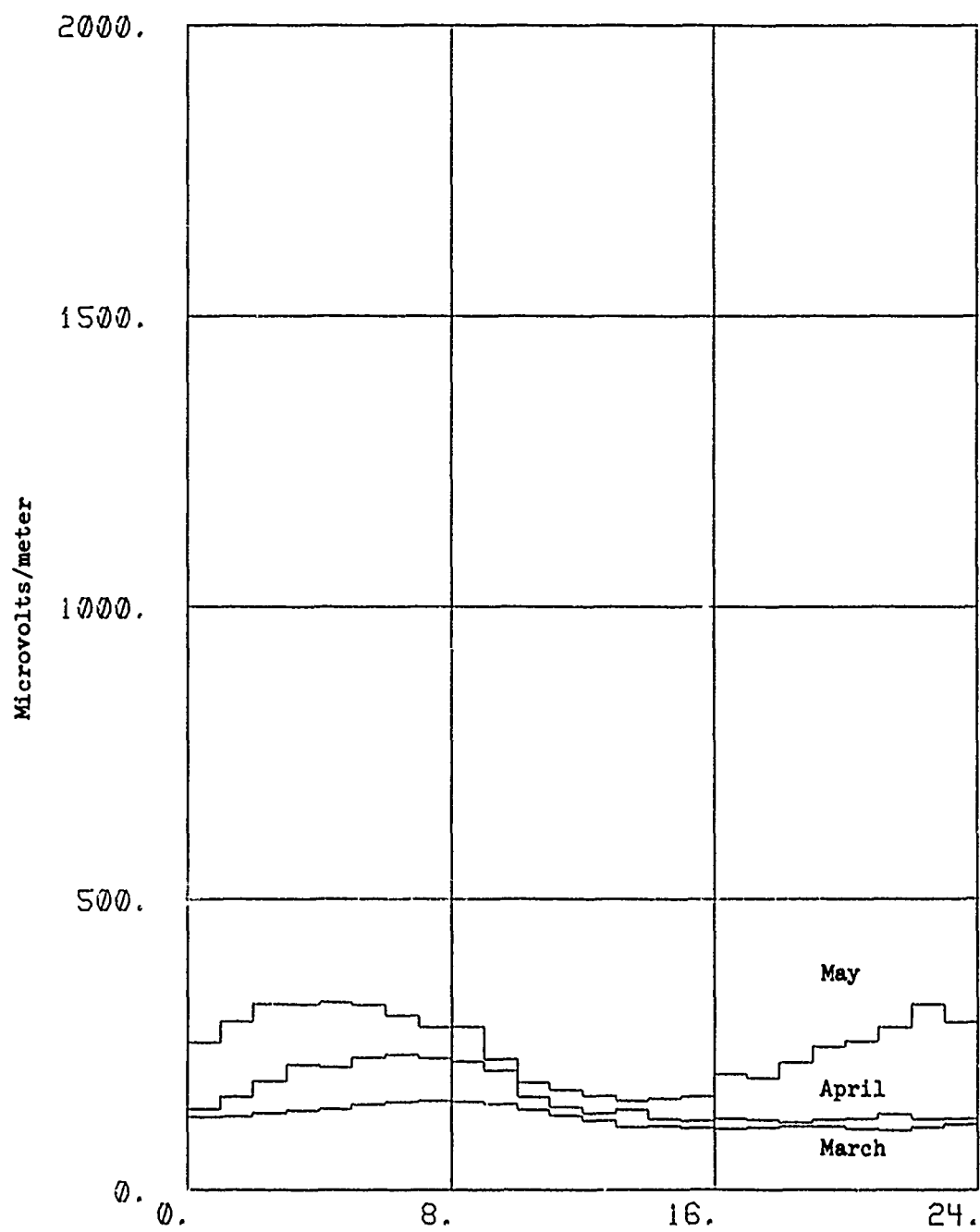


RMS vs Greenwich Mean Time (Hrs)  
 20.0 kHz  
 Spring Season - Monthly Variation

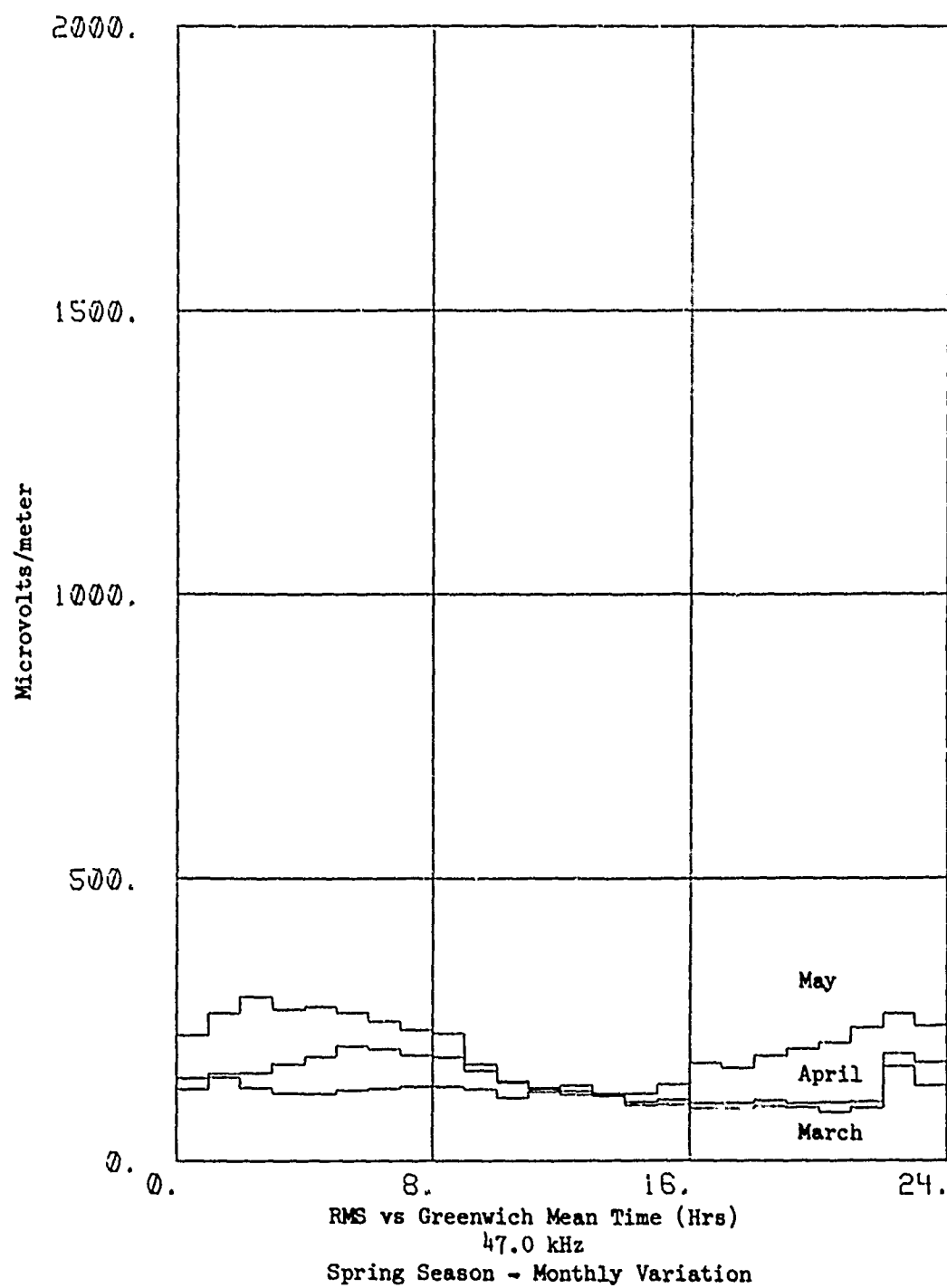


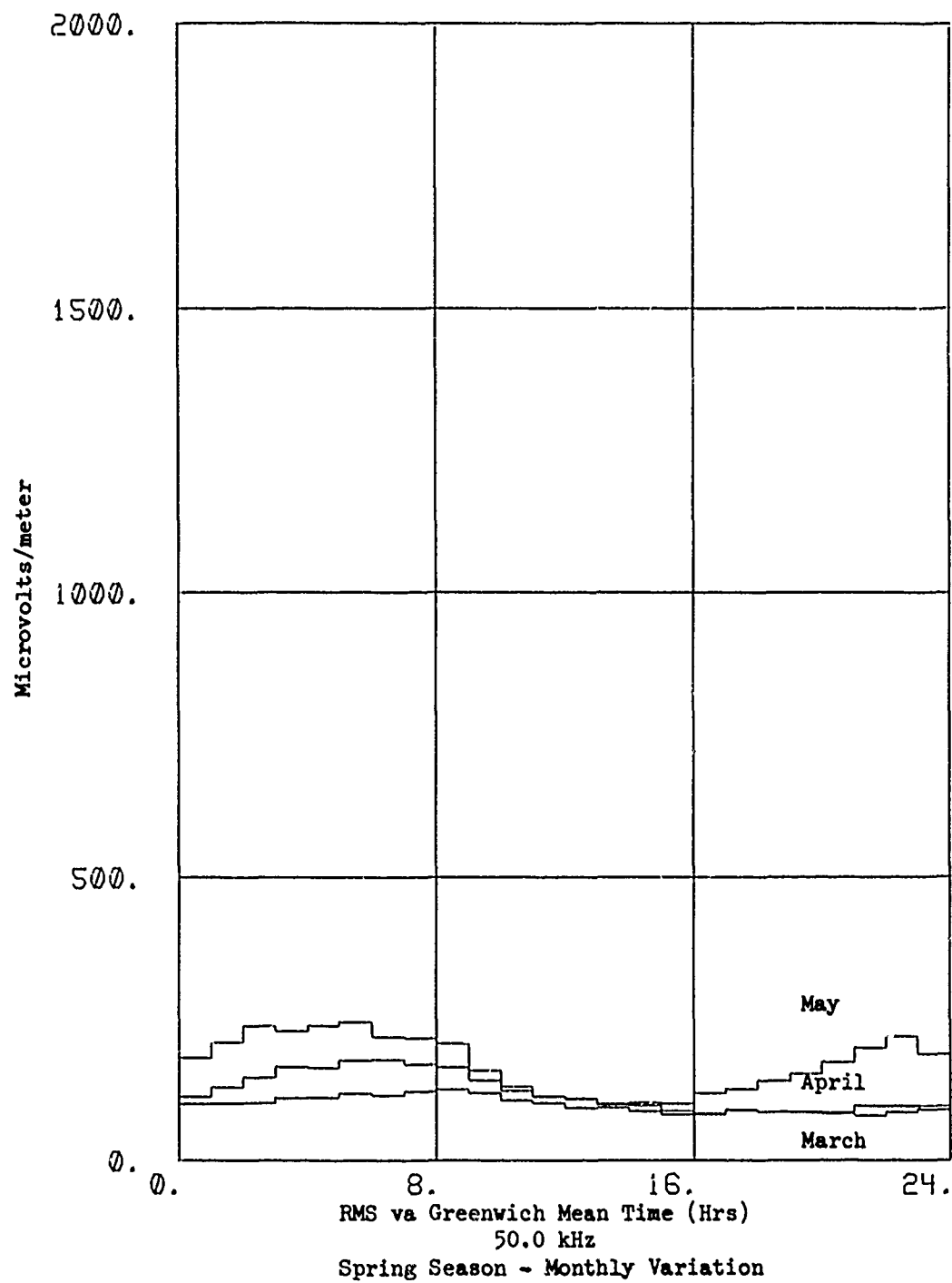


RMS vs Greenwich Mean Time (Hrs)  
40.0 kHz  
Spring Season - Monthly Variation

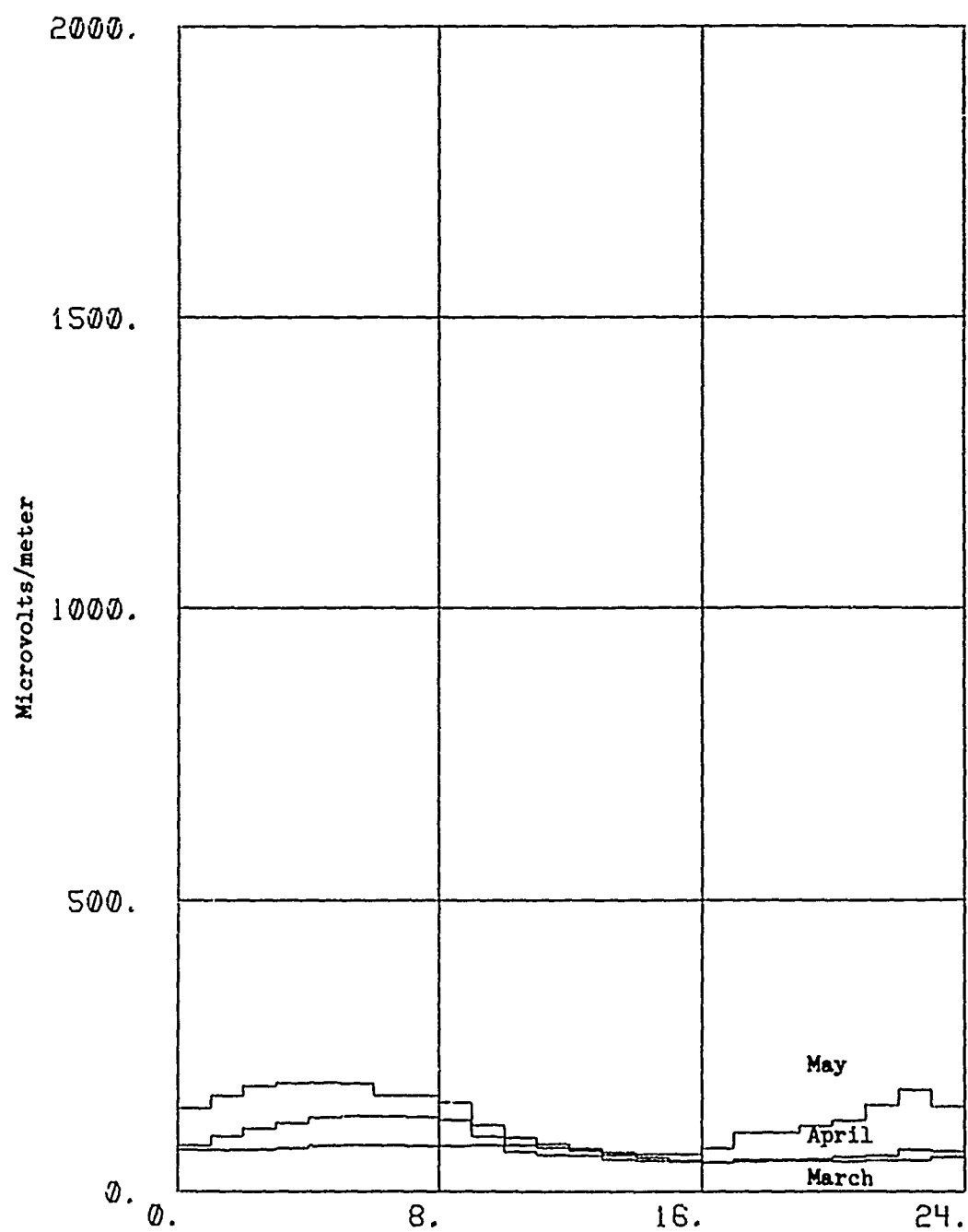


RMS vs Greenwich Mean Time (Hrs)  
43.0 kHz  
Spring Season - Monthly Variation



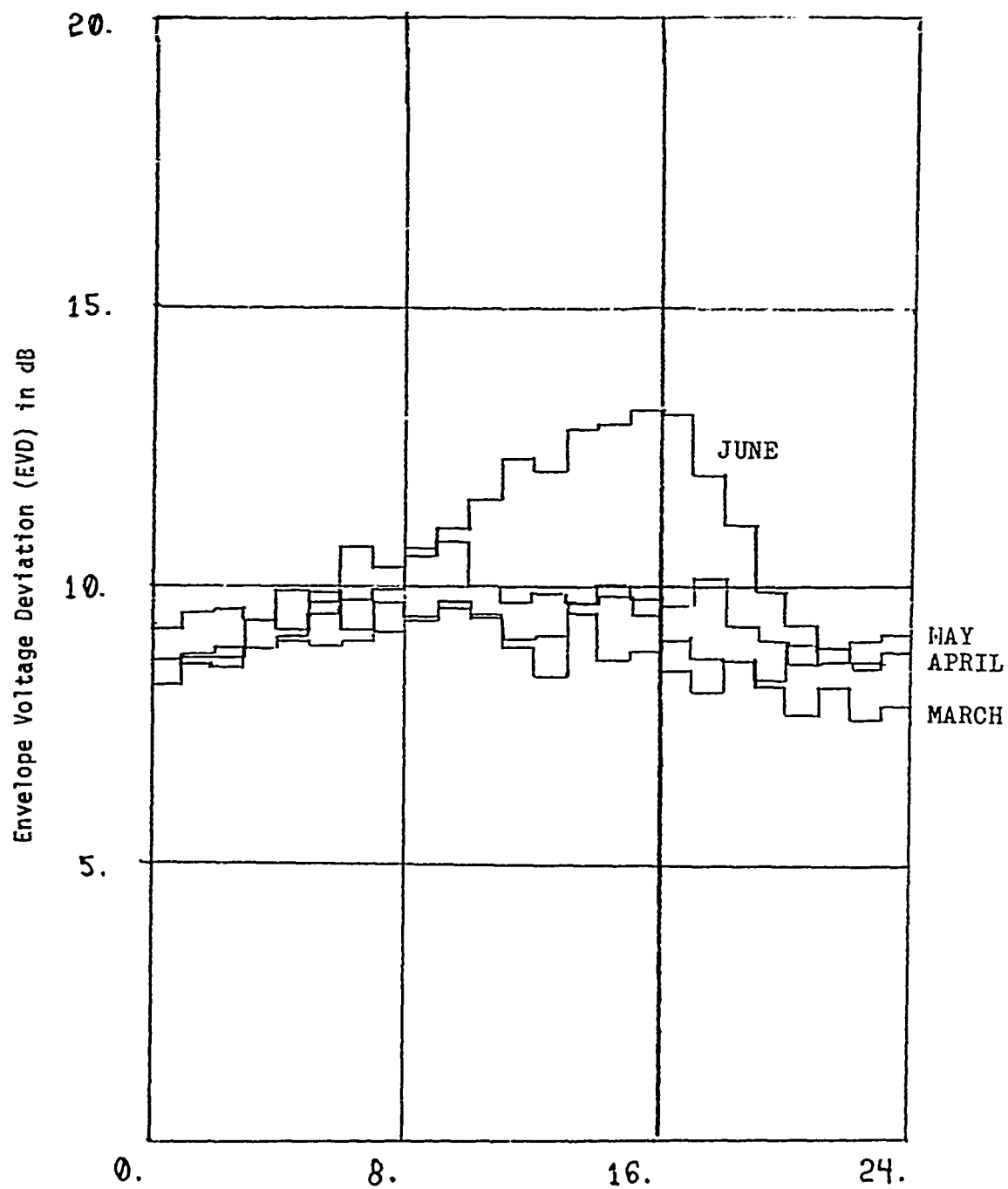




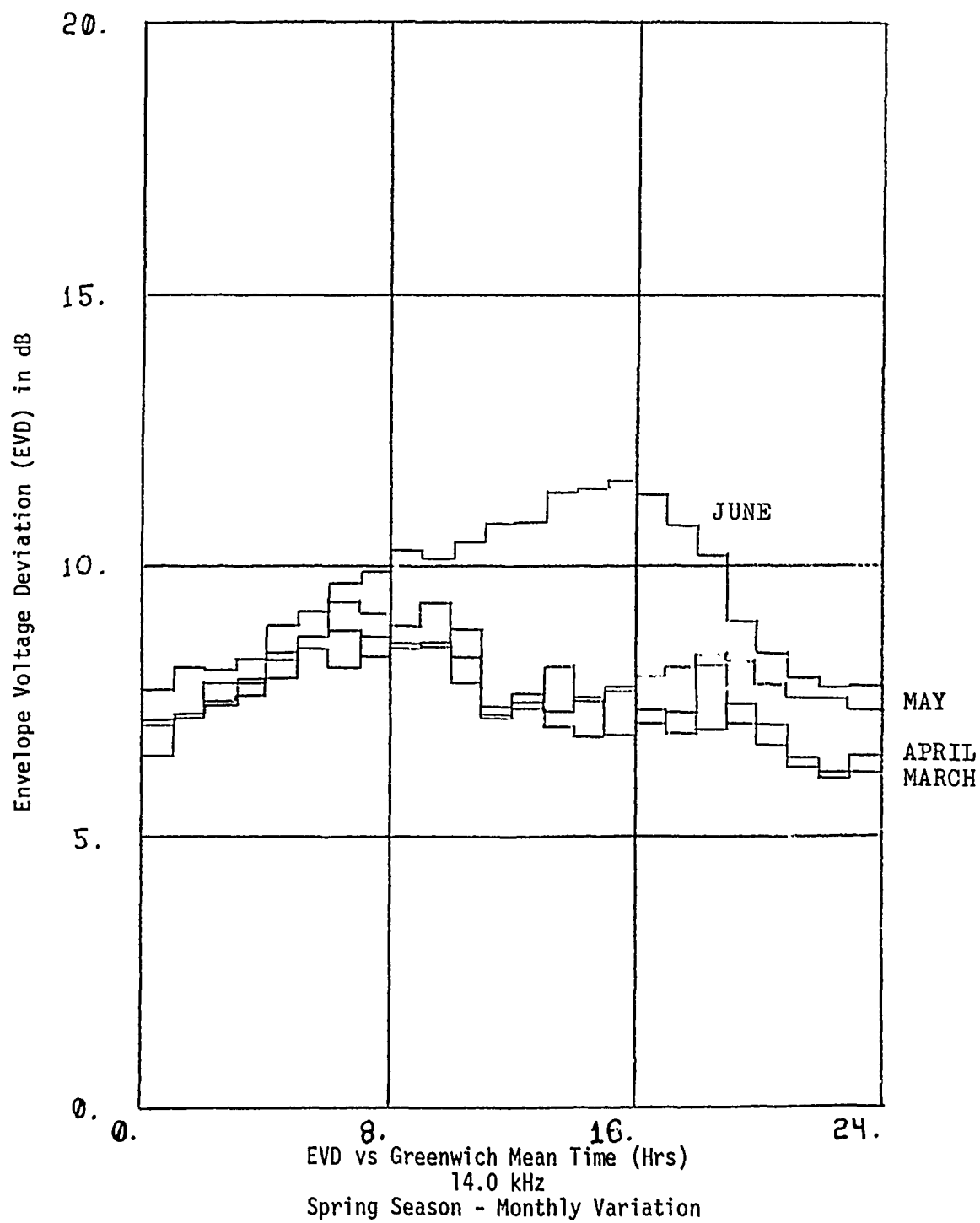


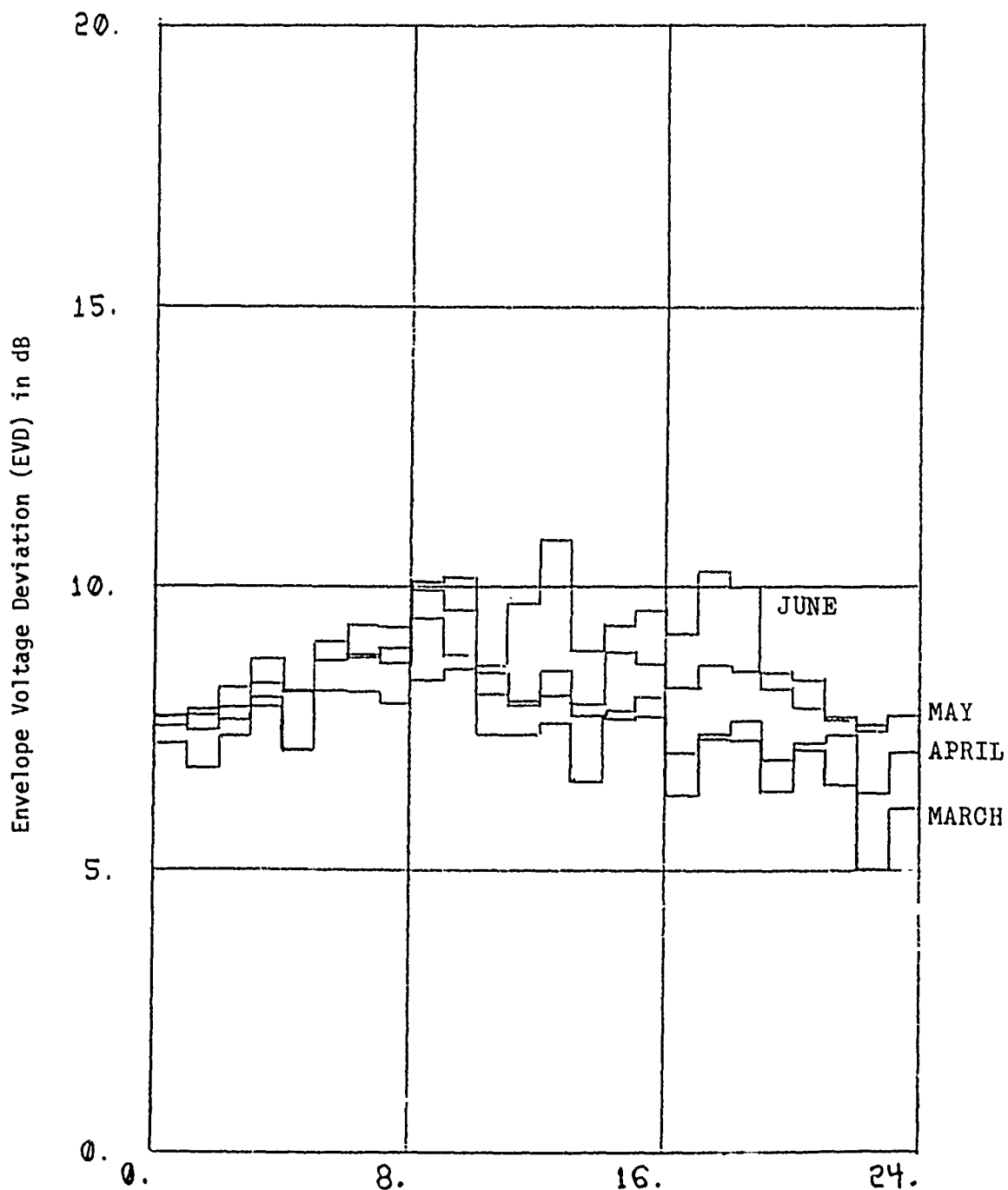
RMS vs Greenwich Mean Time (Hrs)  
 55.0 kHz  
 Spring Season - Monthly Variation

#### 5.4 - EVD vs TIME (SPRING VARIATION)

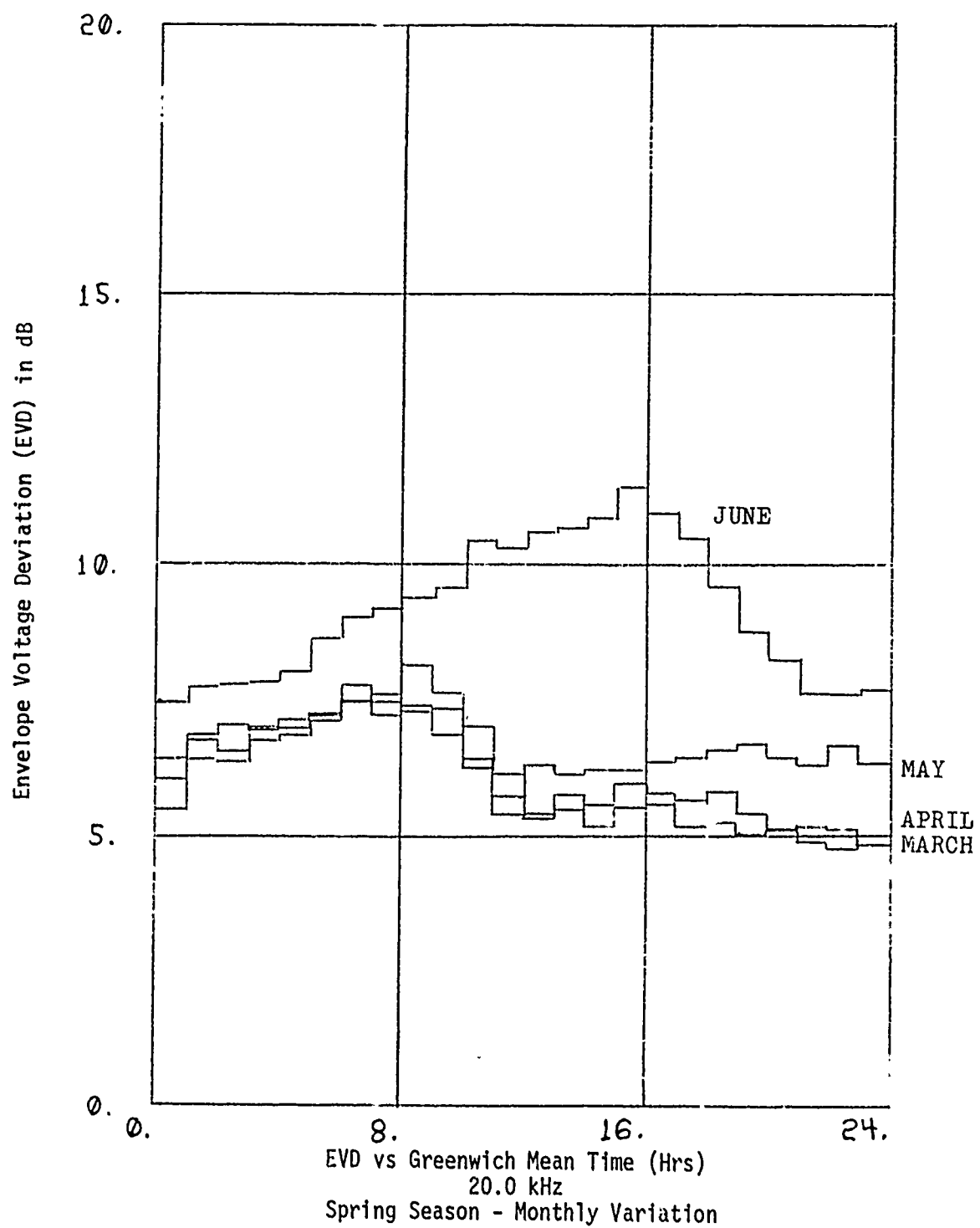


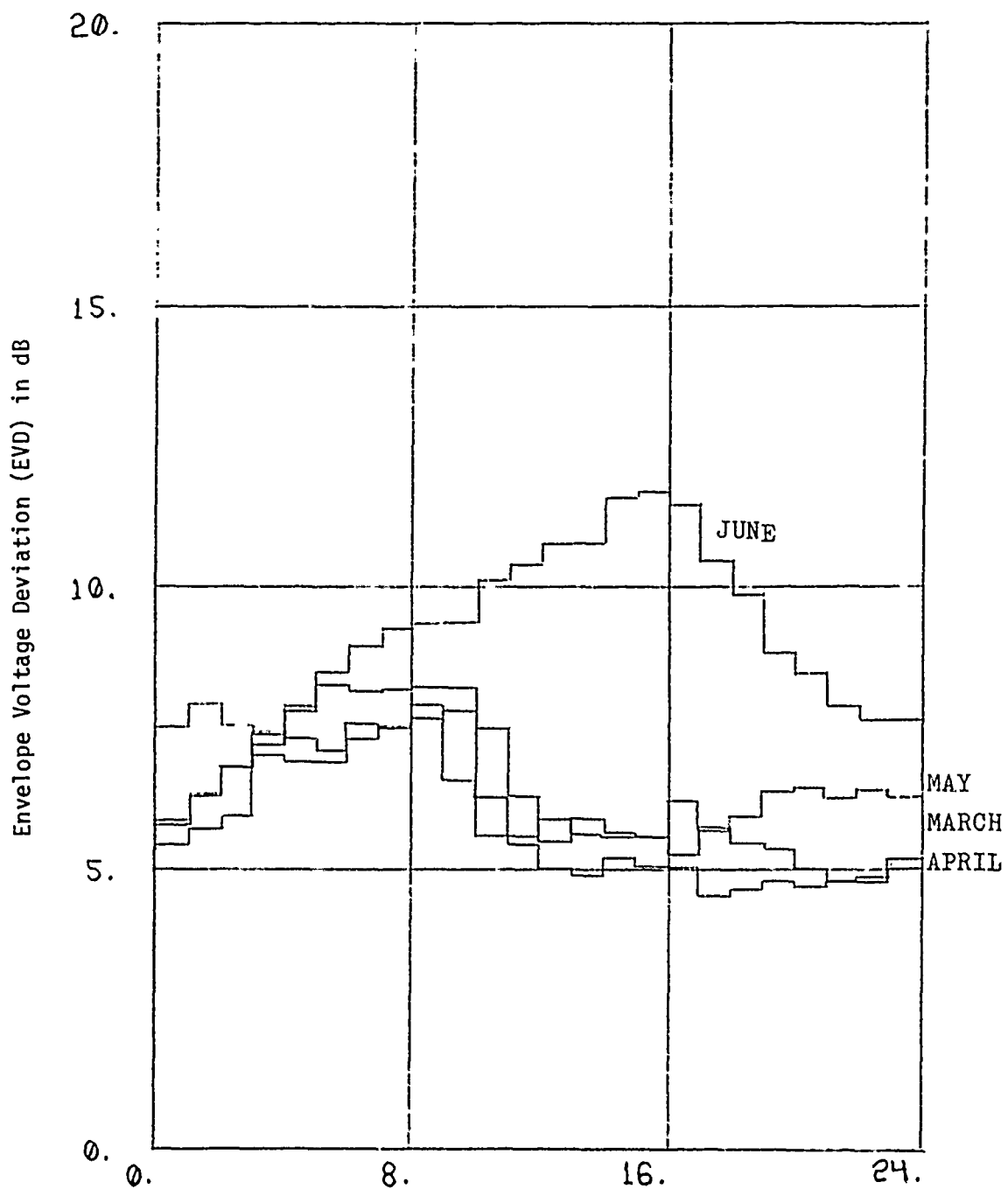
EVD vs Greenwich Mean Time (Hrs)  
10.7 kHz  
Spring Season - Monthly Variation



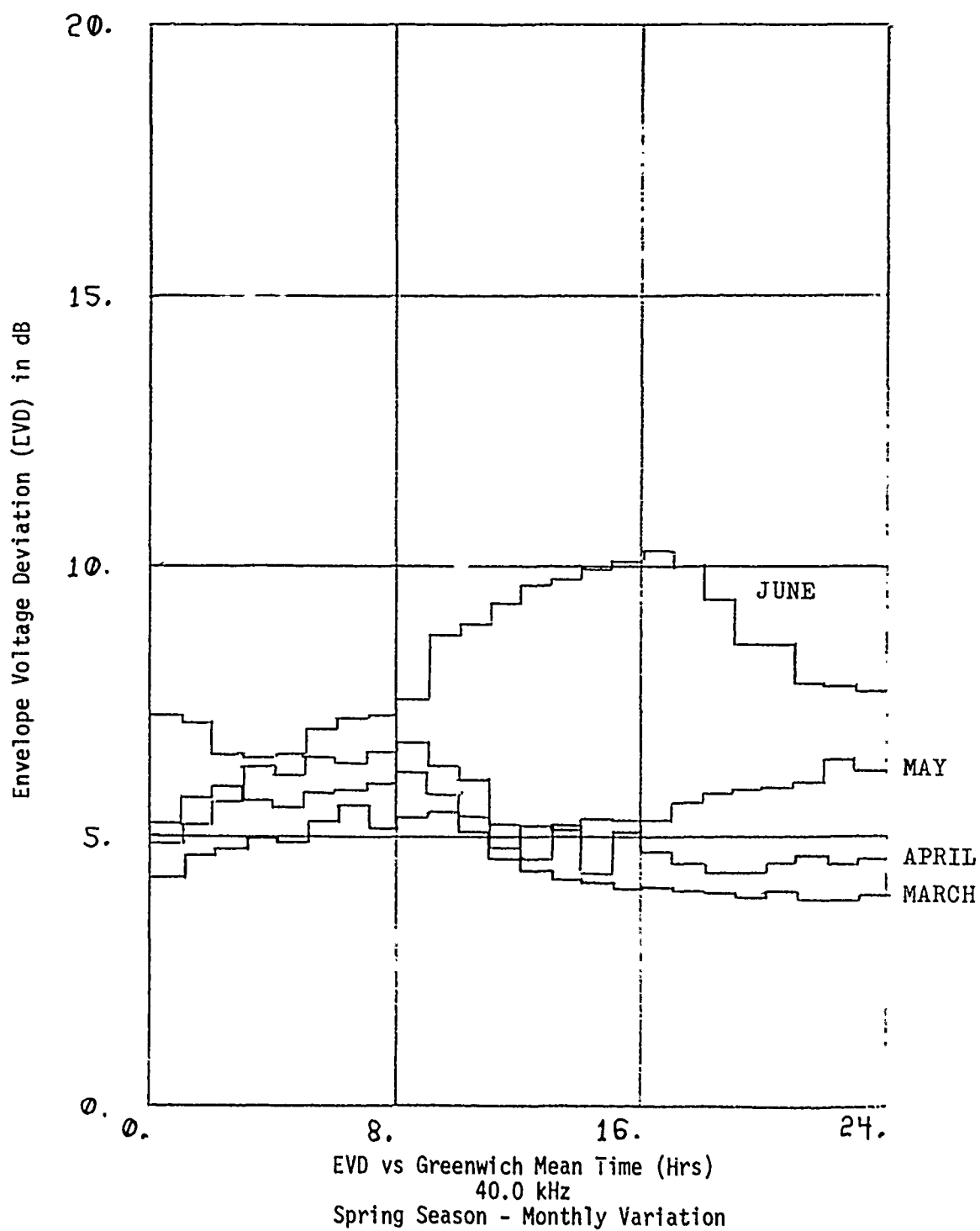


EVD vs Greenwich Mean Time (Hrs)  
 17.0 kHz  
 Spring Season - Monthly Variation

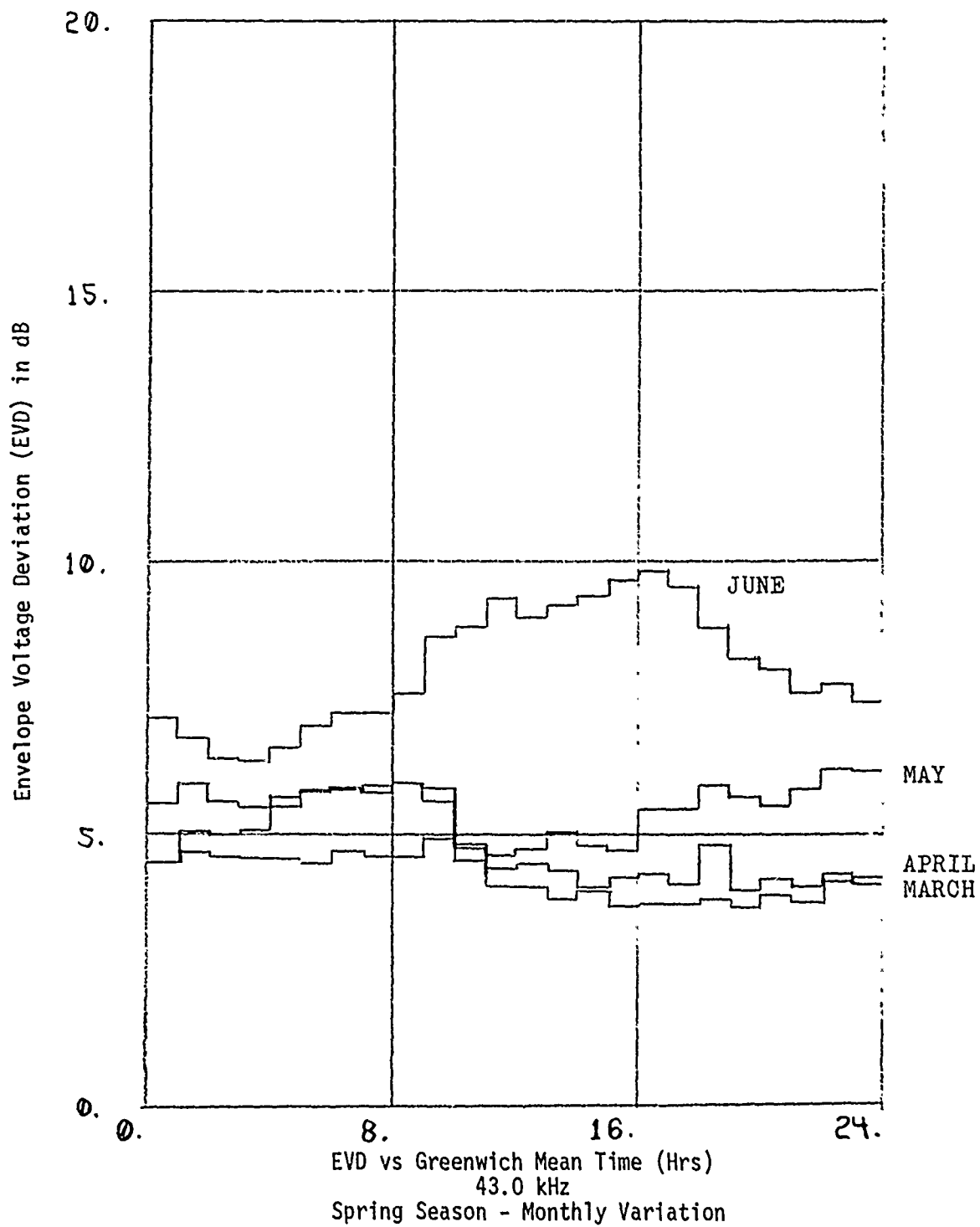


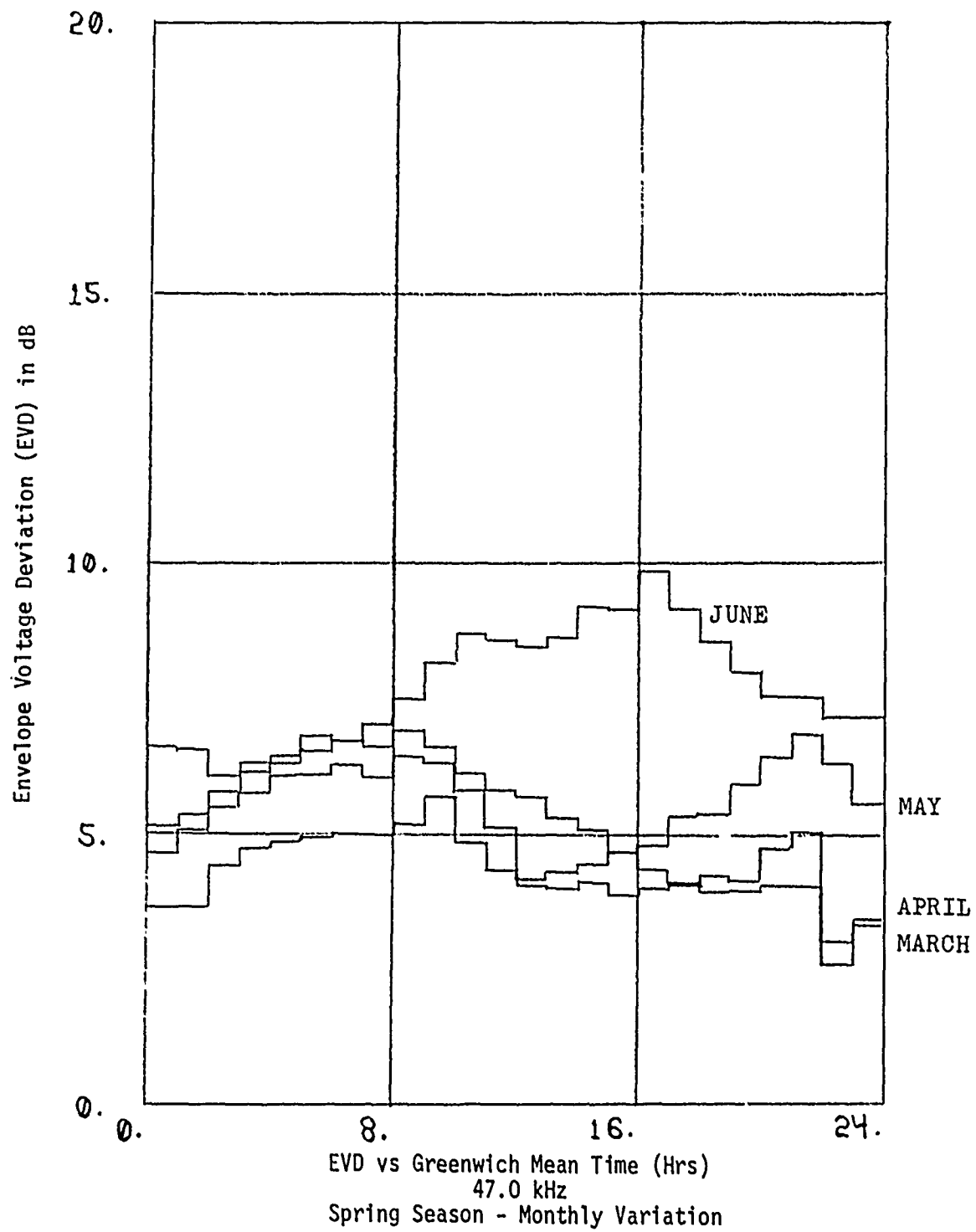


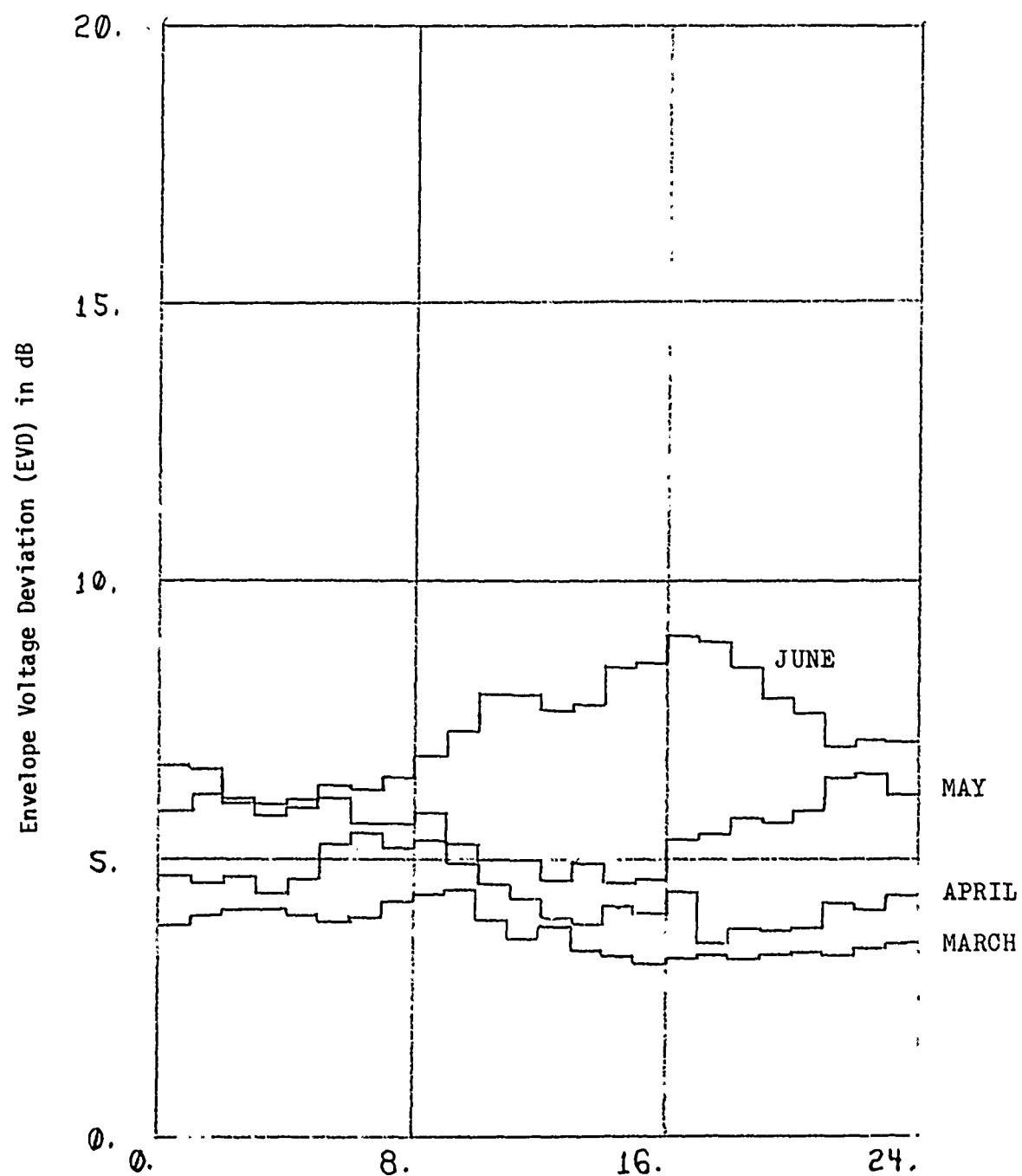
EVD vs Greenwich Mean Time (Hrs)  
27.0 kHz  
Spring Season - Monthly Variation



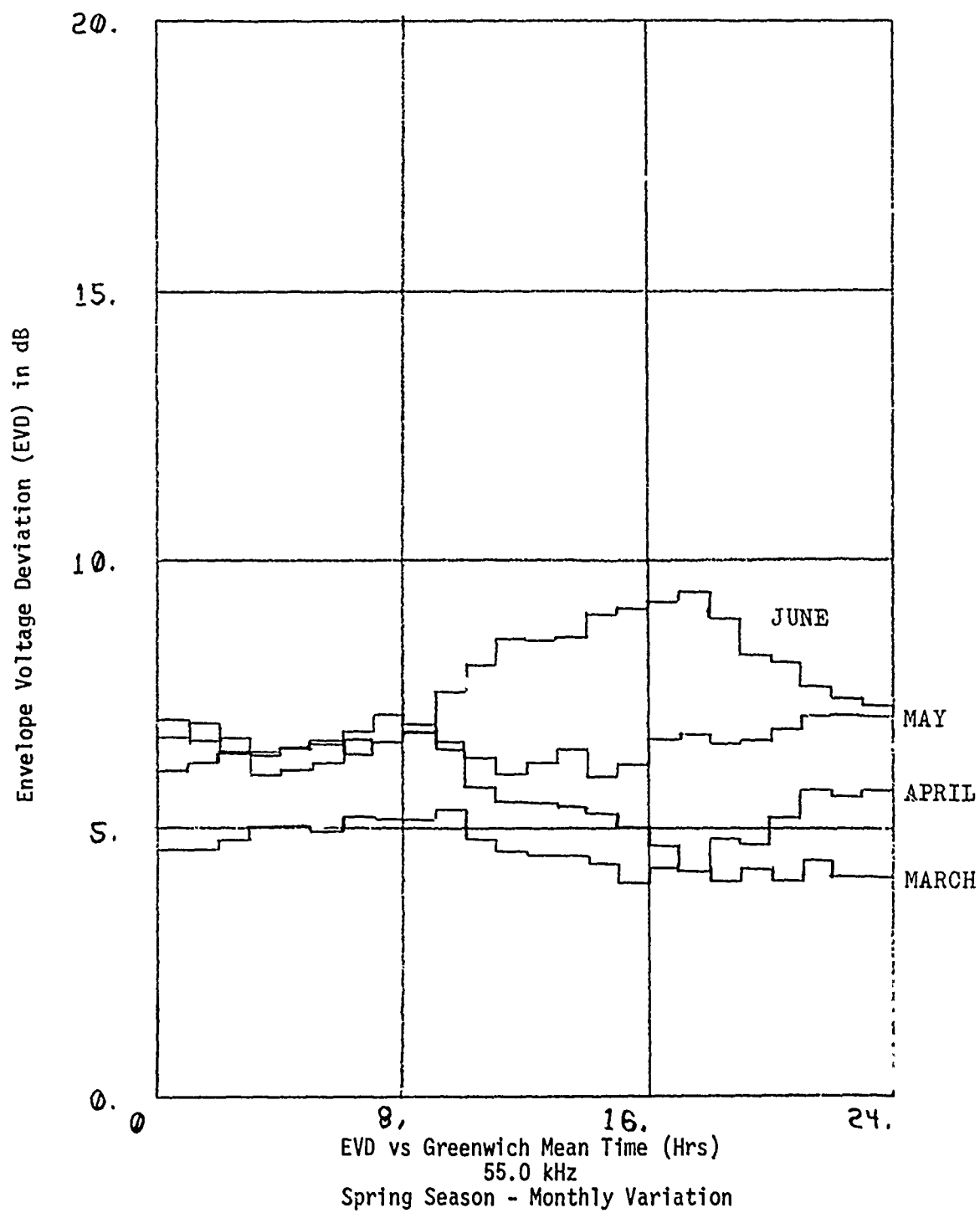




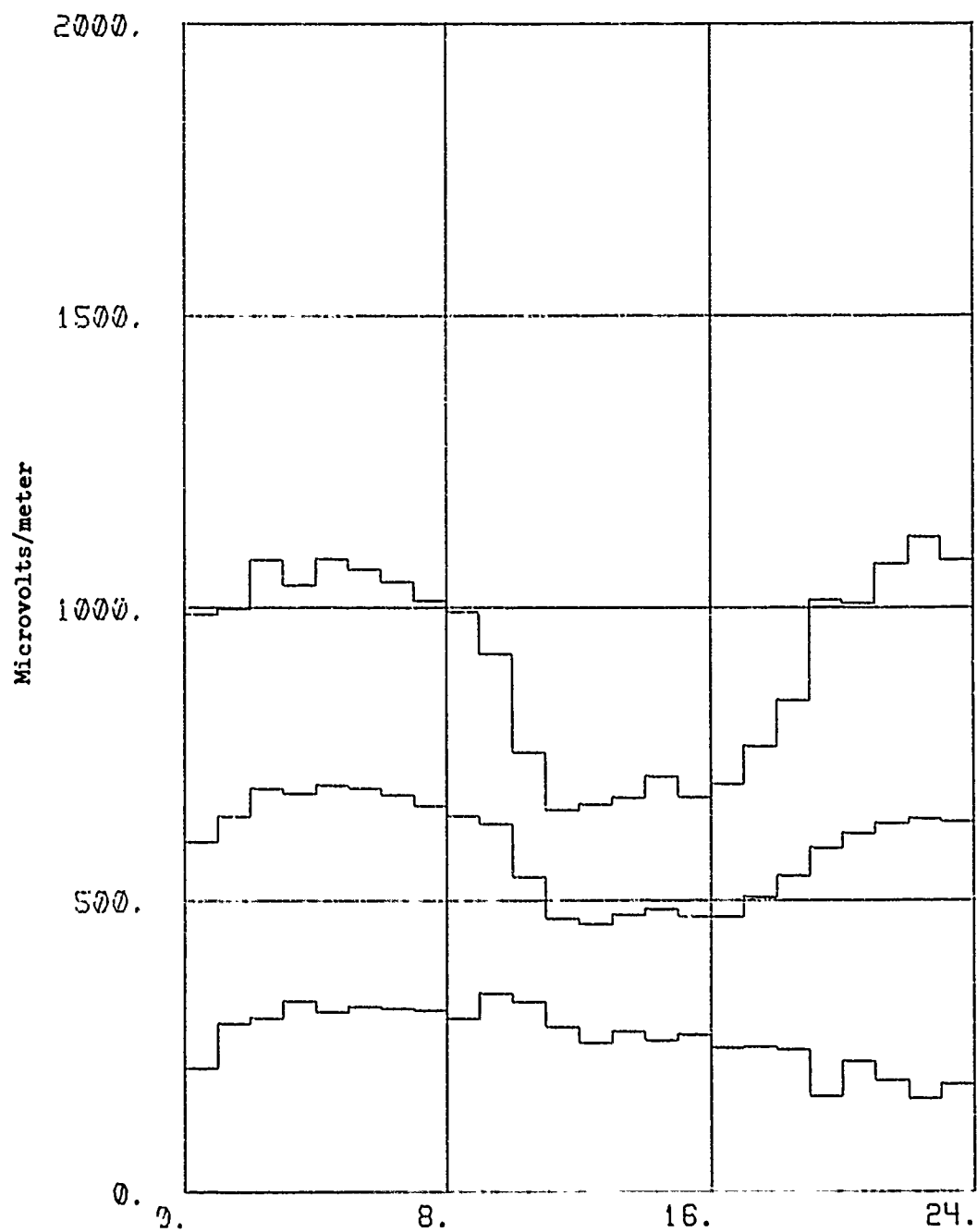




EVD vs Greenwich Mean Time (Hrs)  
 50.0 kHz  
 Spring Season - Monthly Variation

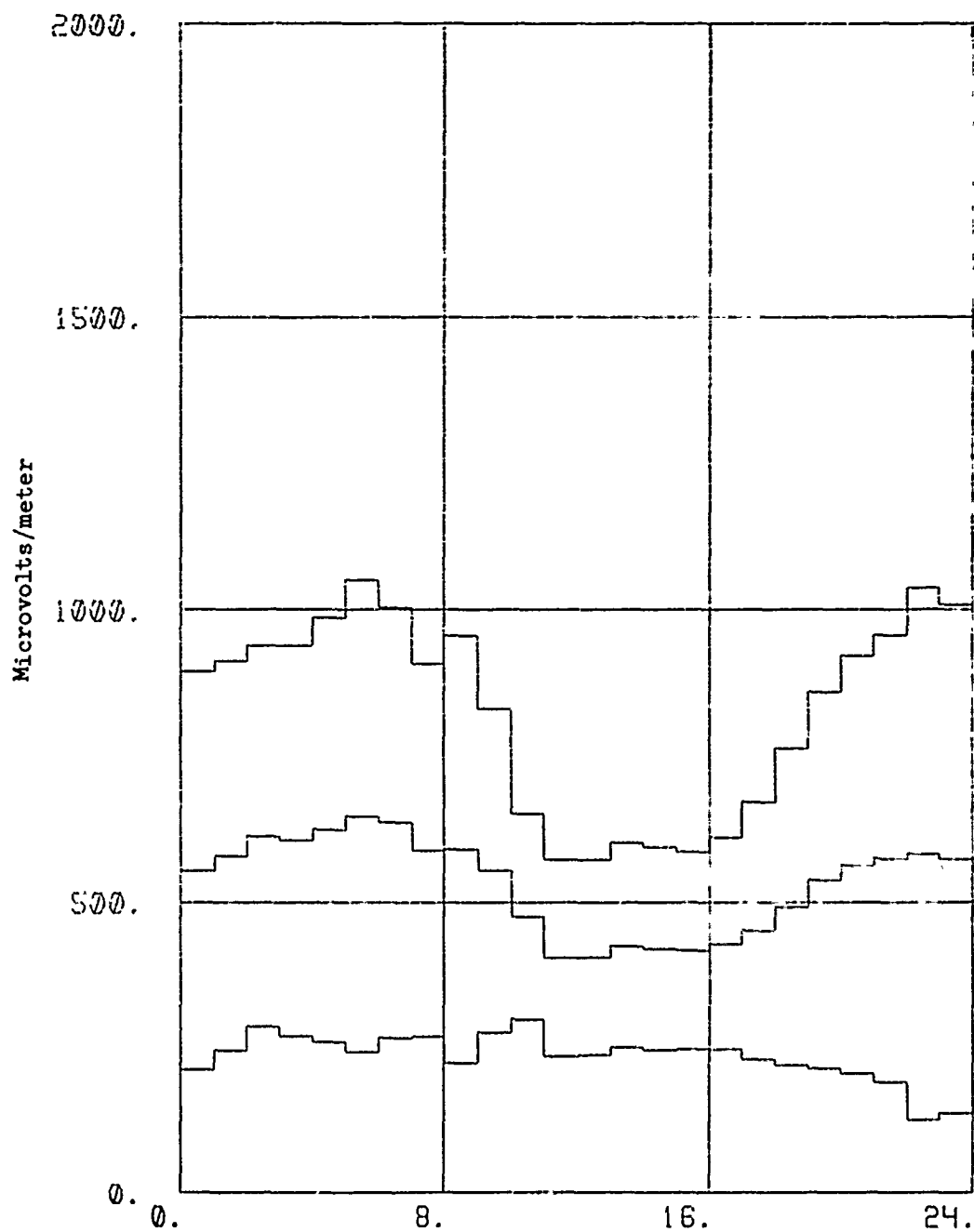


5.5 - ERMS vs TIME (@ FREQS. - SPRING SEASON)

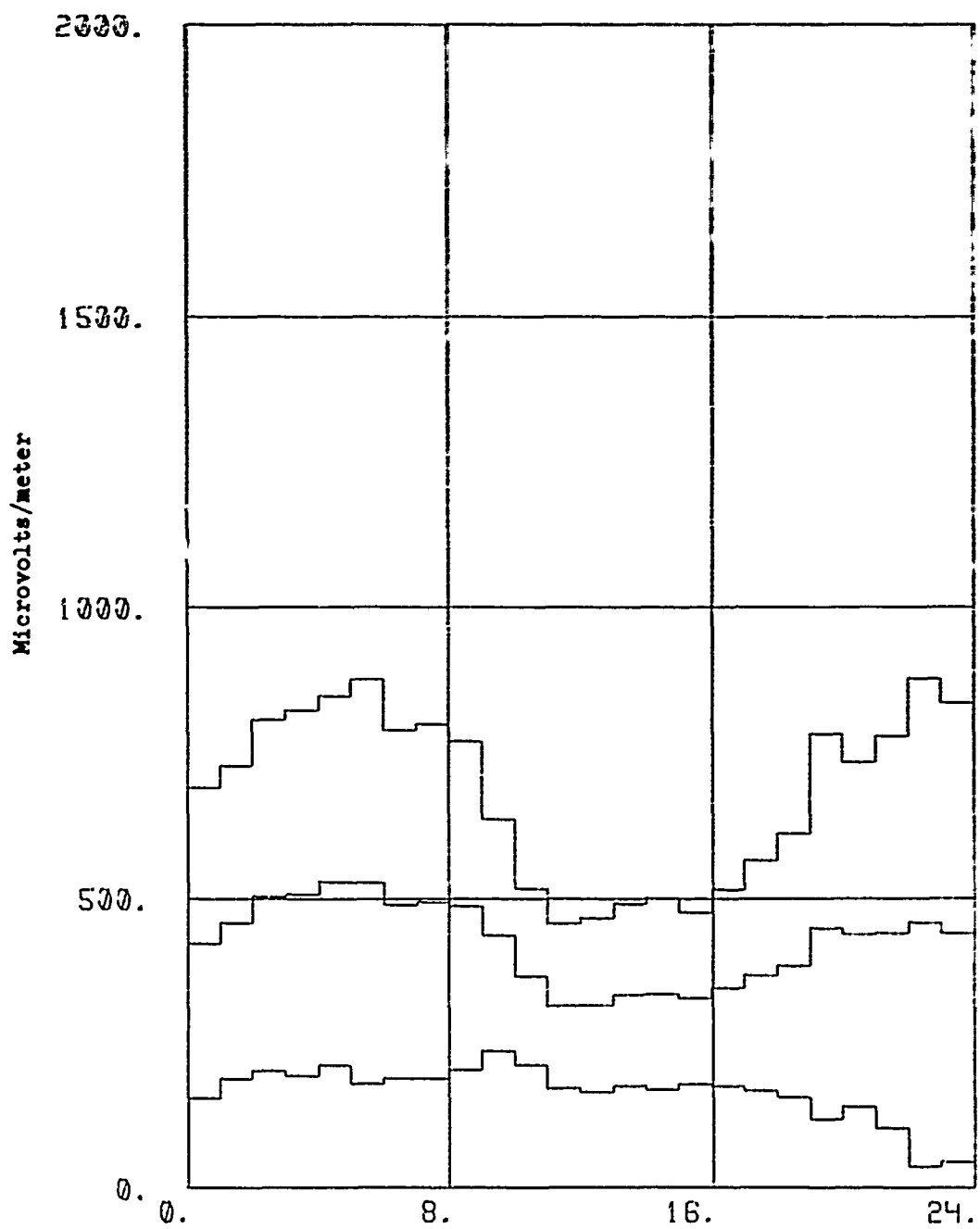


RMS vs Greenwich Mean Time (Hrs)  
 10.7 kHz  
 Spring Season-March, April, May

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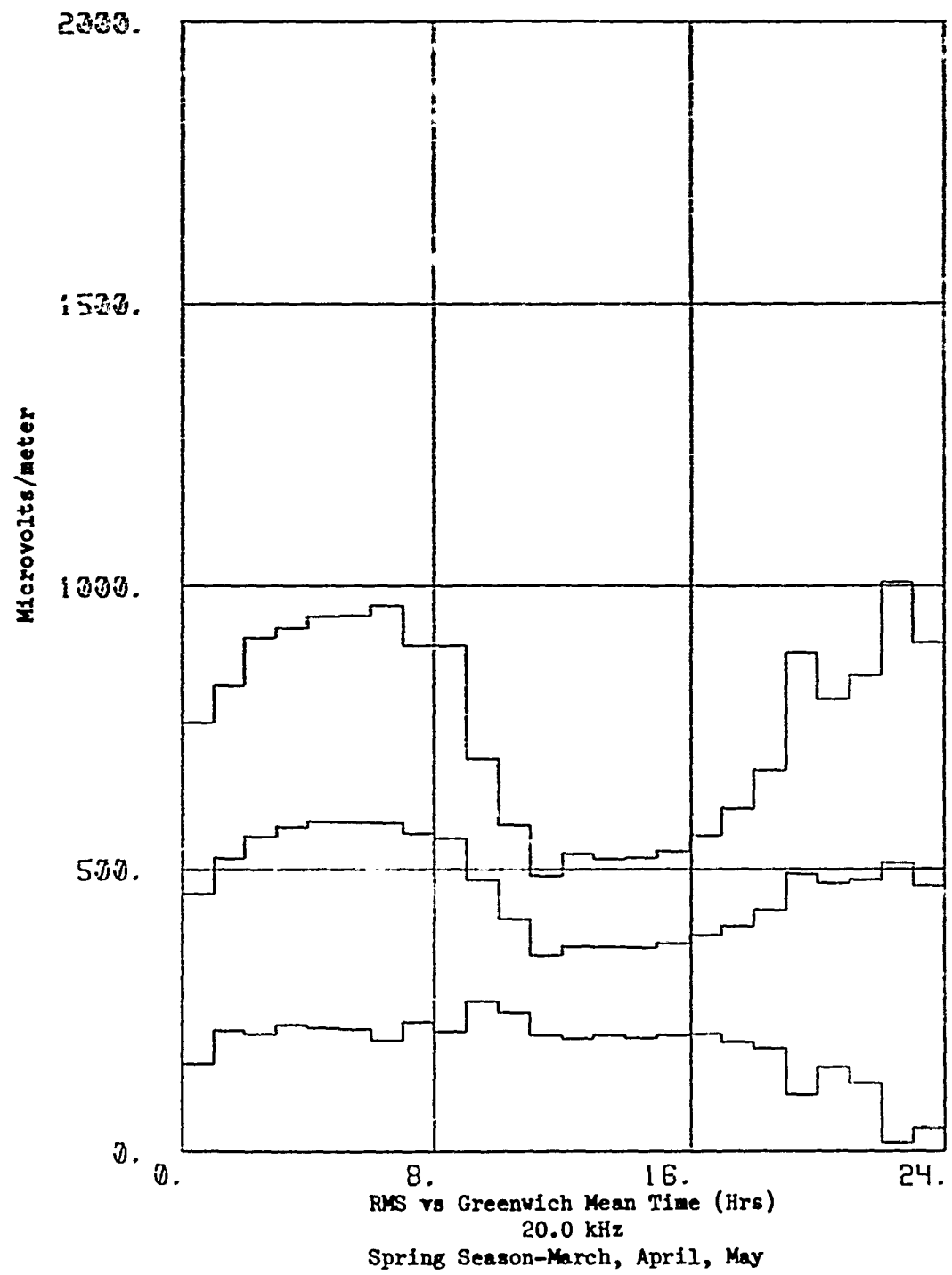


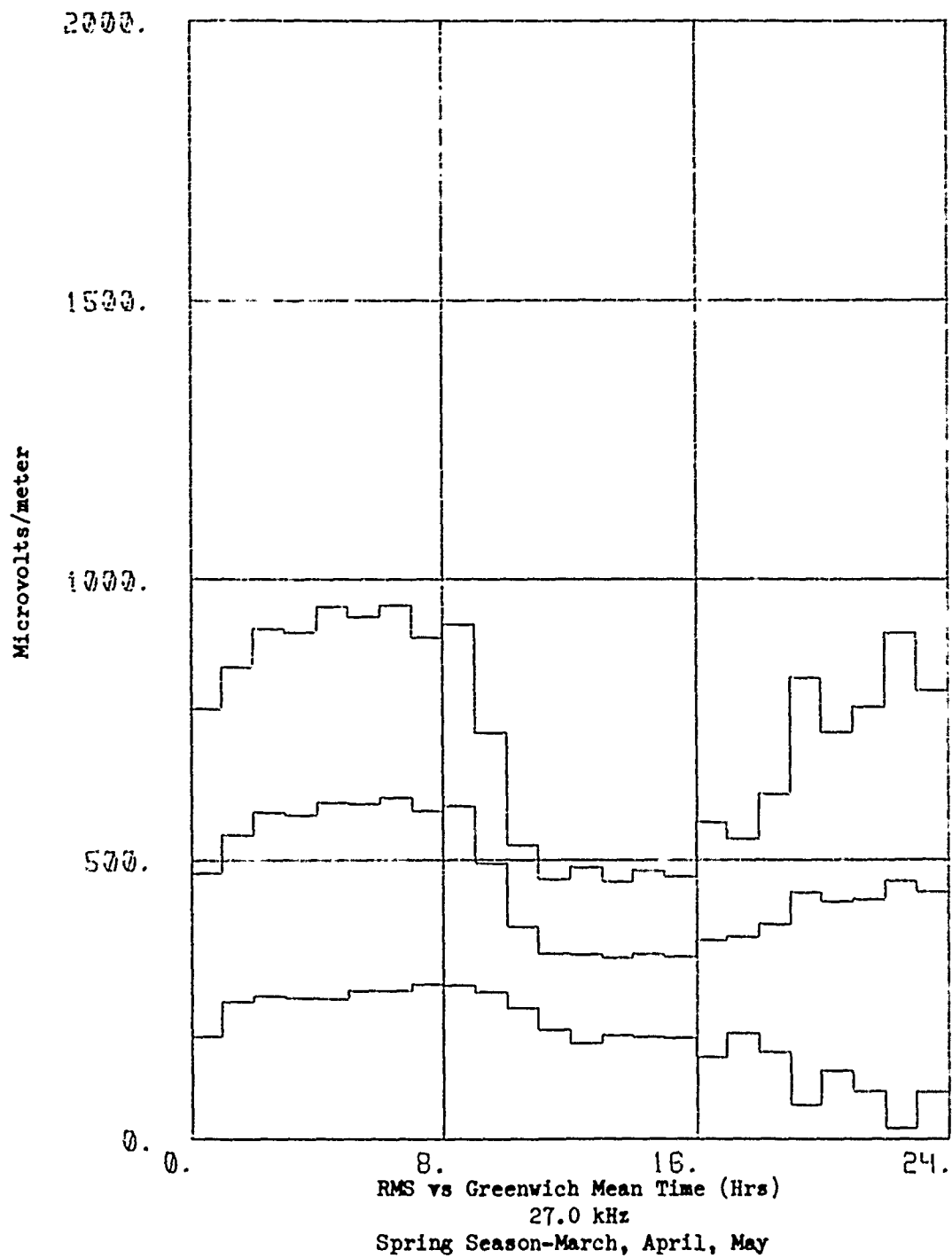
RMS vs Greenwich Mean Time (Hrs)  
14.0 kHz  
Spring Season-March, April, May

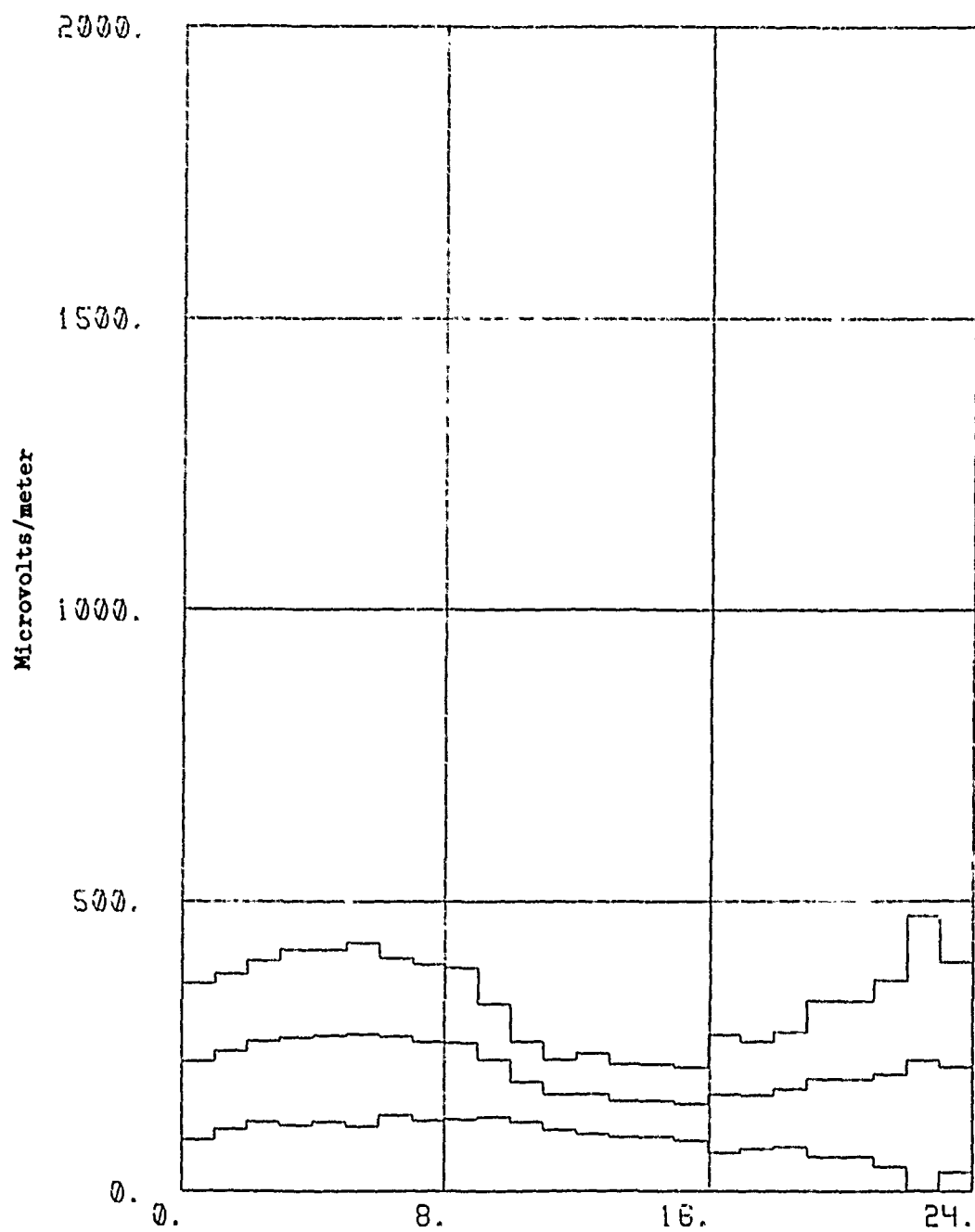


RMS vs Greenwich Mean Time (Hrs)  
17.0 kHz  
Spring Season-March, April, May

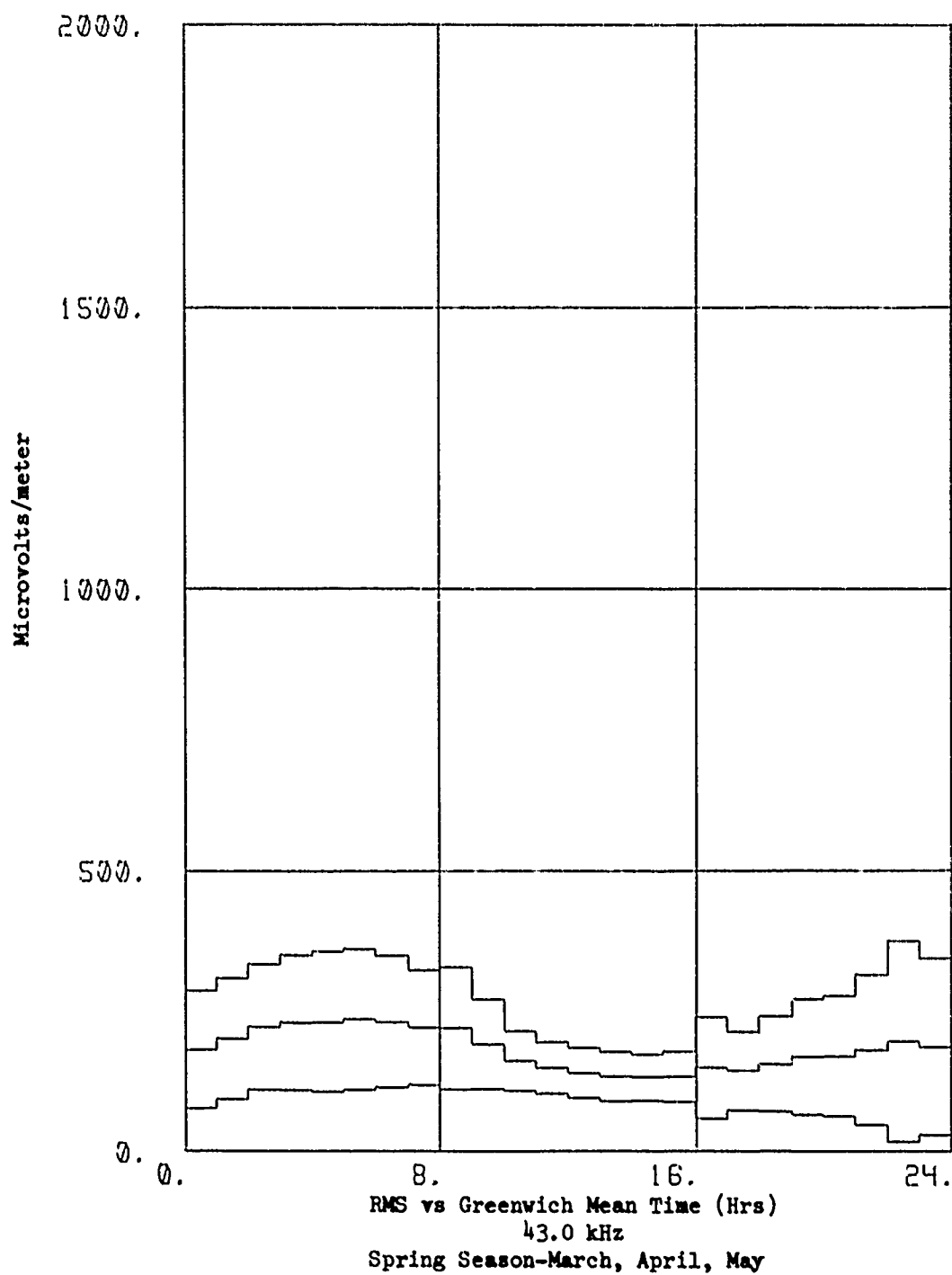


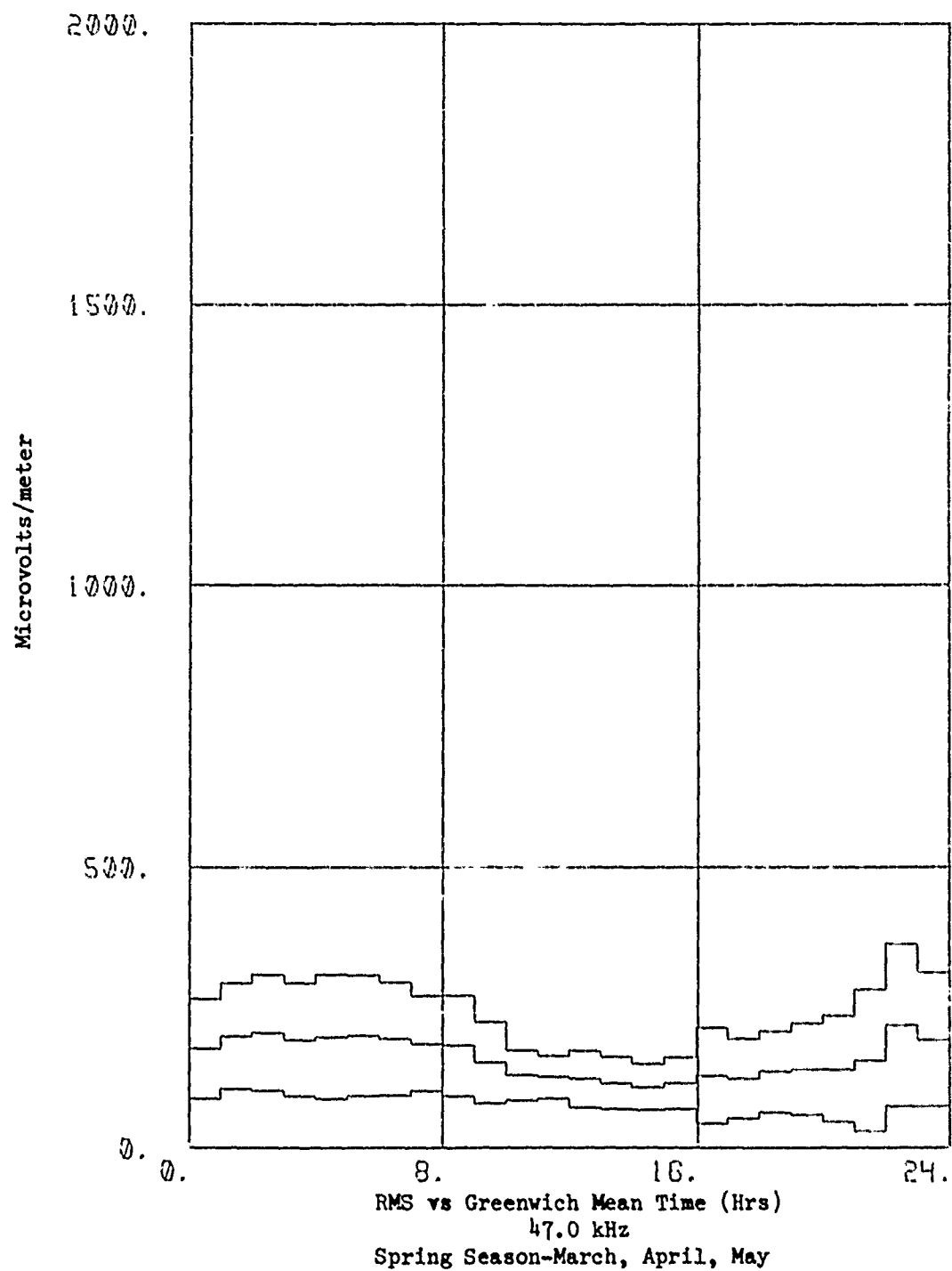


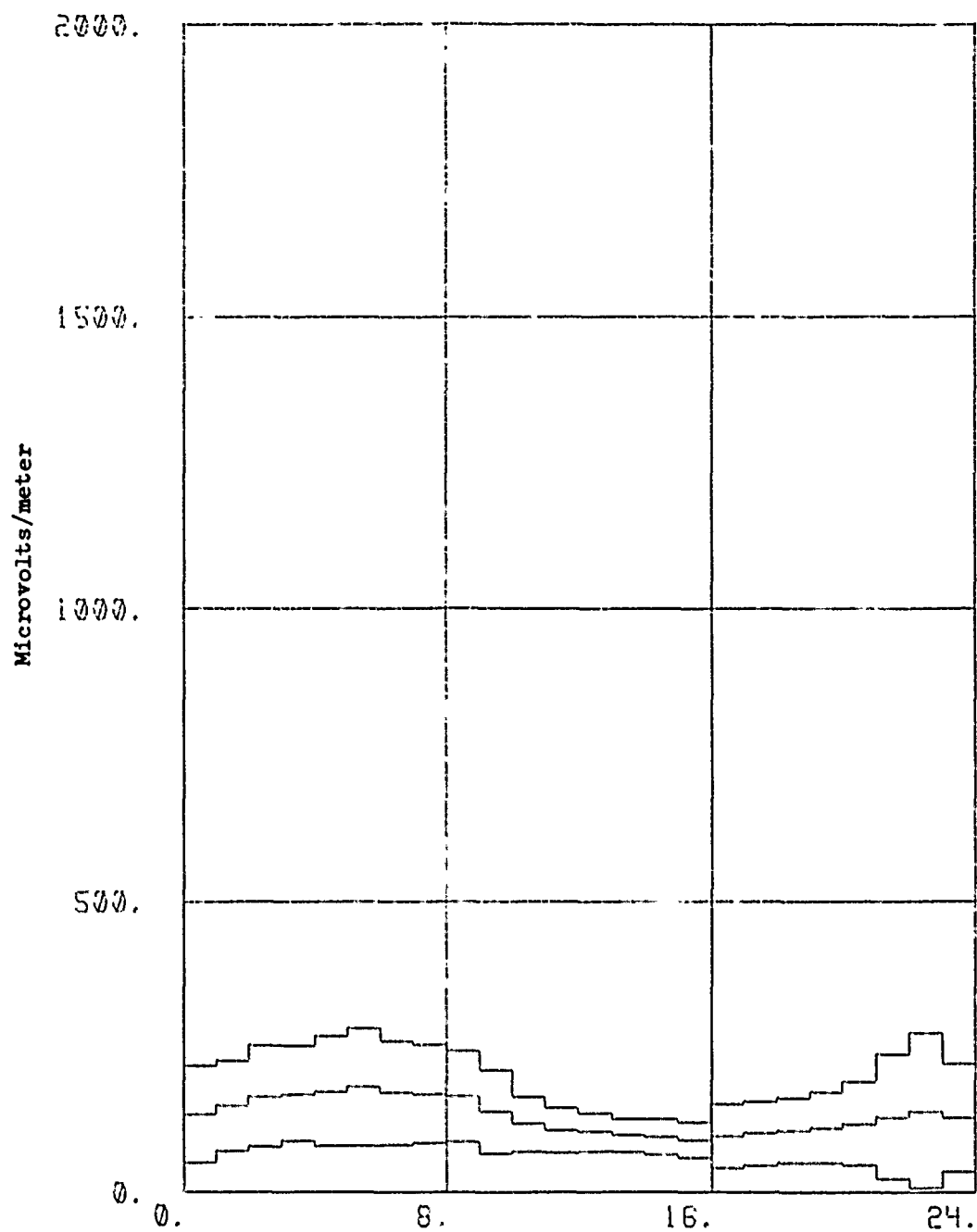




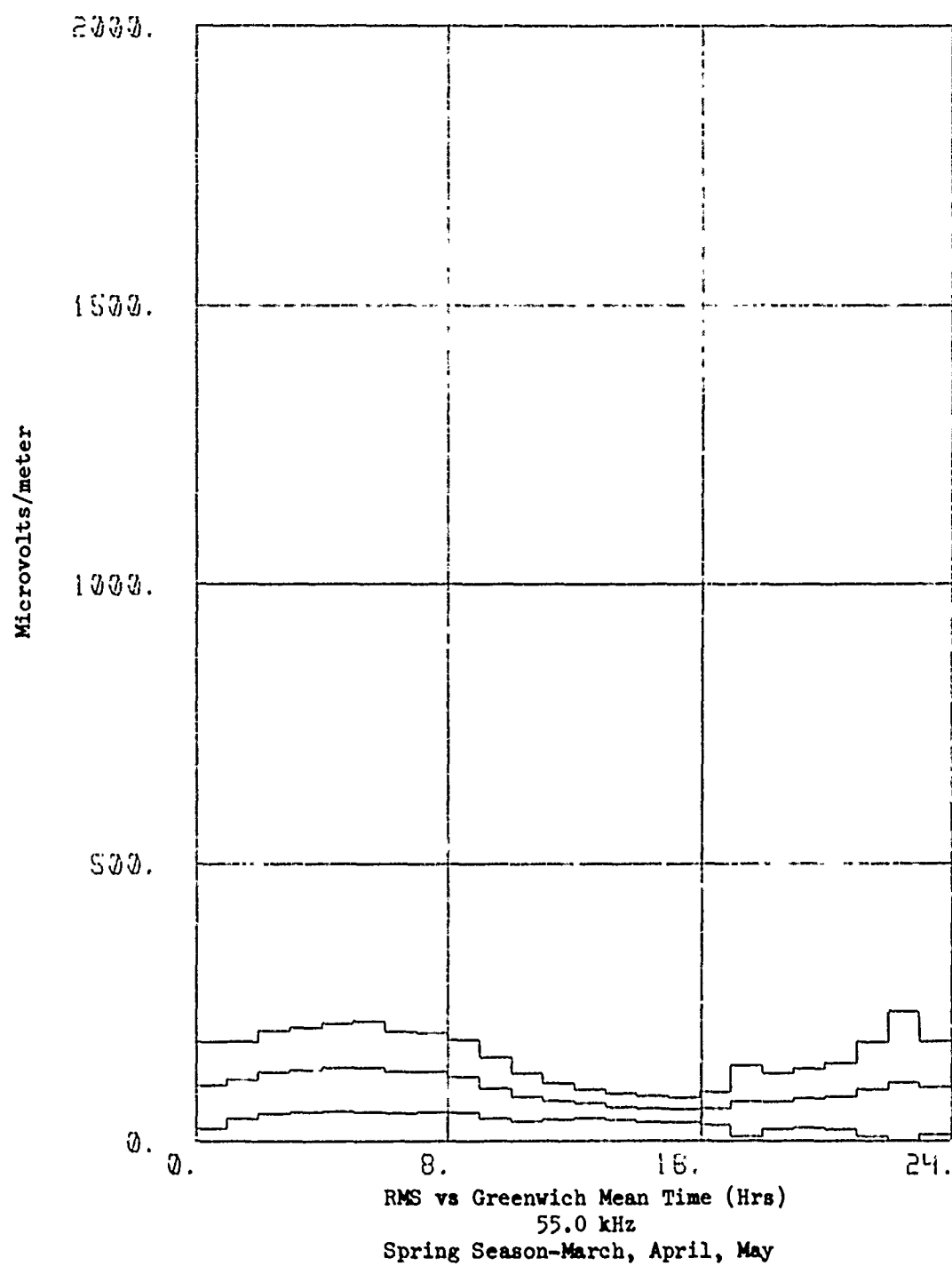
RMS vs Greenwich Mean Time (Hrs)  
40.0 kHz  
Spring Season-March, April, May





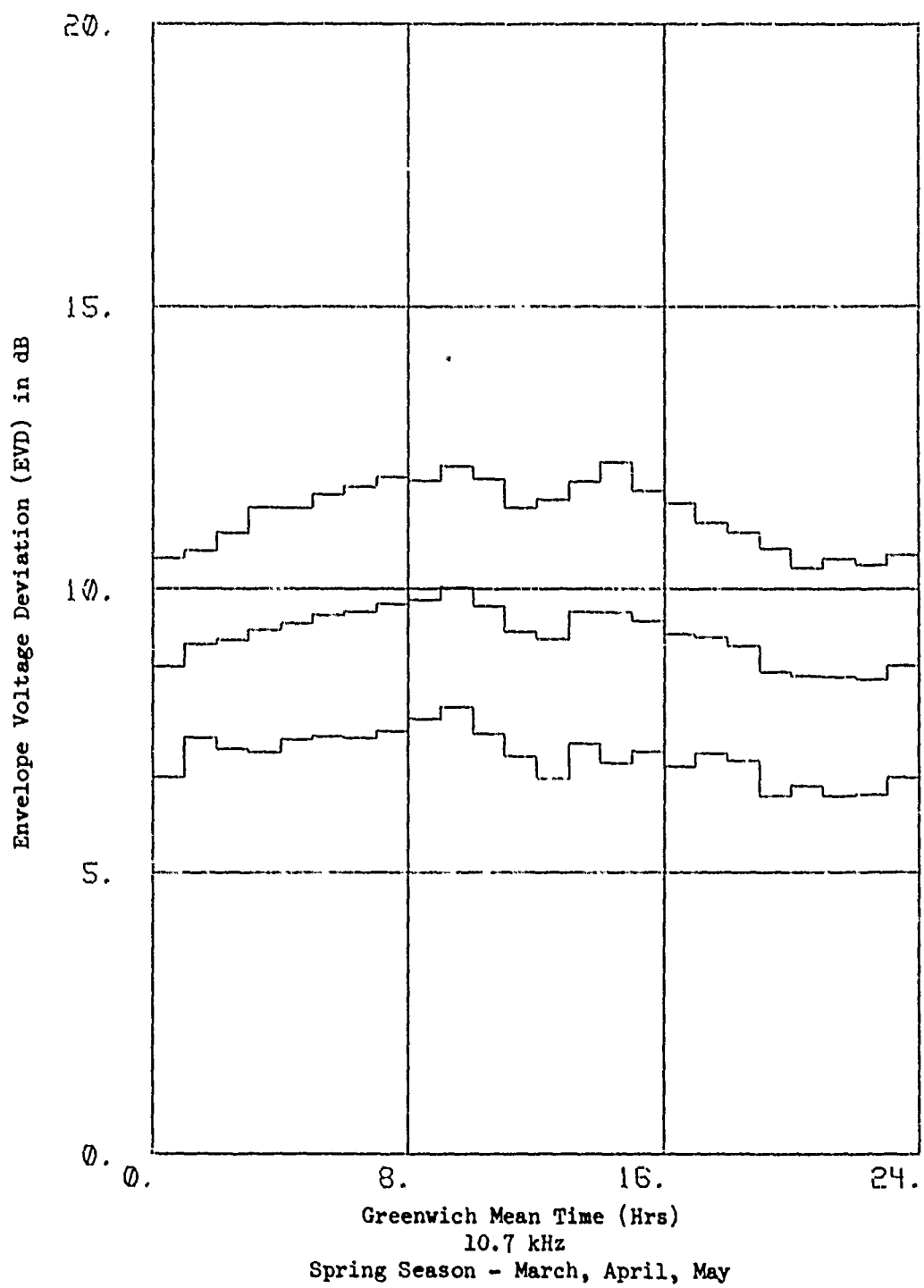


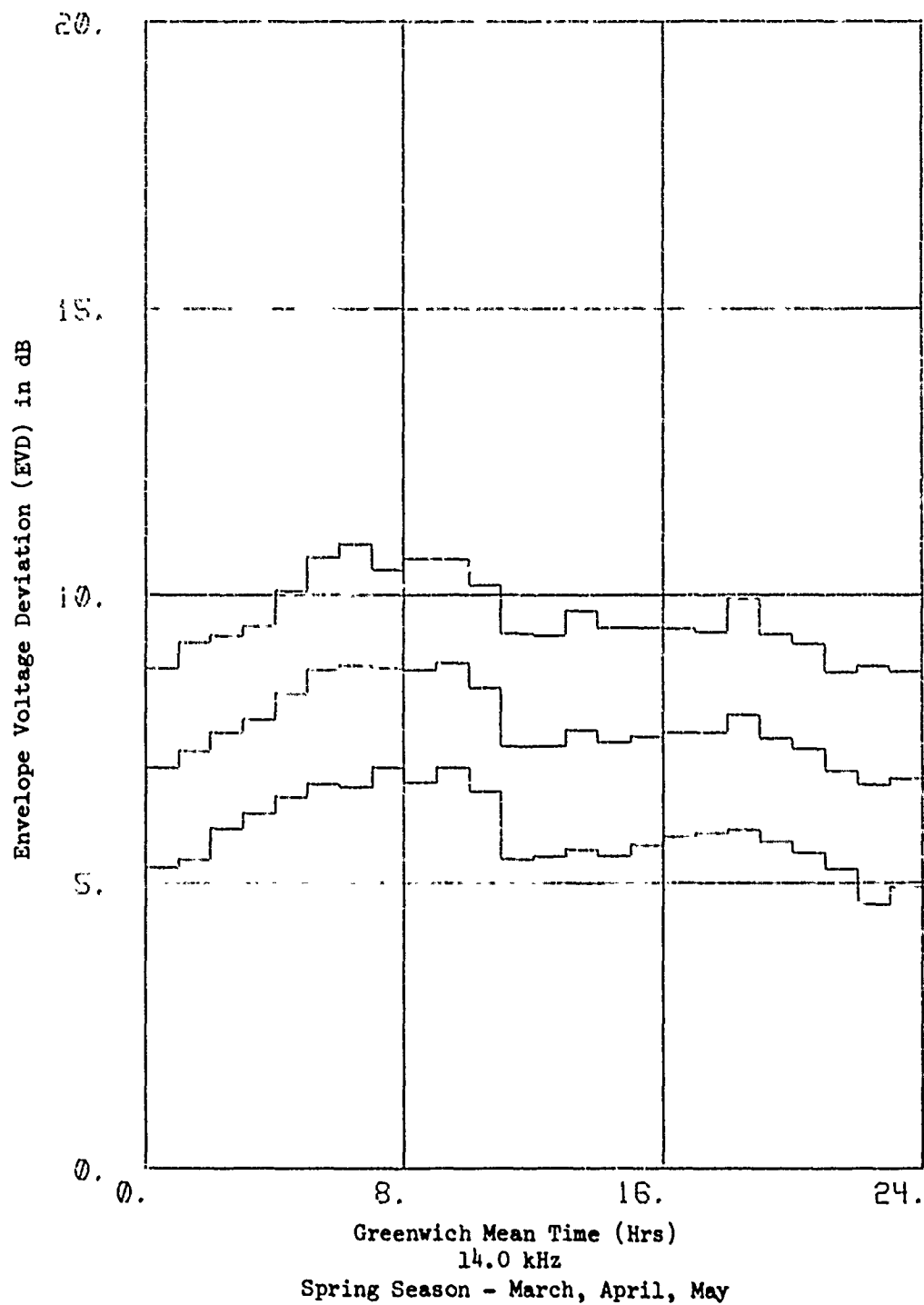
RMS vs Greenwich Mean Time (Hrs)  
50.0 kHz  
Spring Season-March, April, May

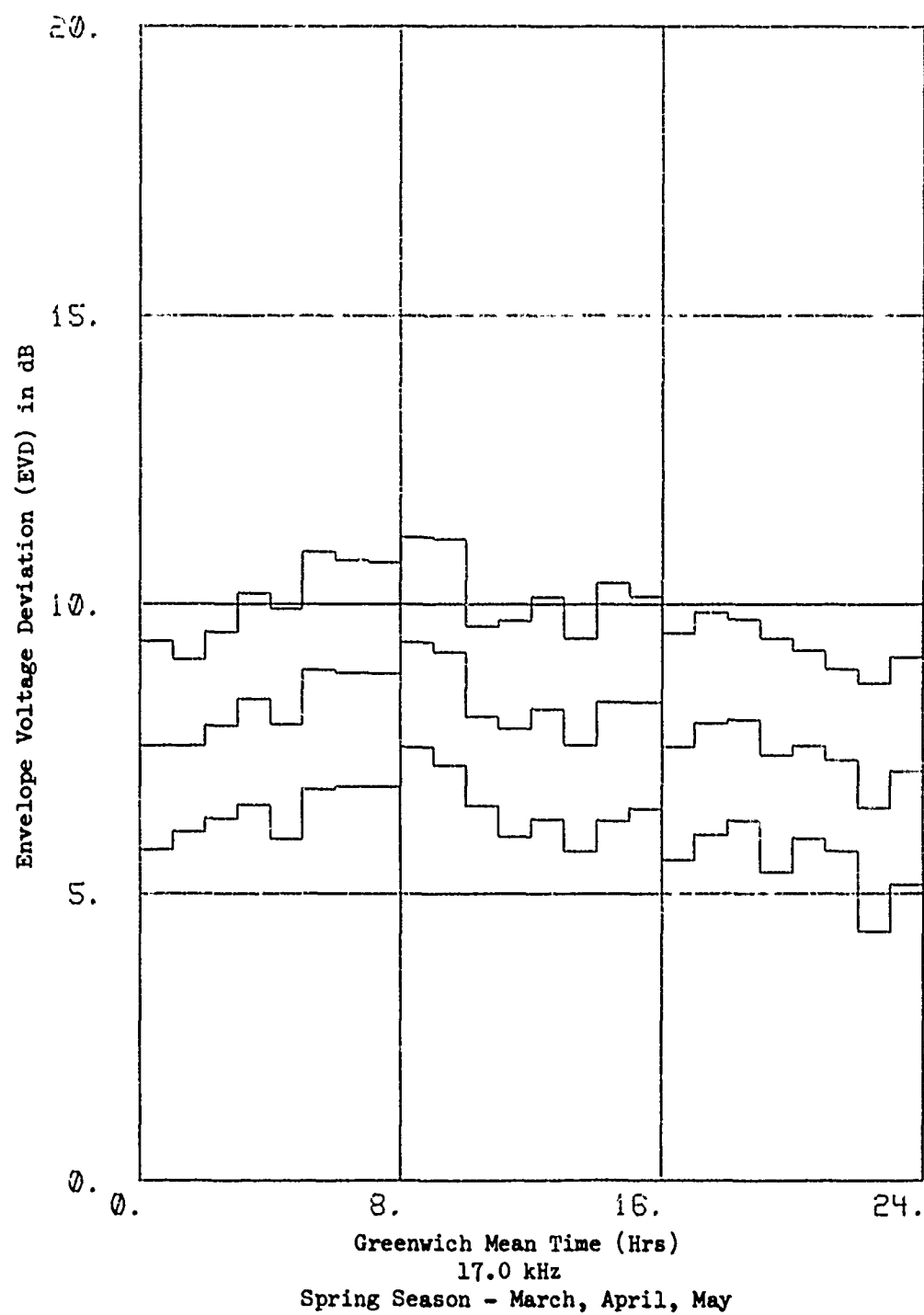


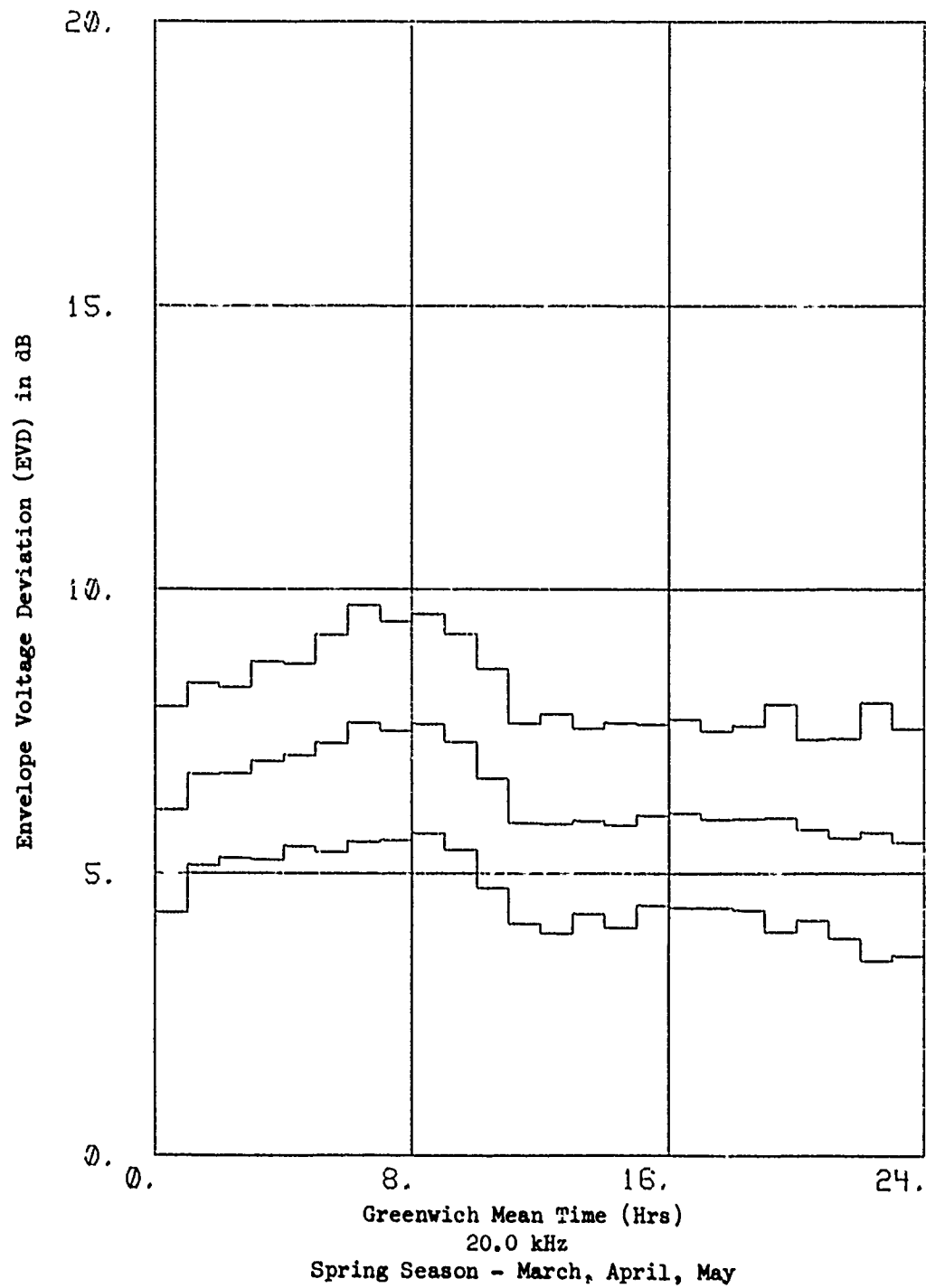
5.6 - EVD vs TIME (@ FREQ. - SPRING SEASON)

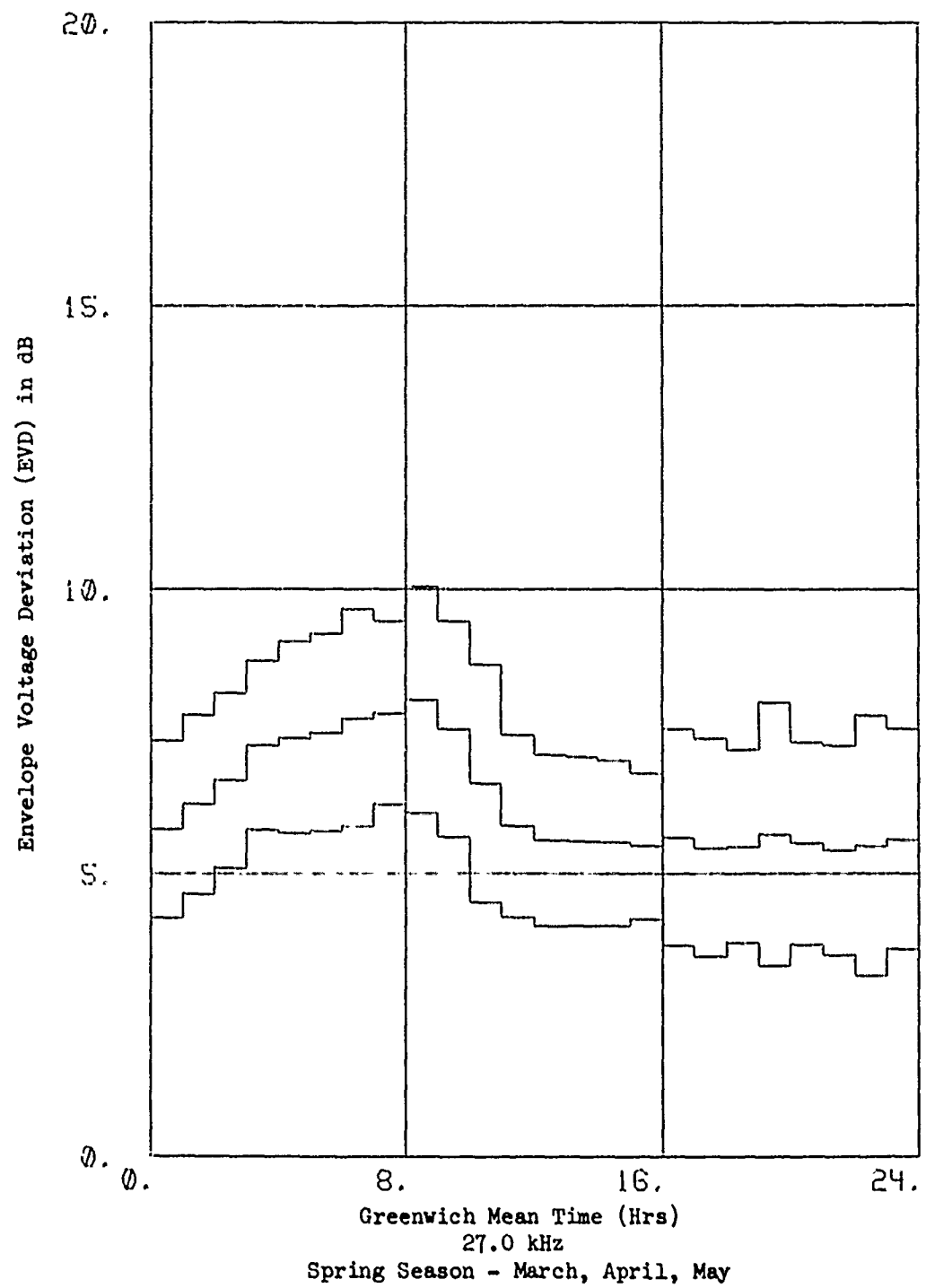


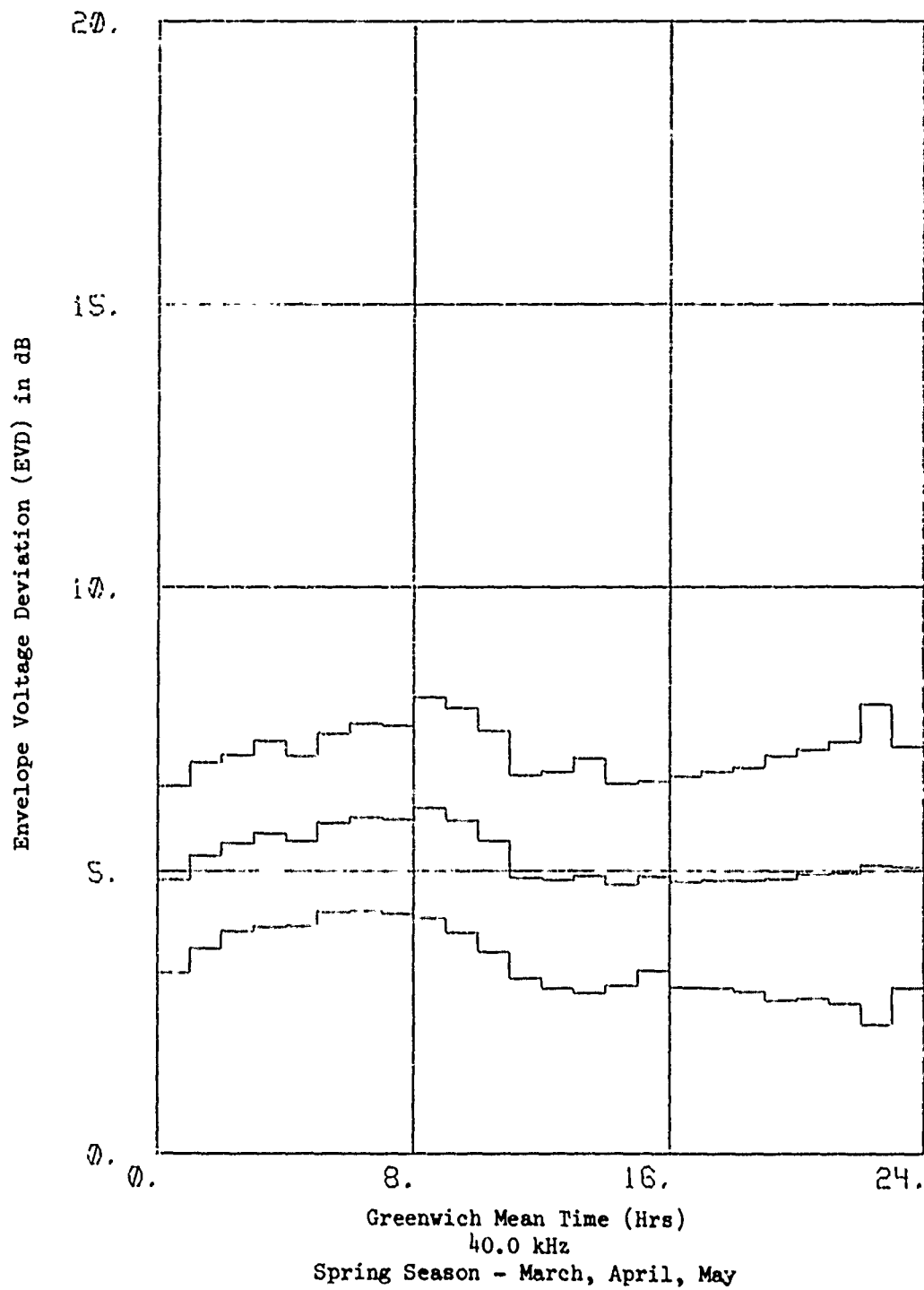


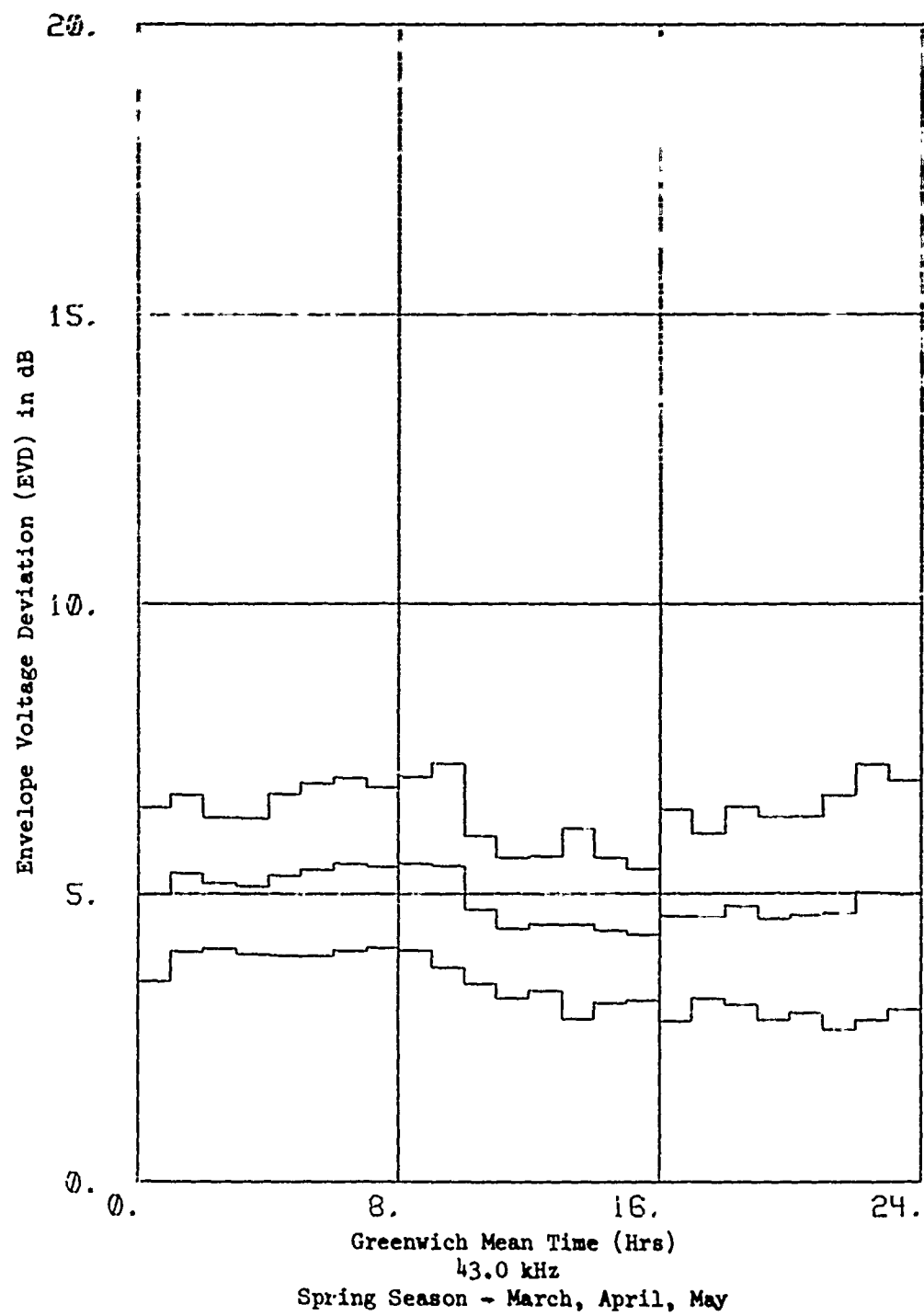


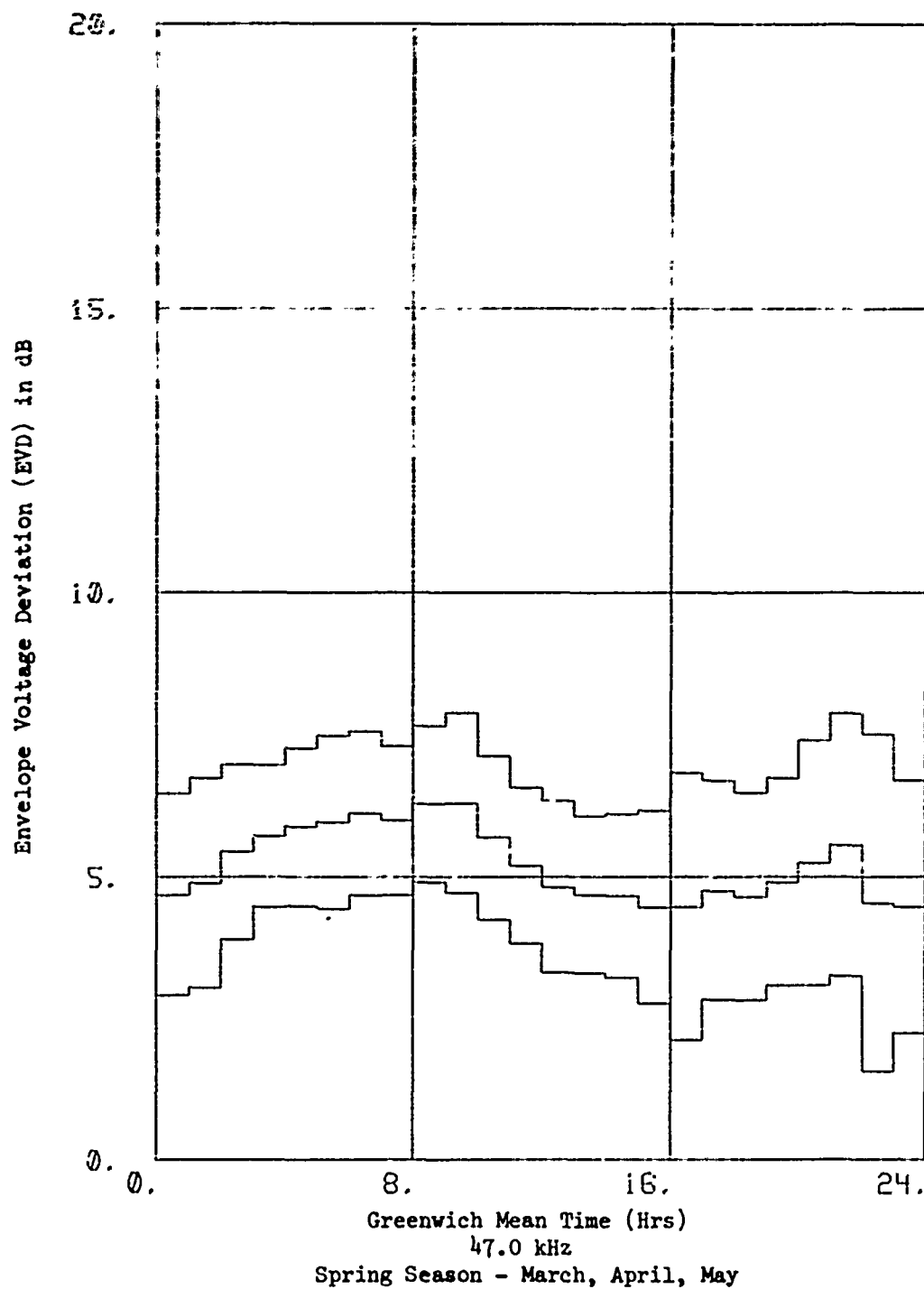




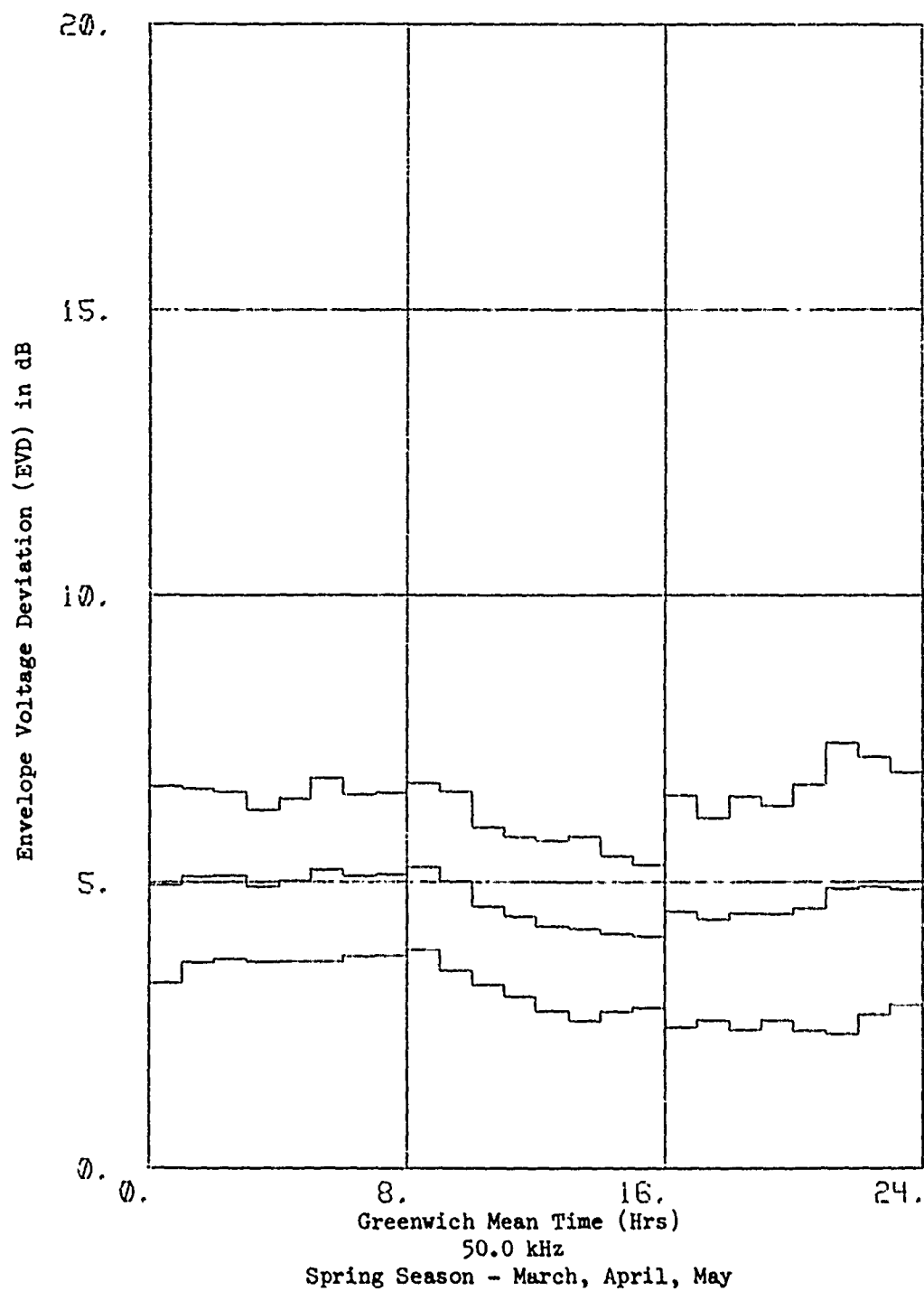


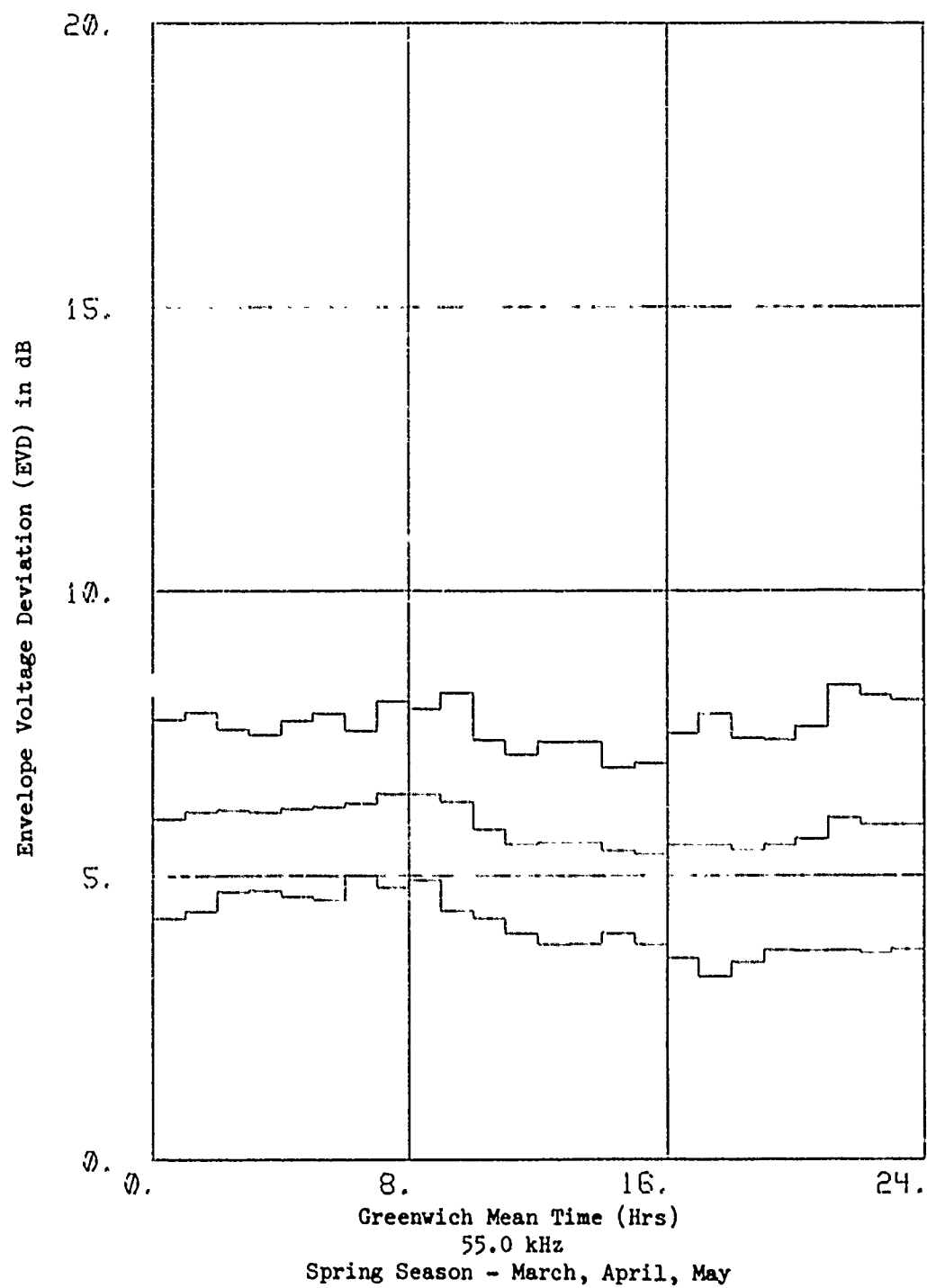




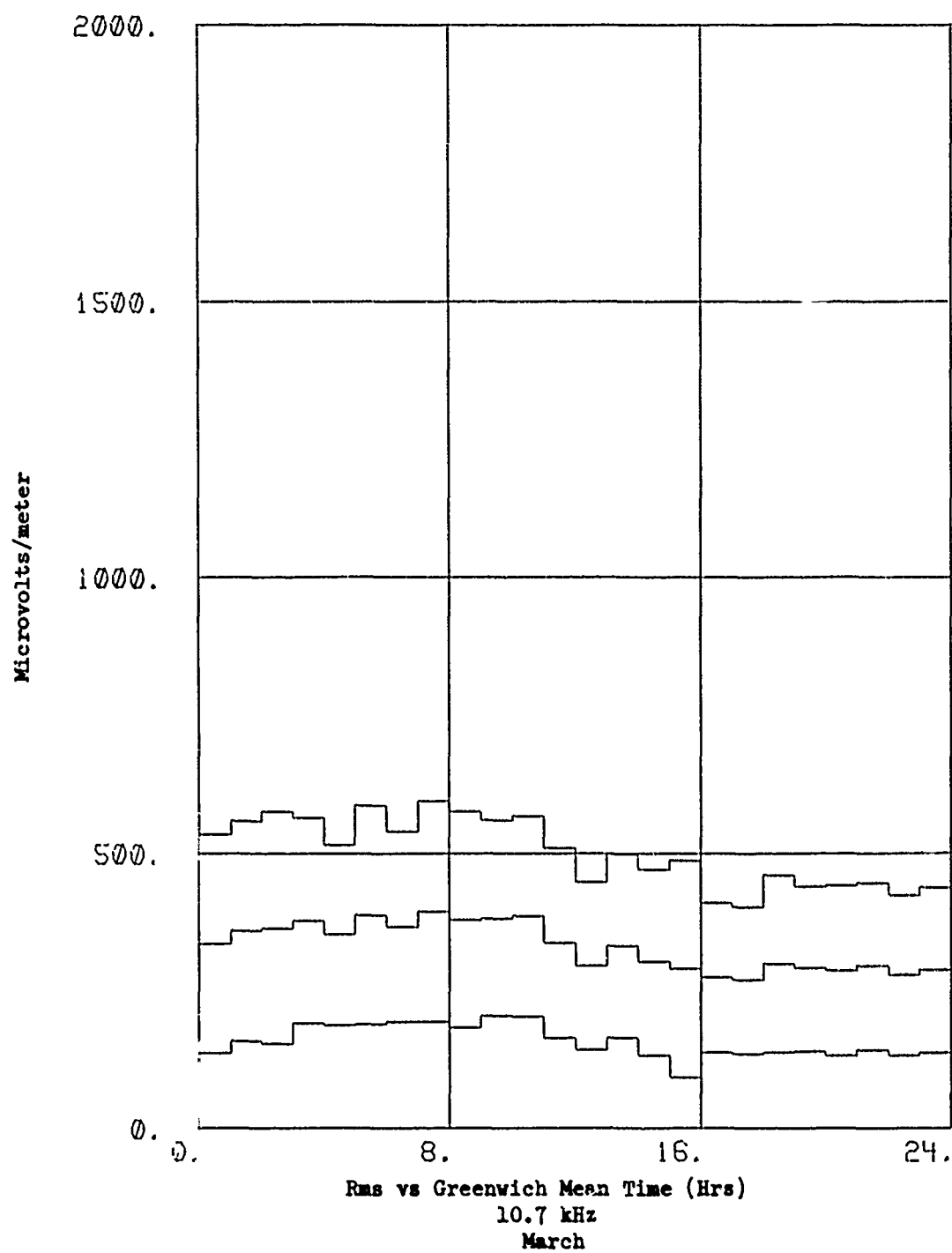


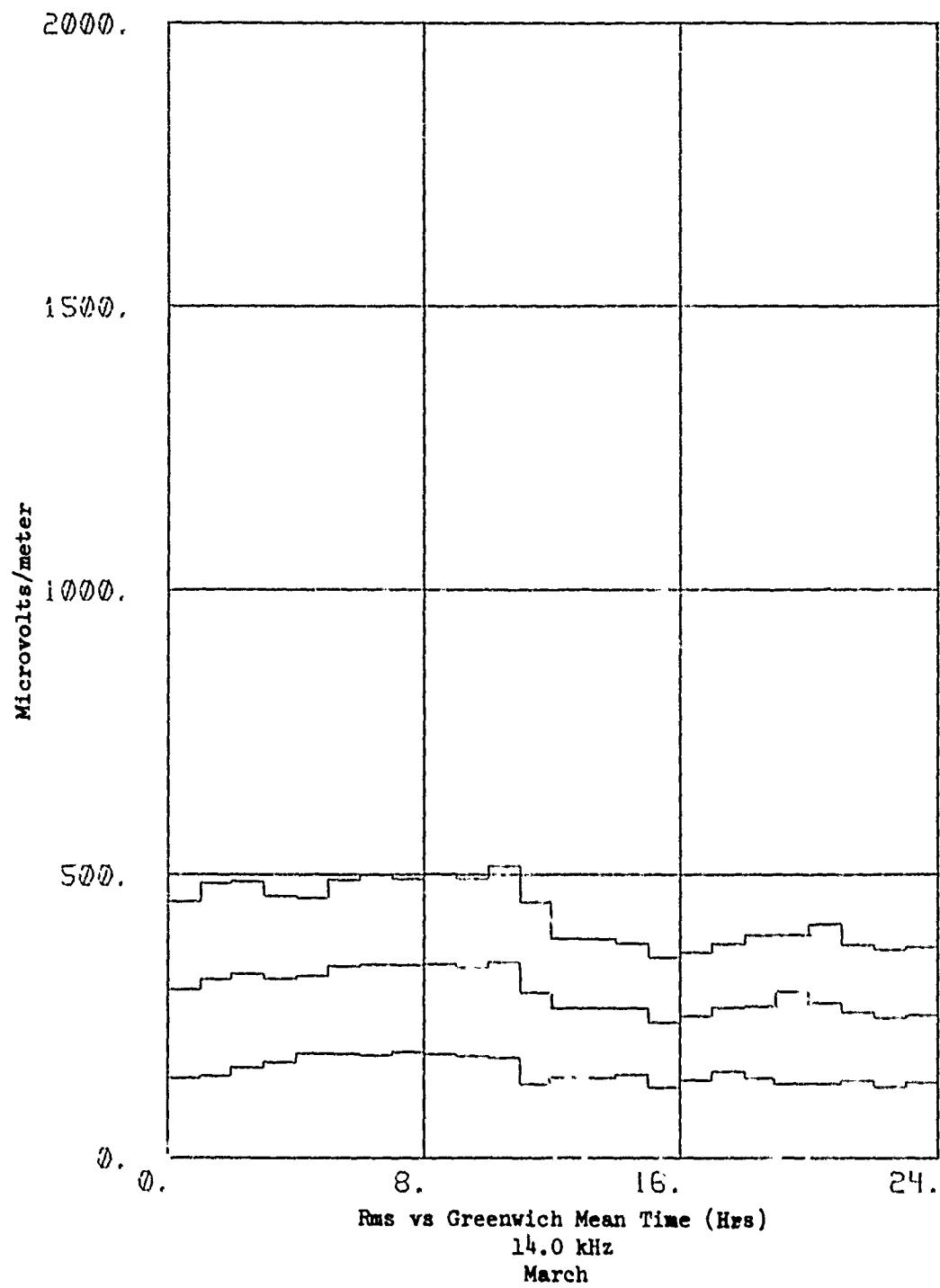


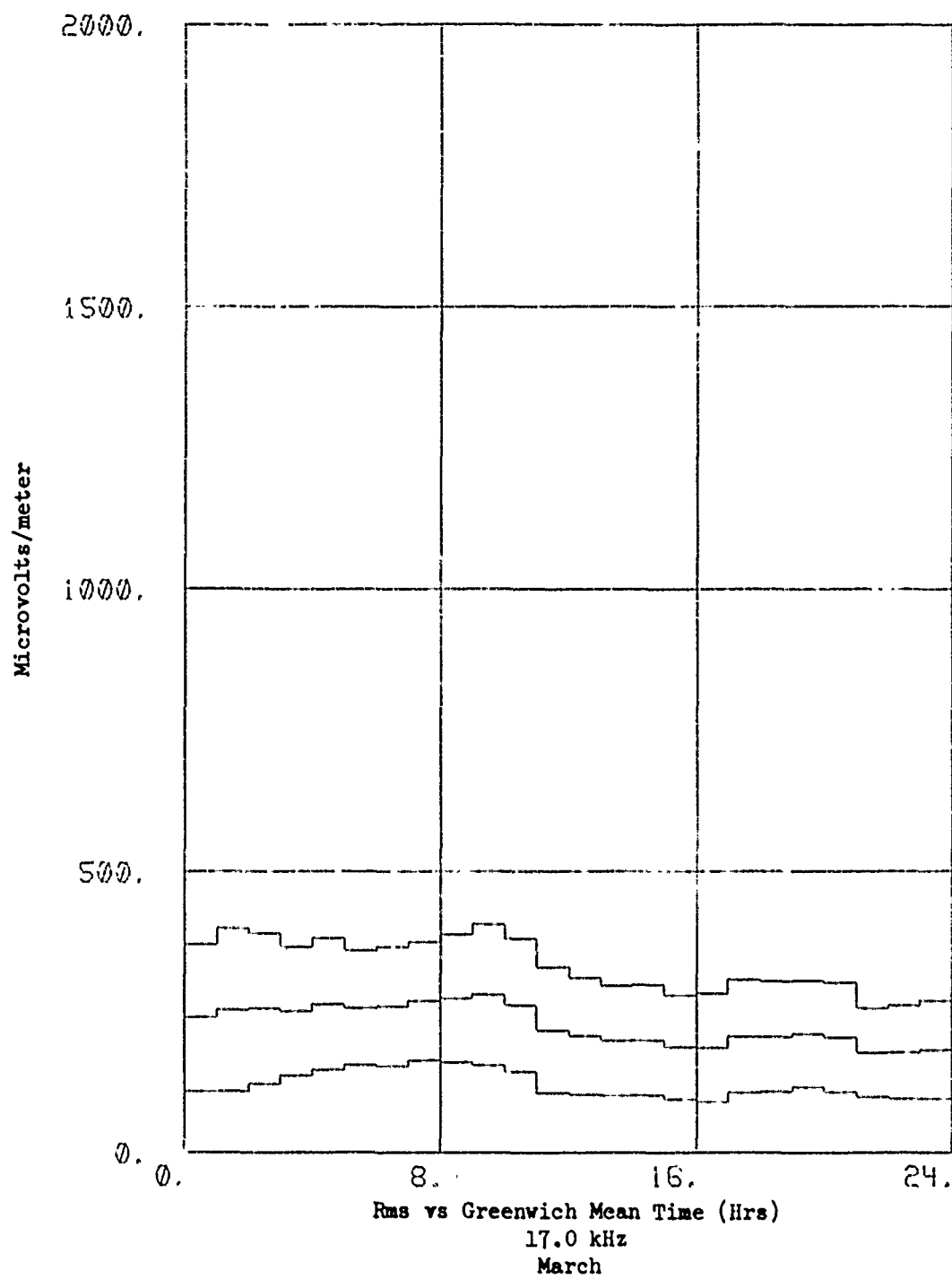


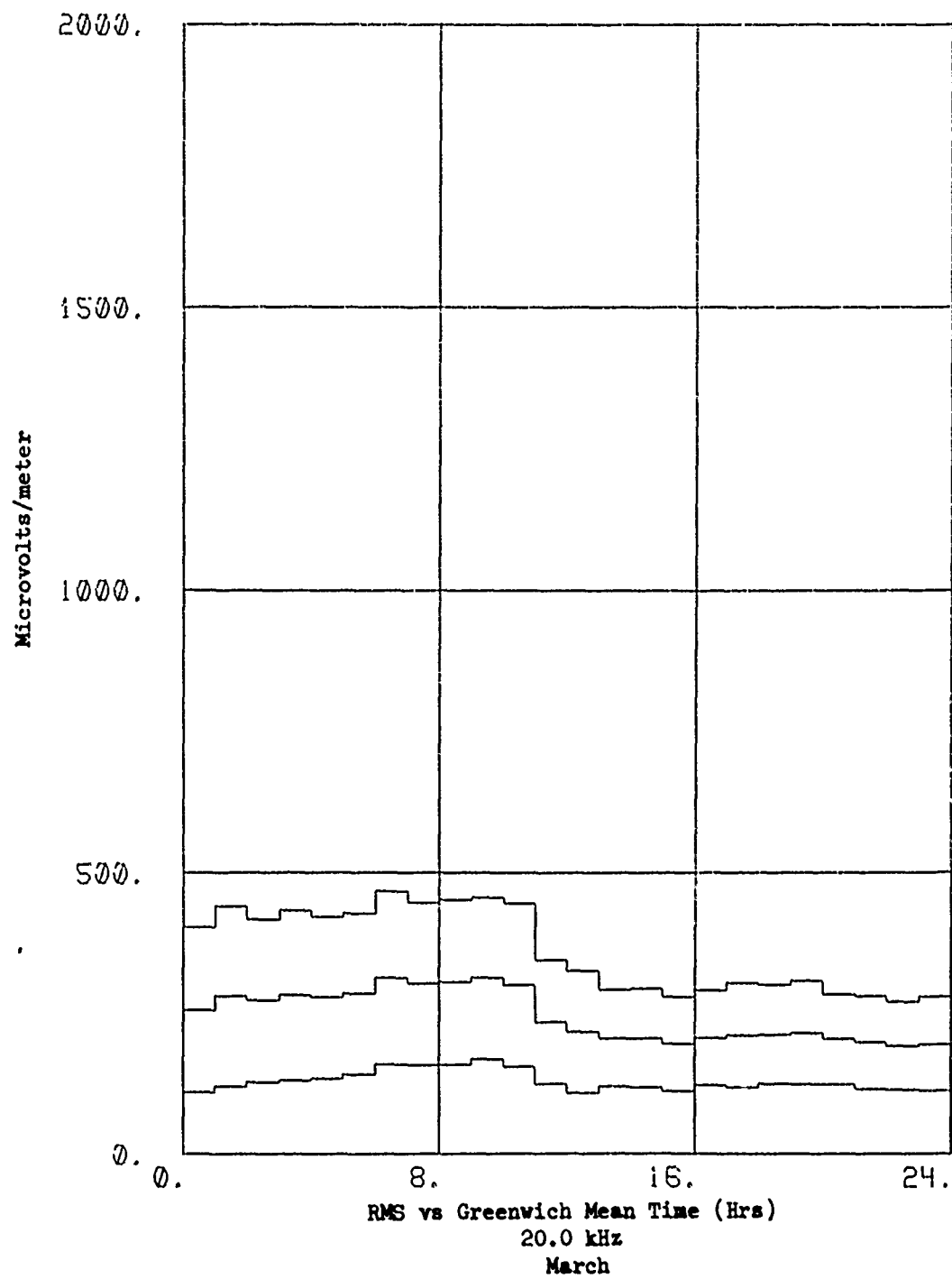


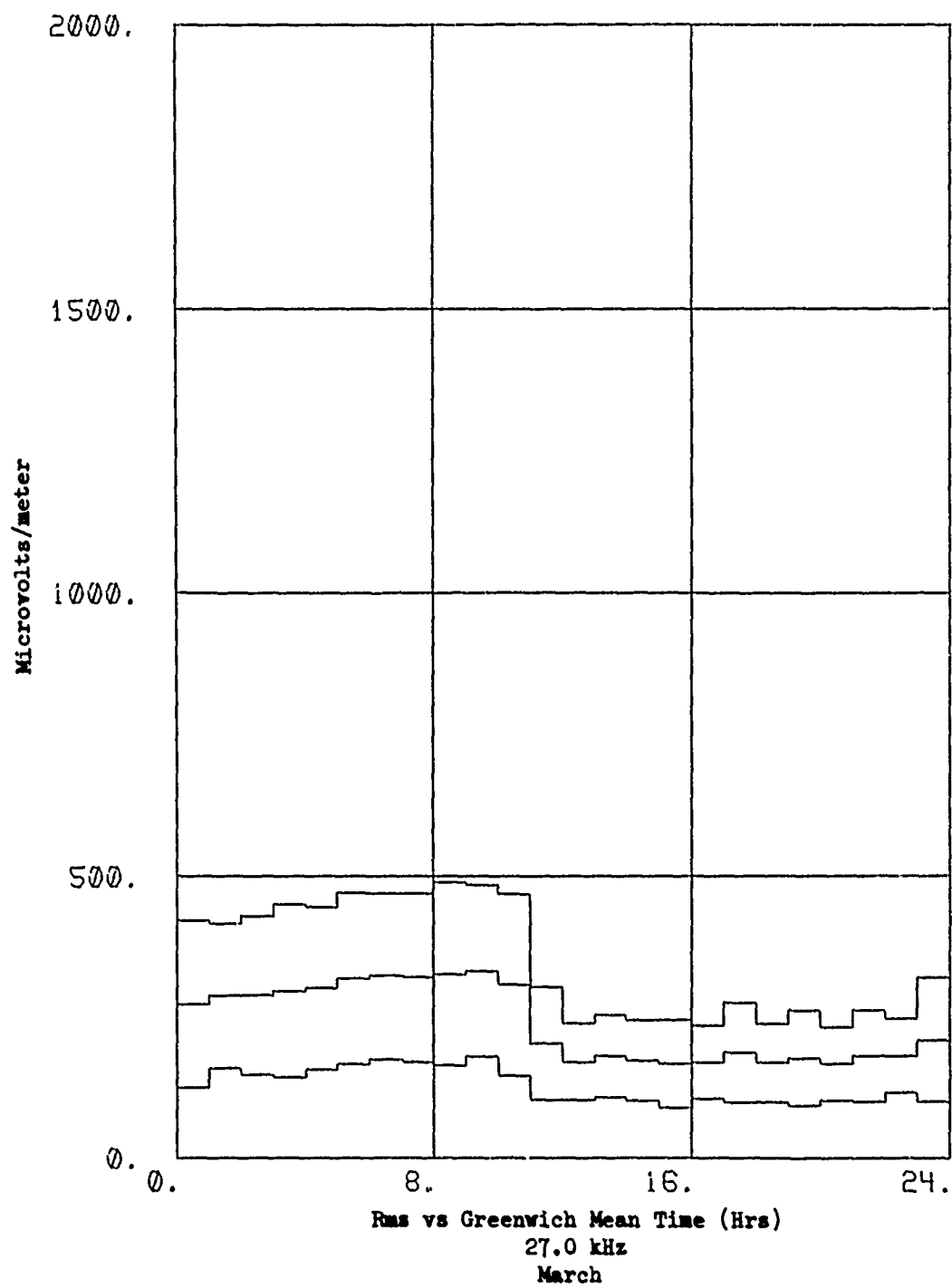
5.7 - ERMS vs TIME (@ FREQS. - FOR MARCH)



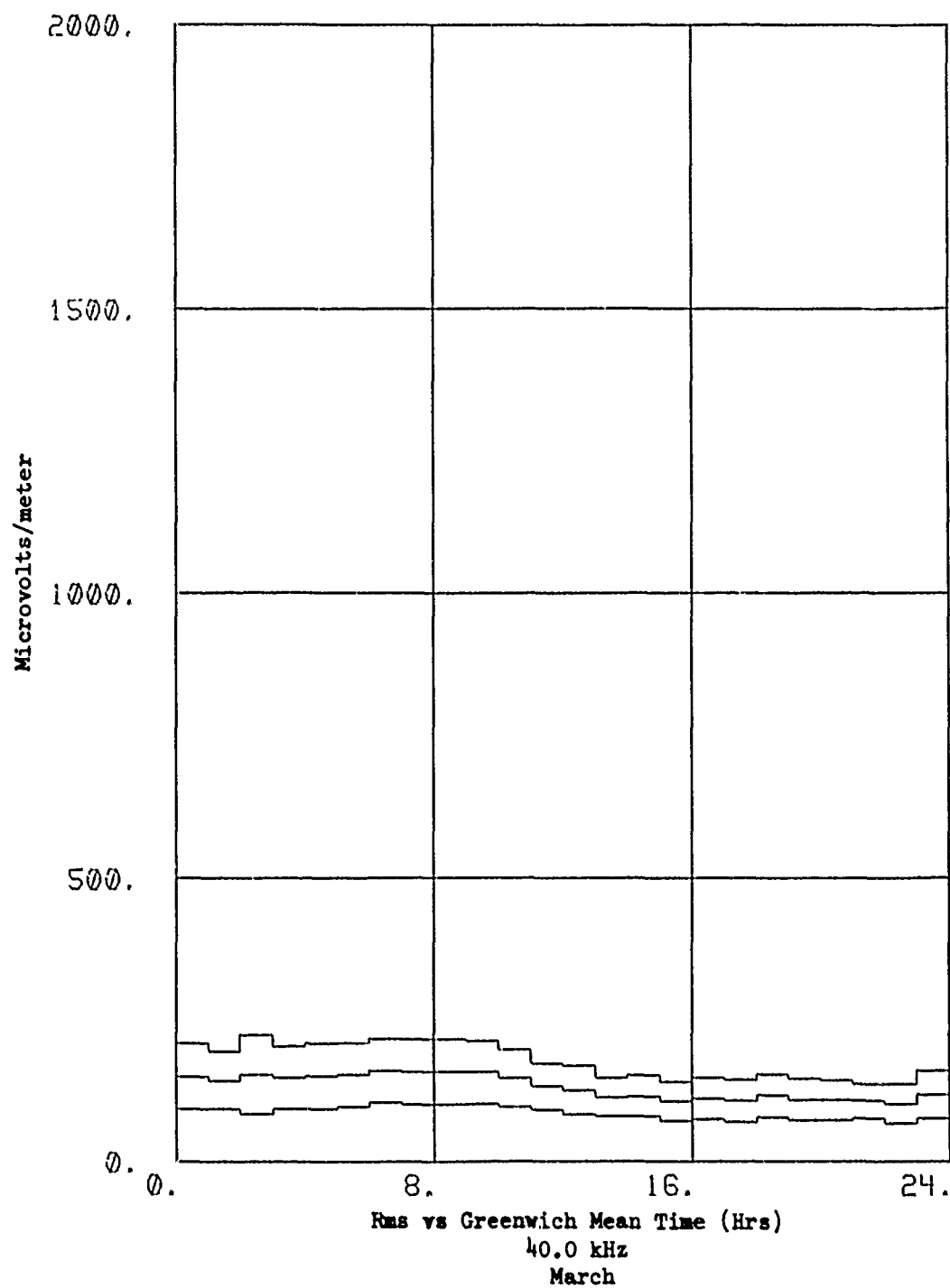


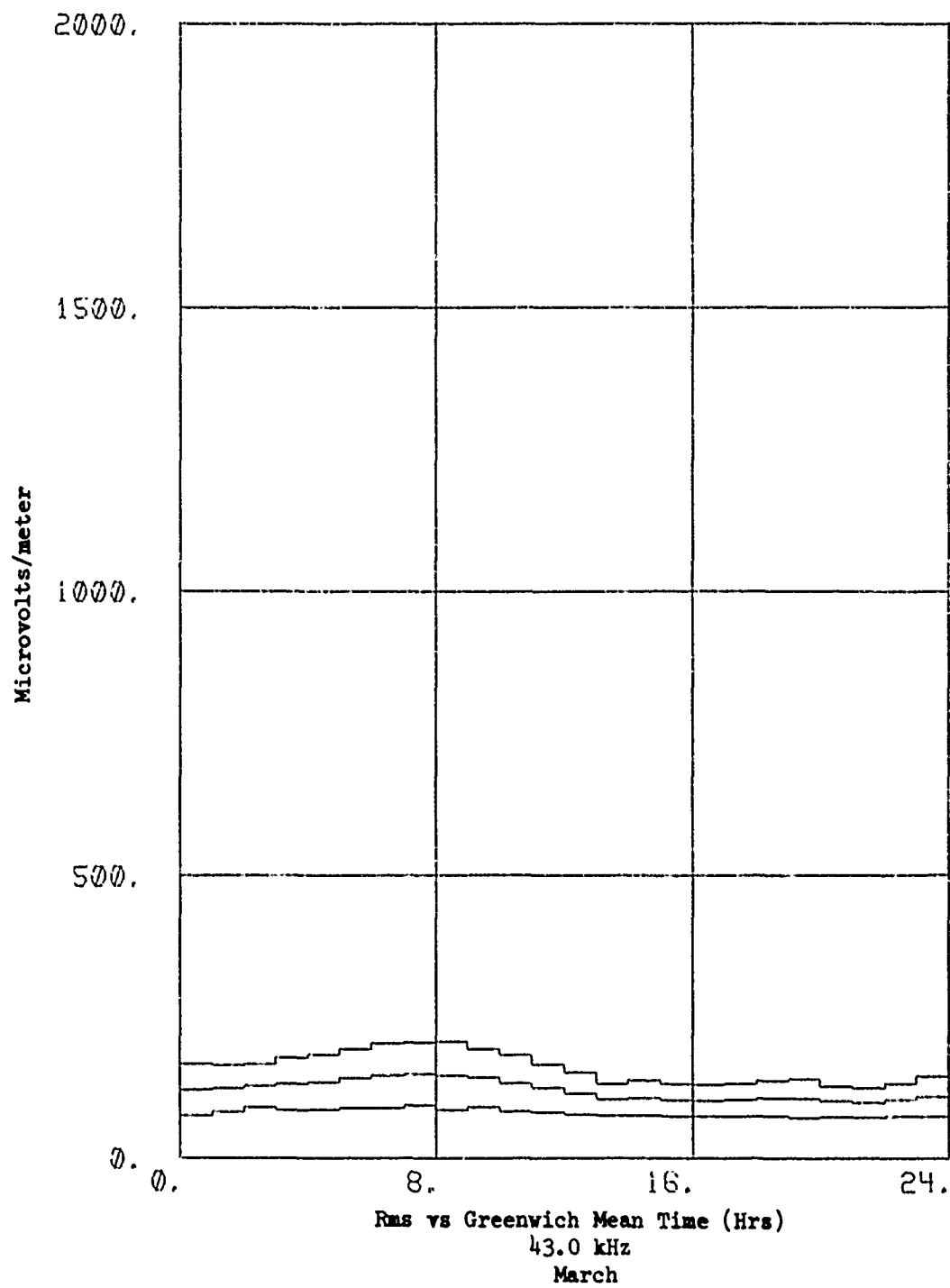


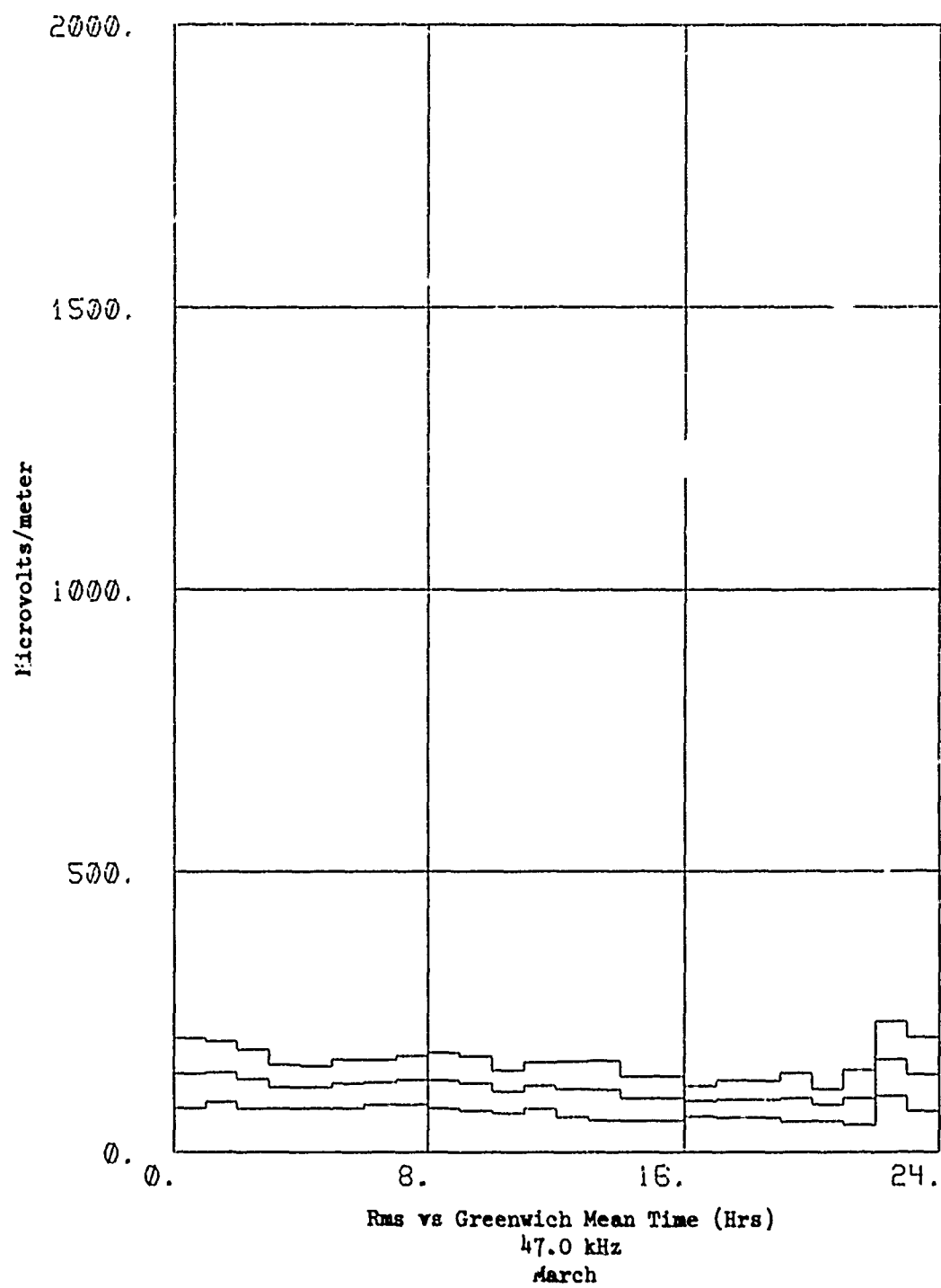


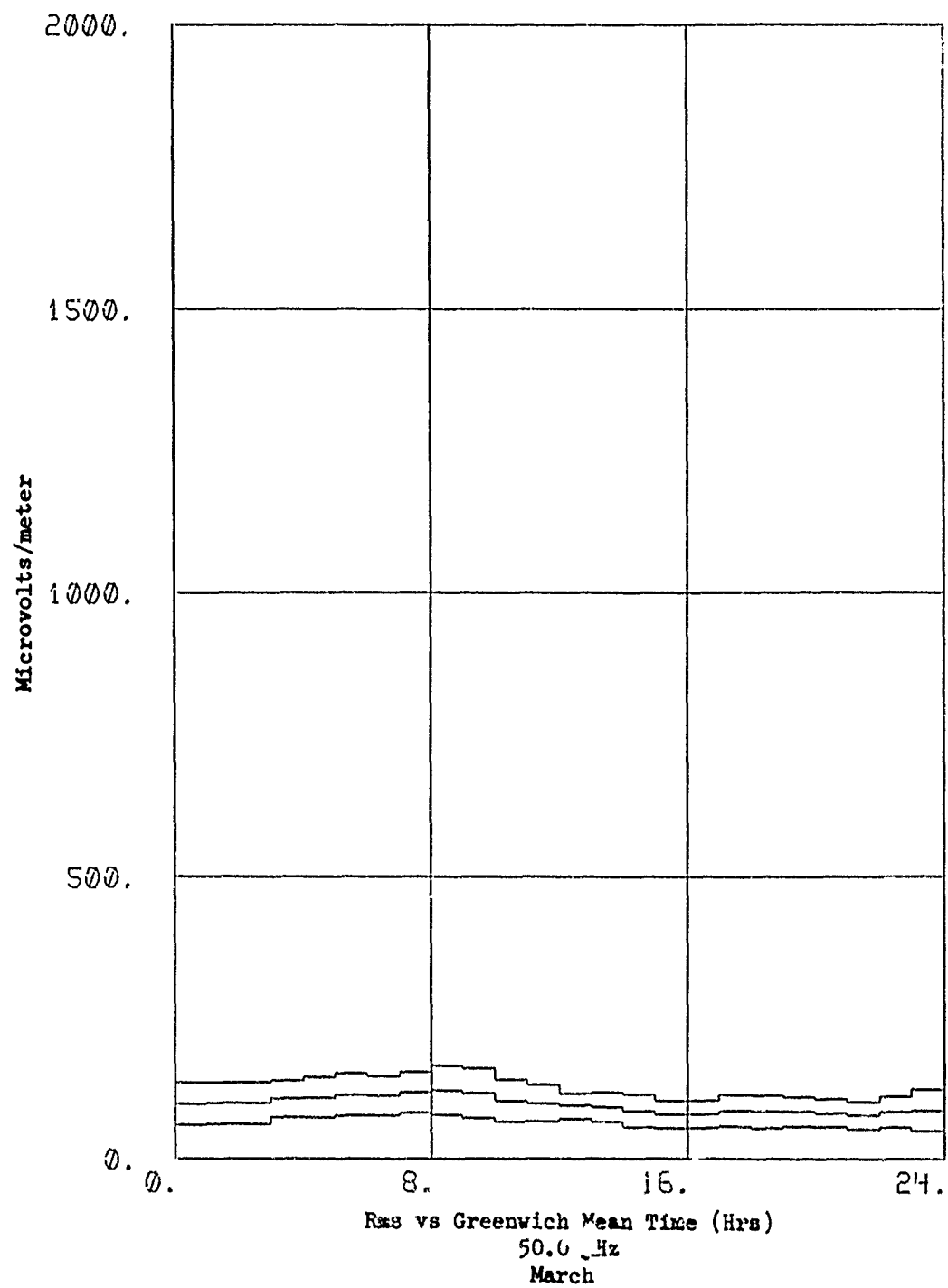


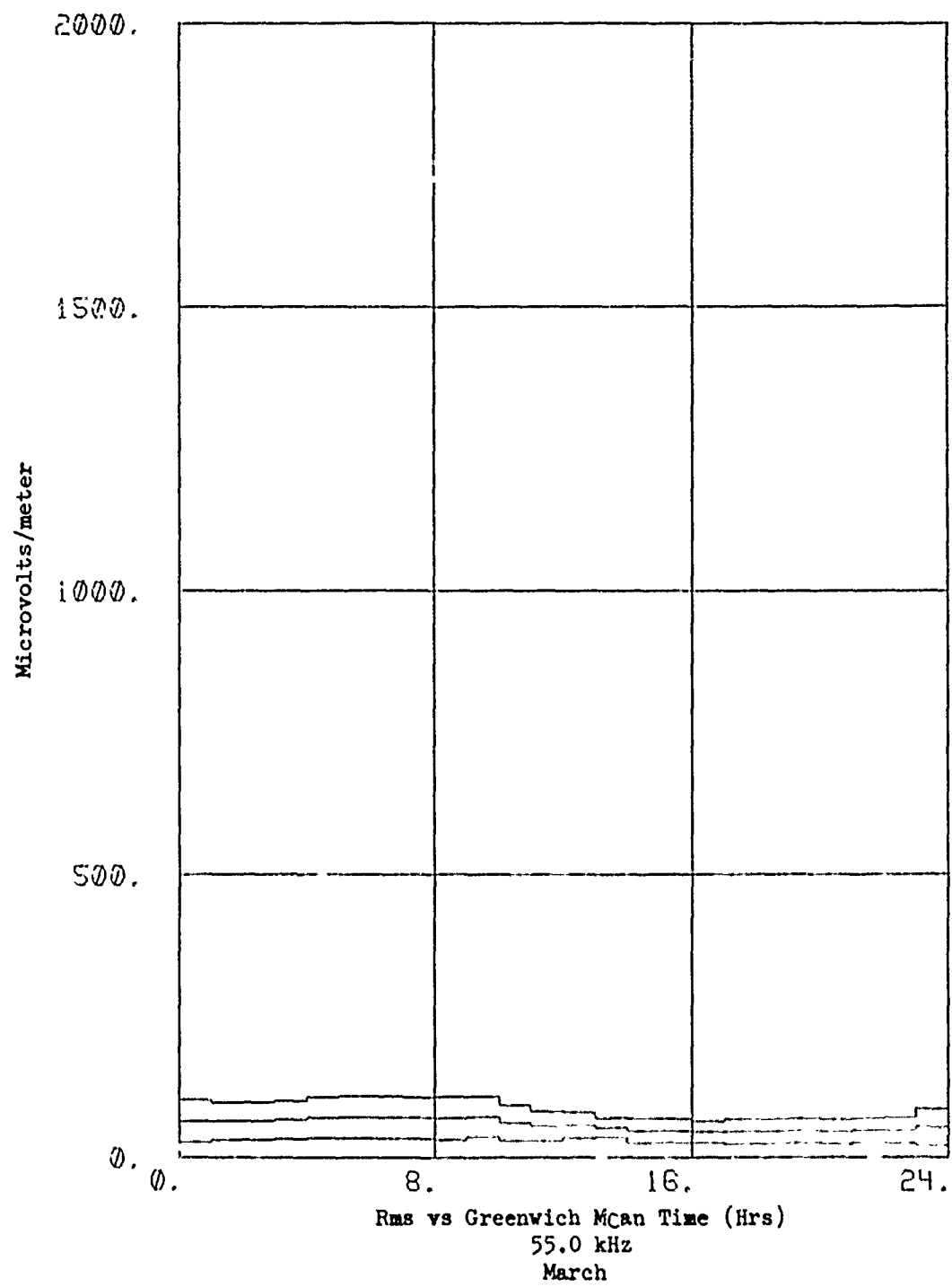




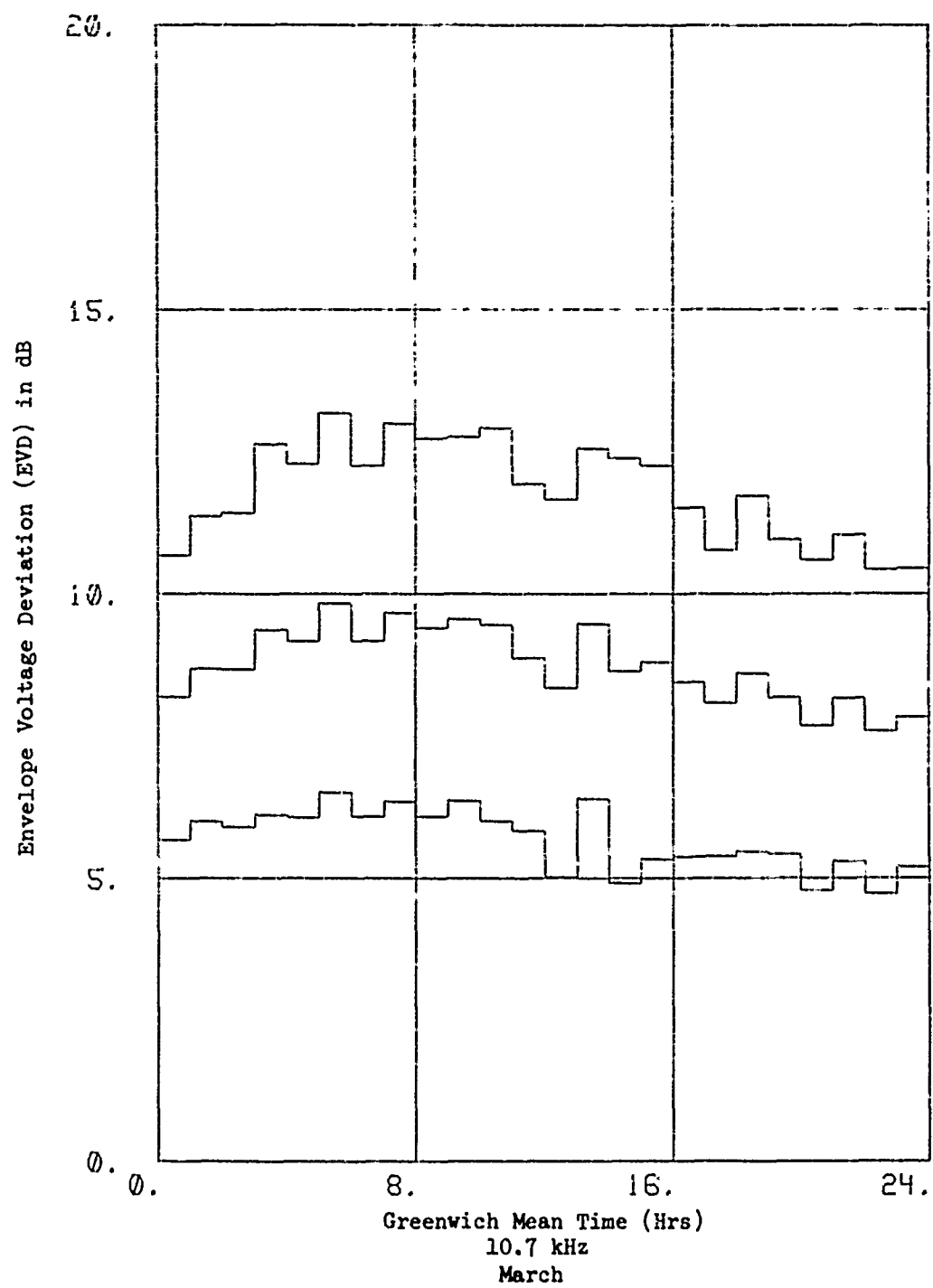


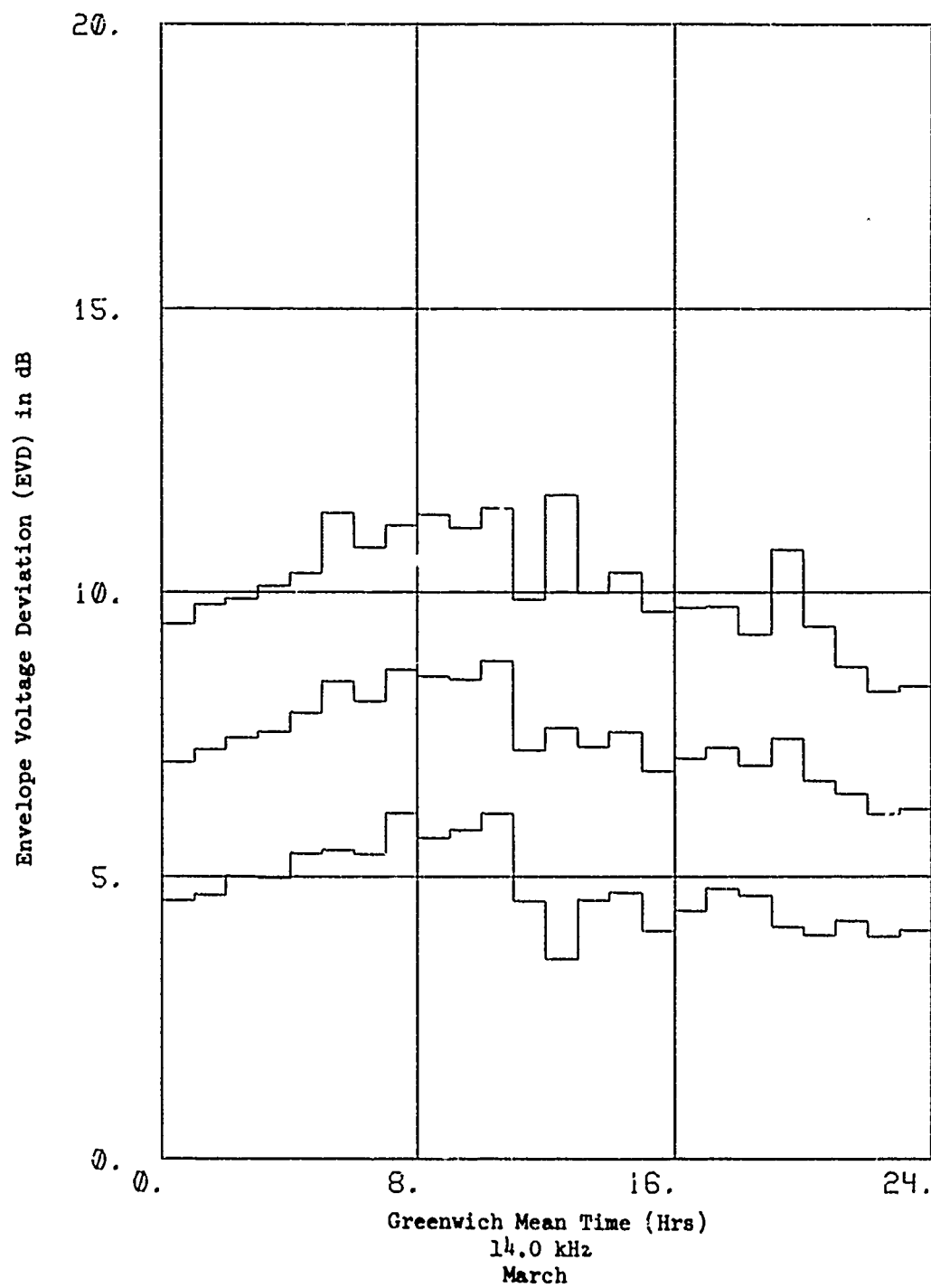




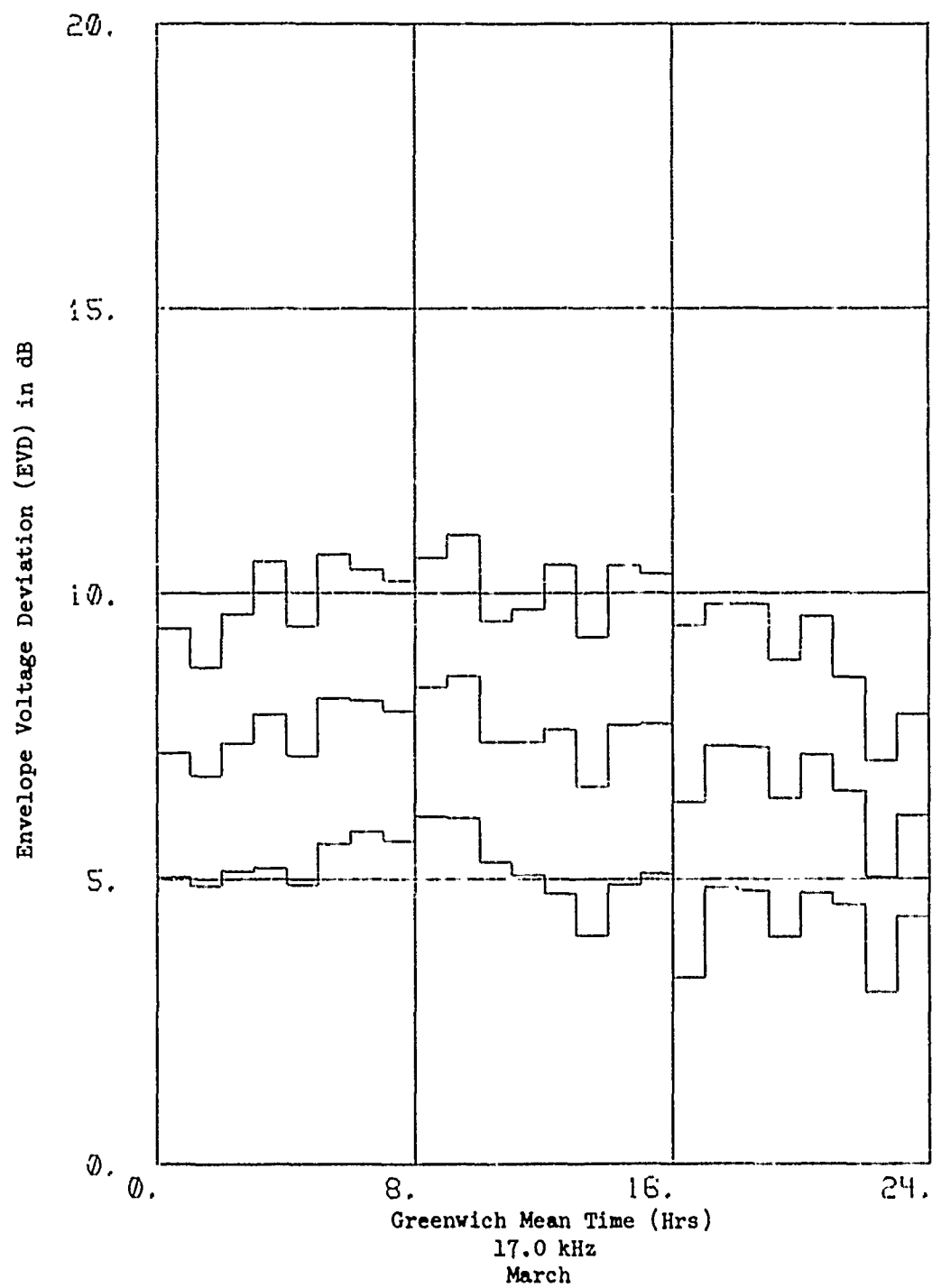


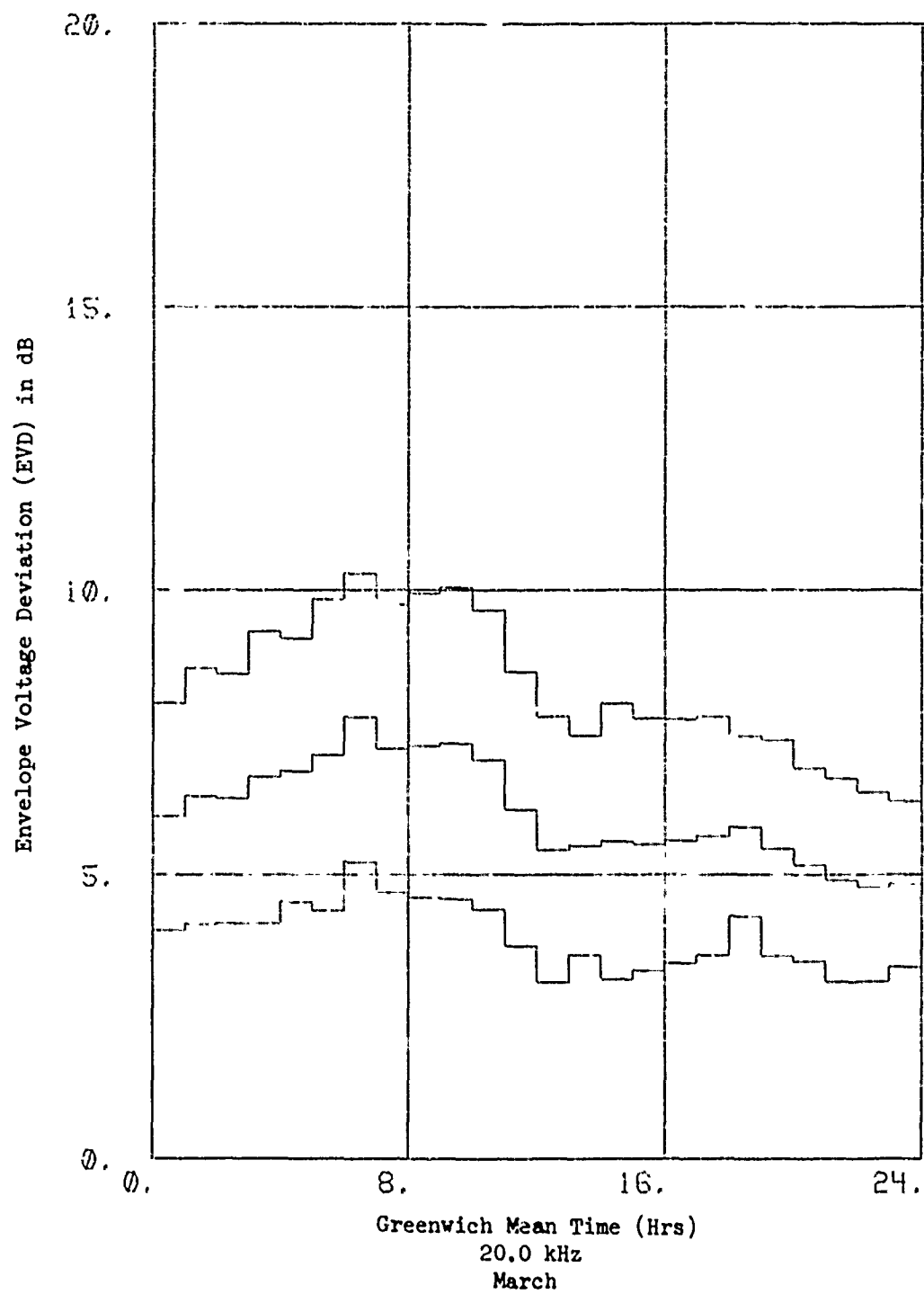
5.8 - EVD vs TIME (@ FREQS. - FOR MARCH)

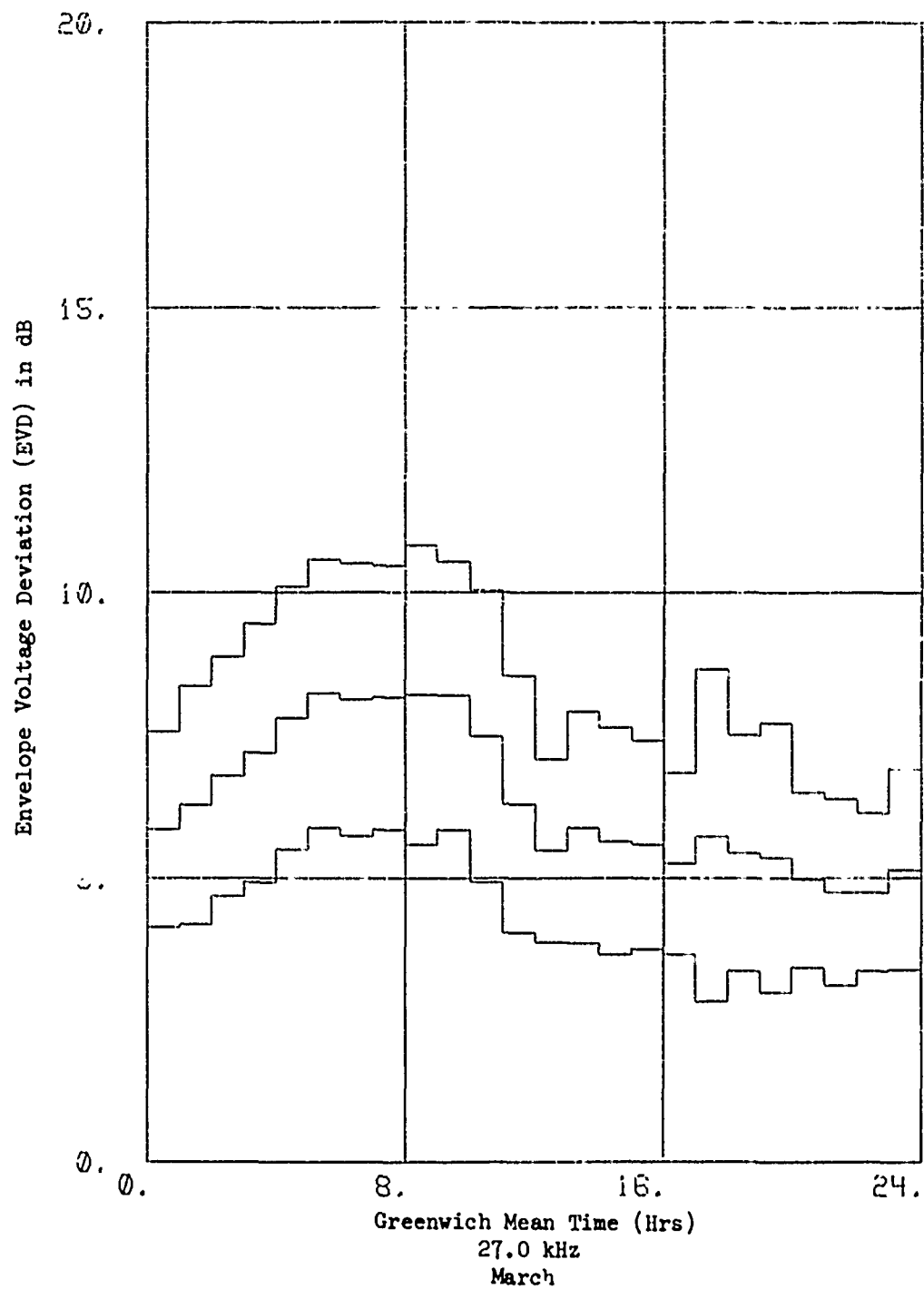


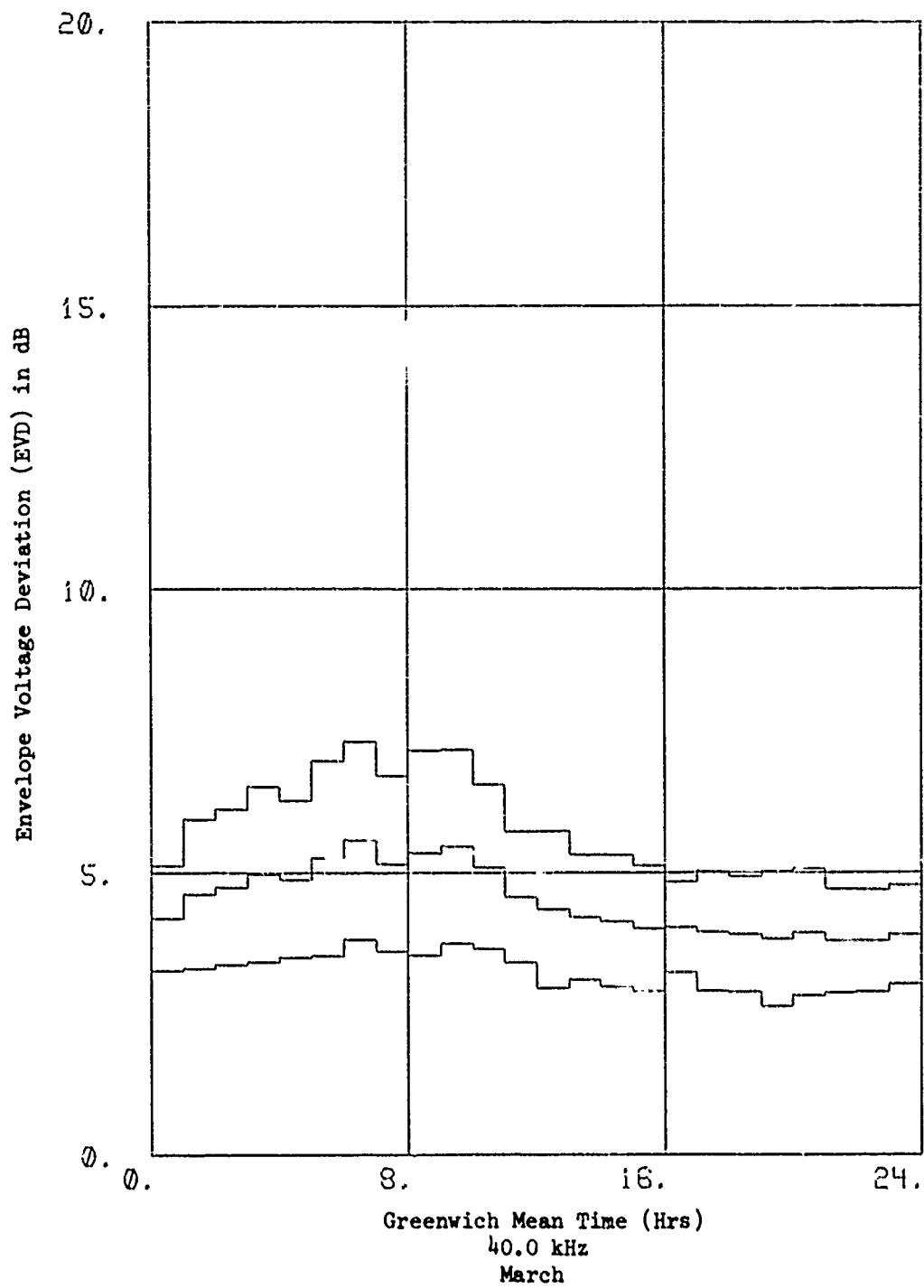


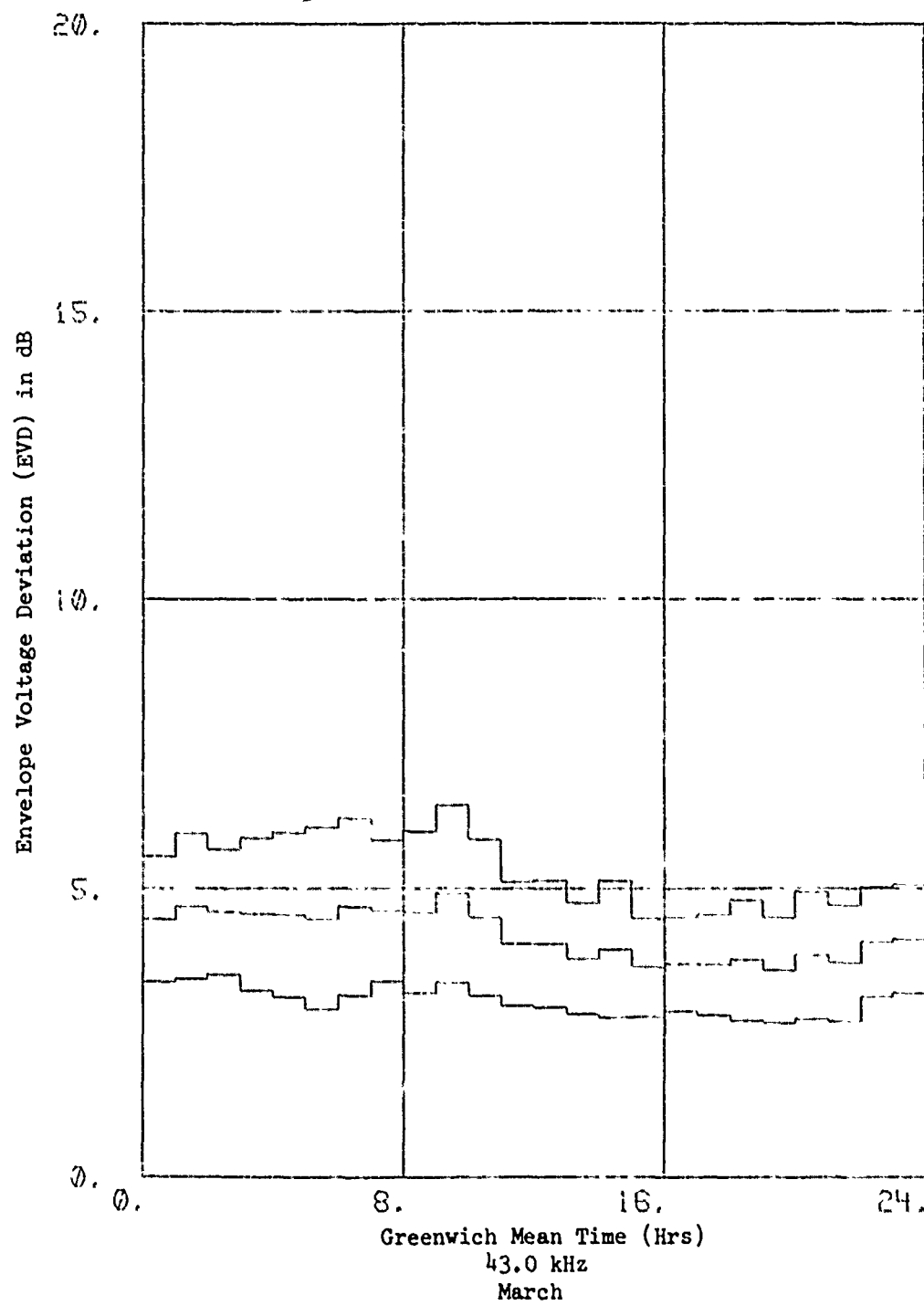


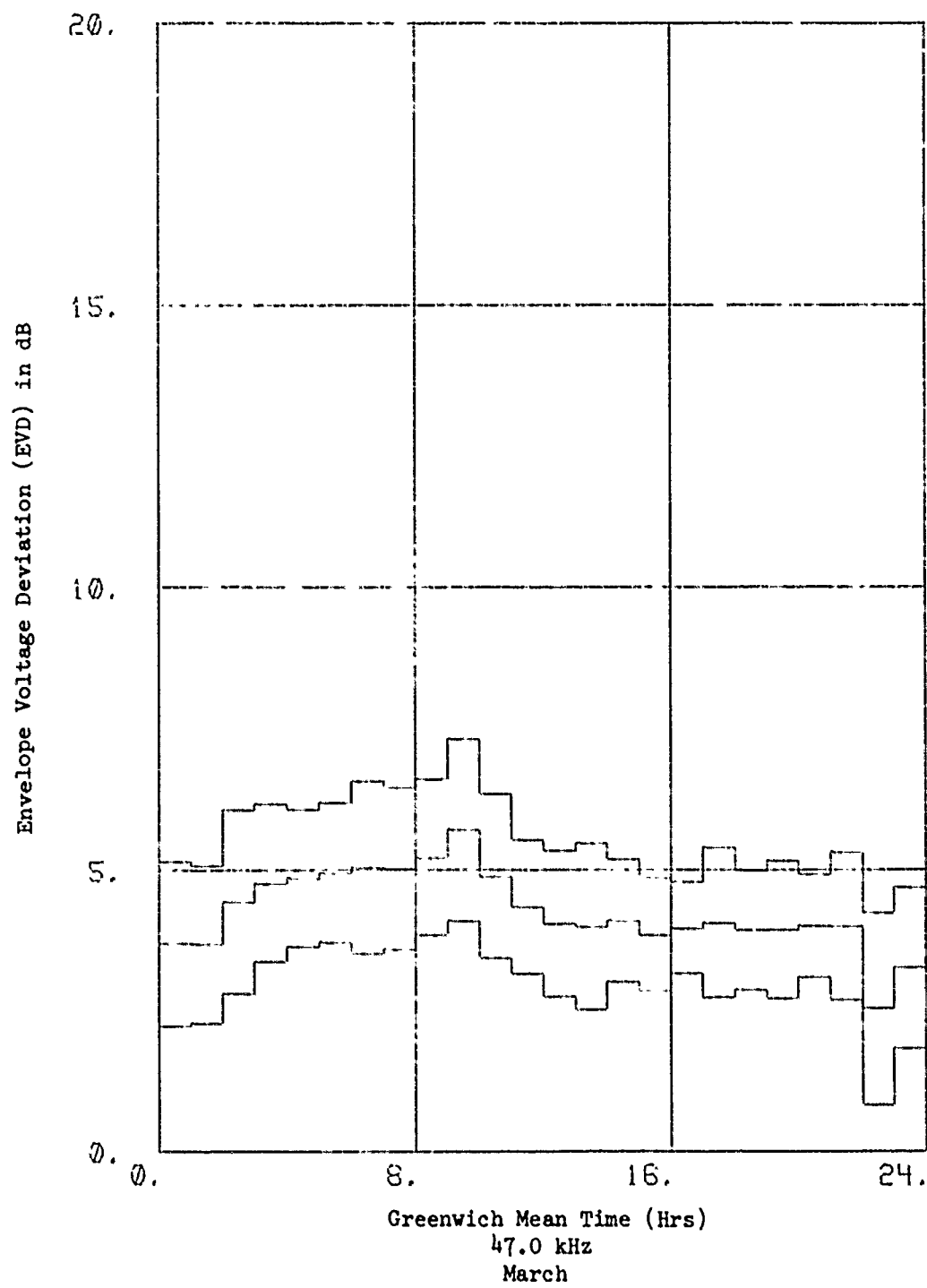


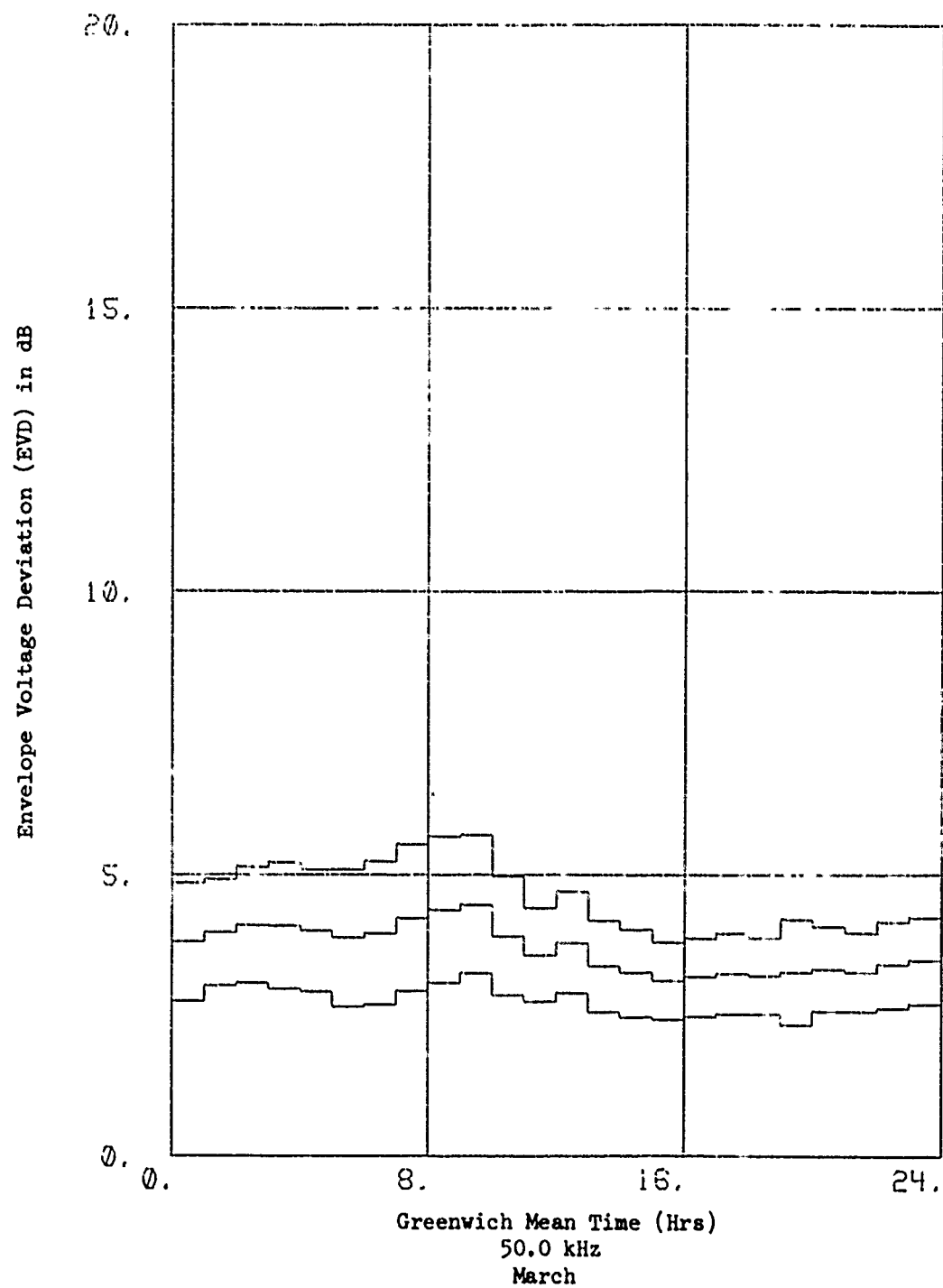


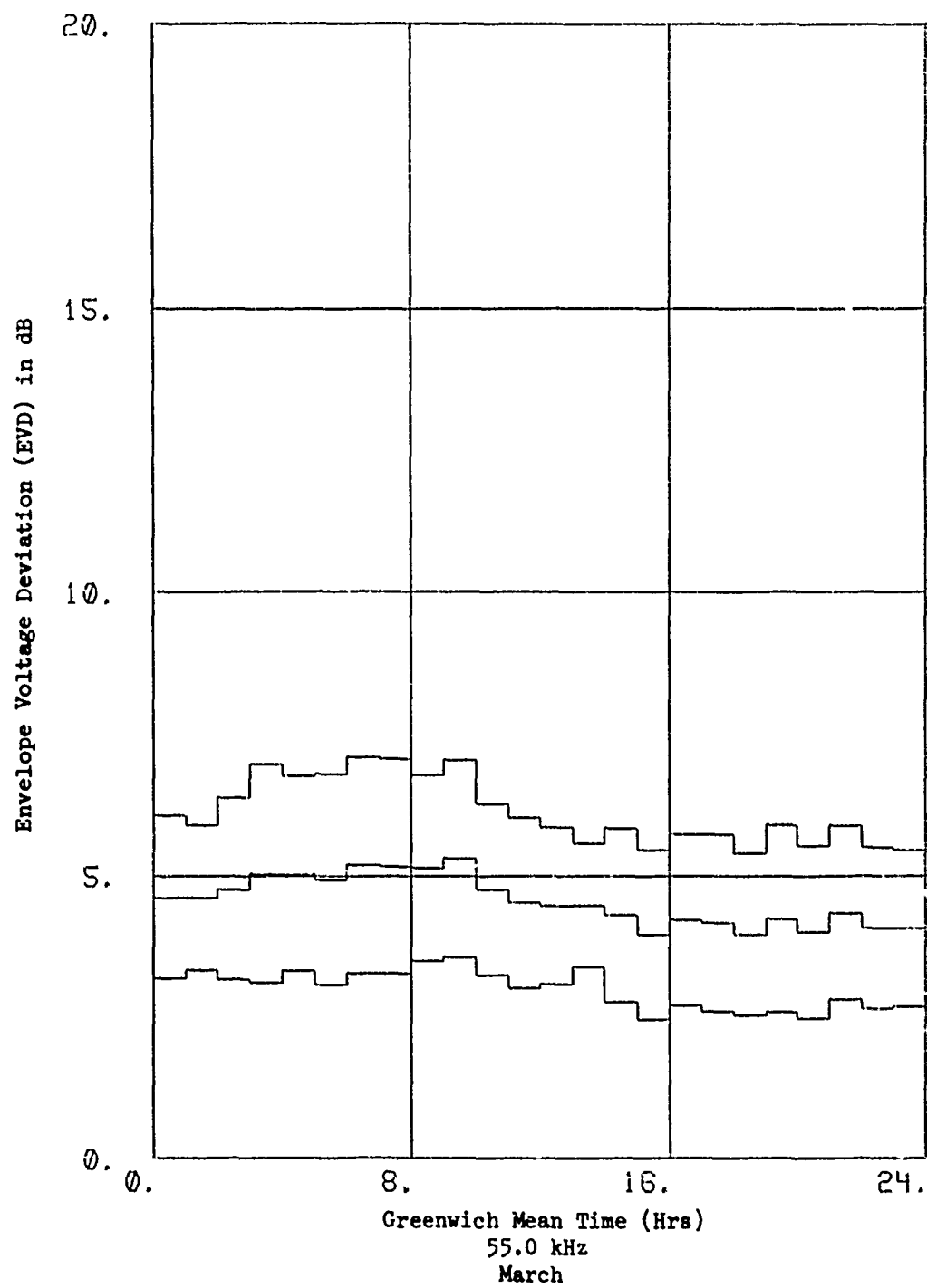






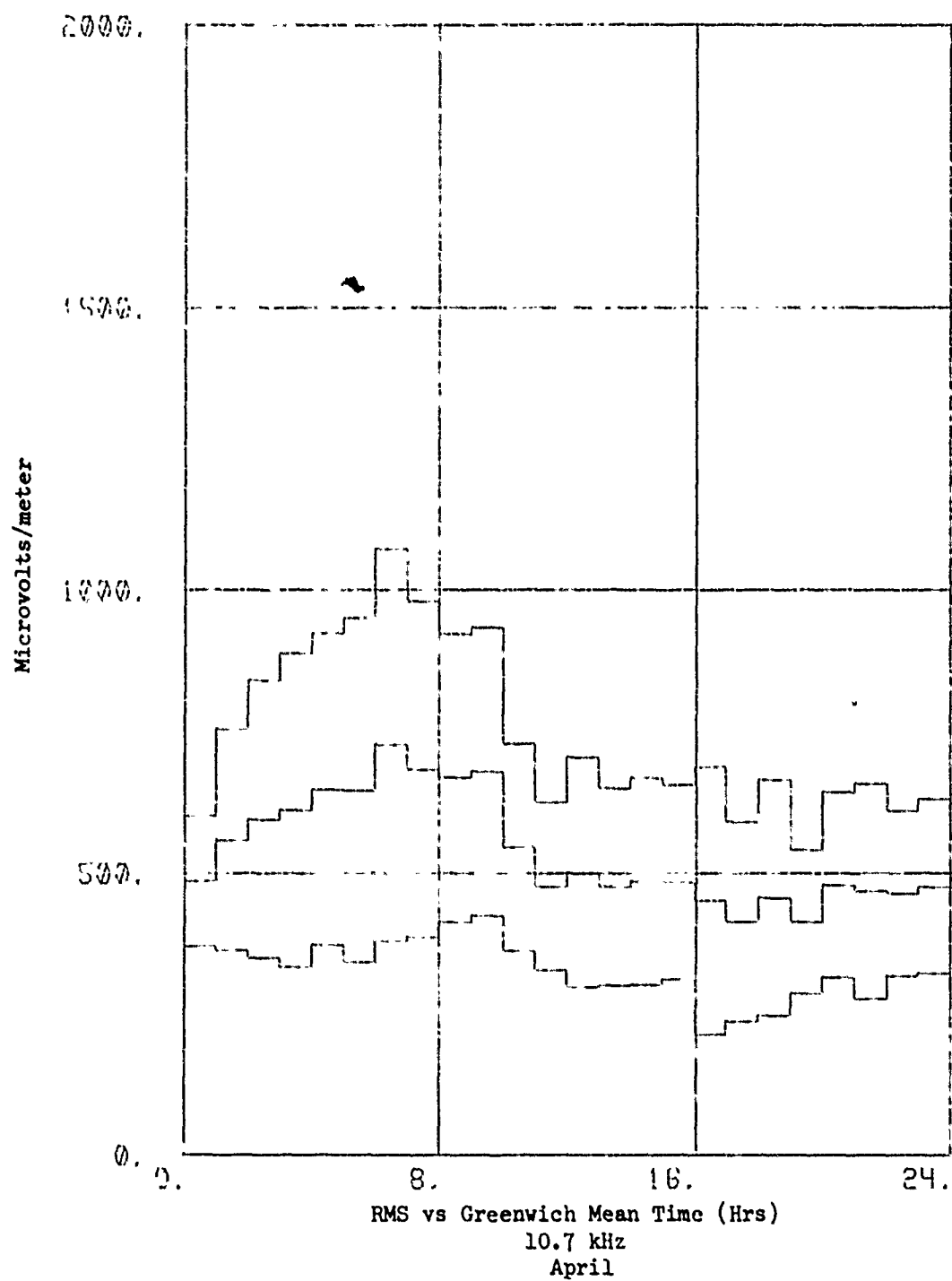


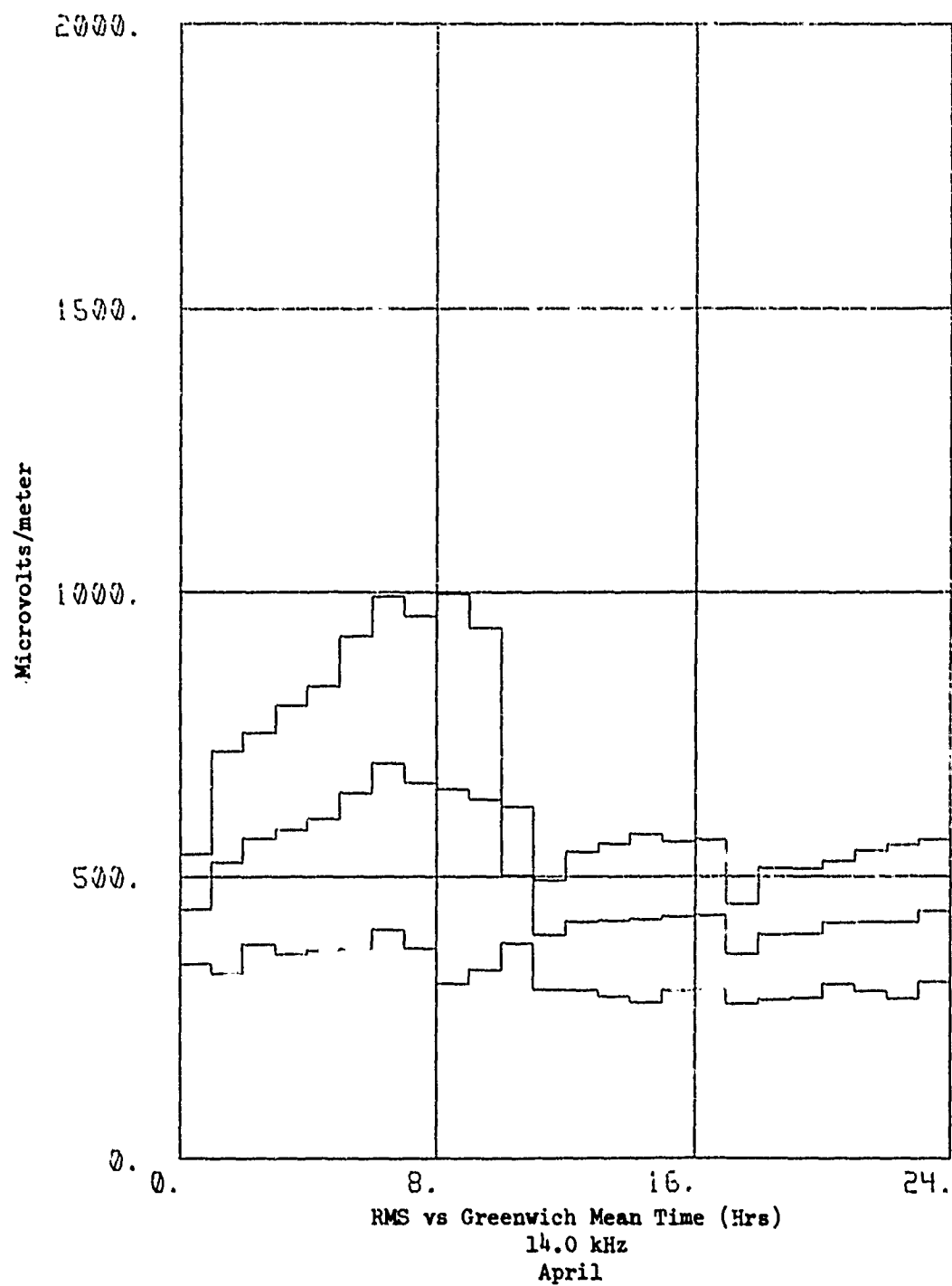


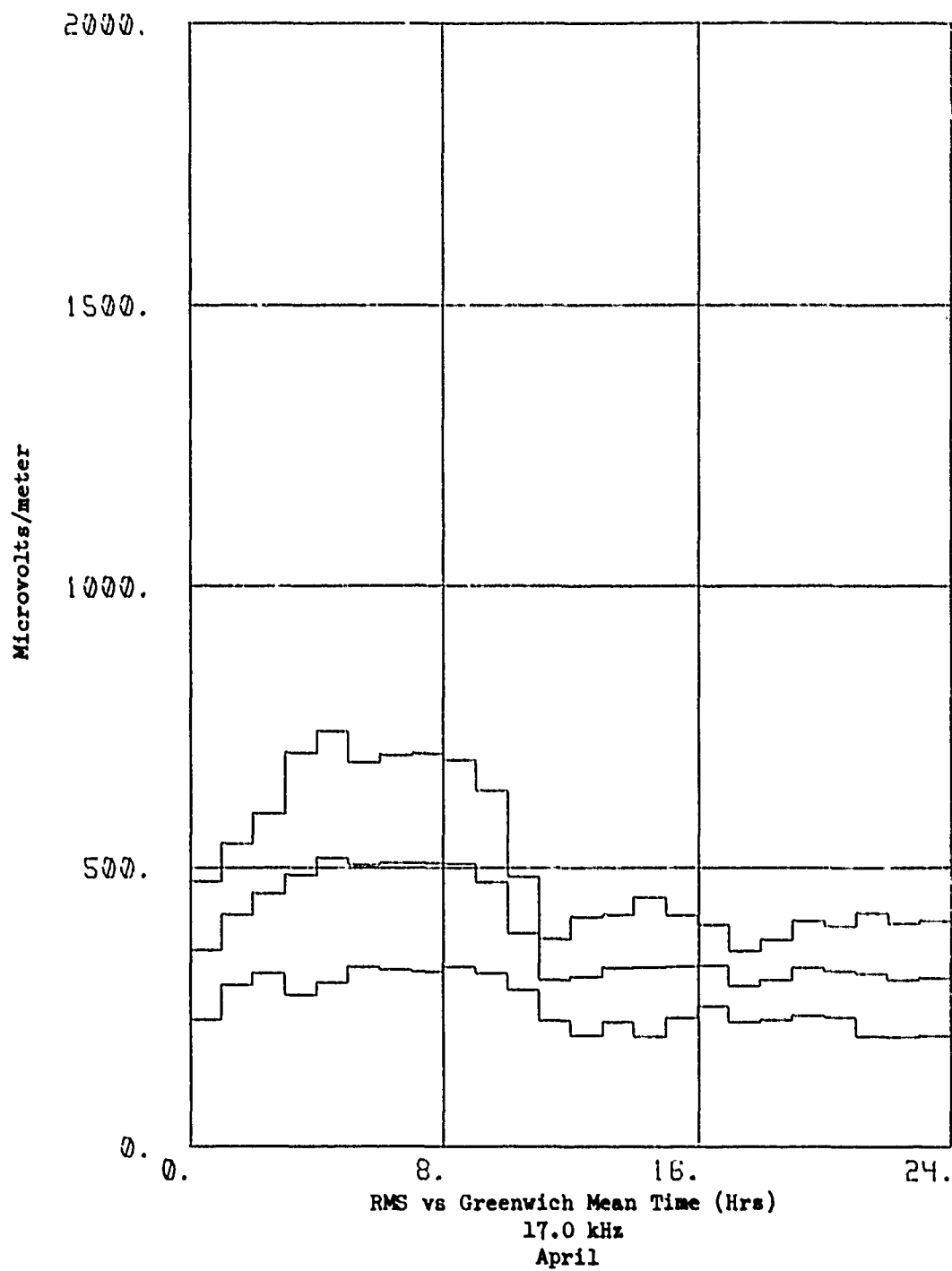


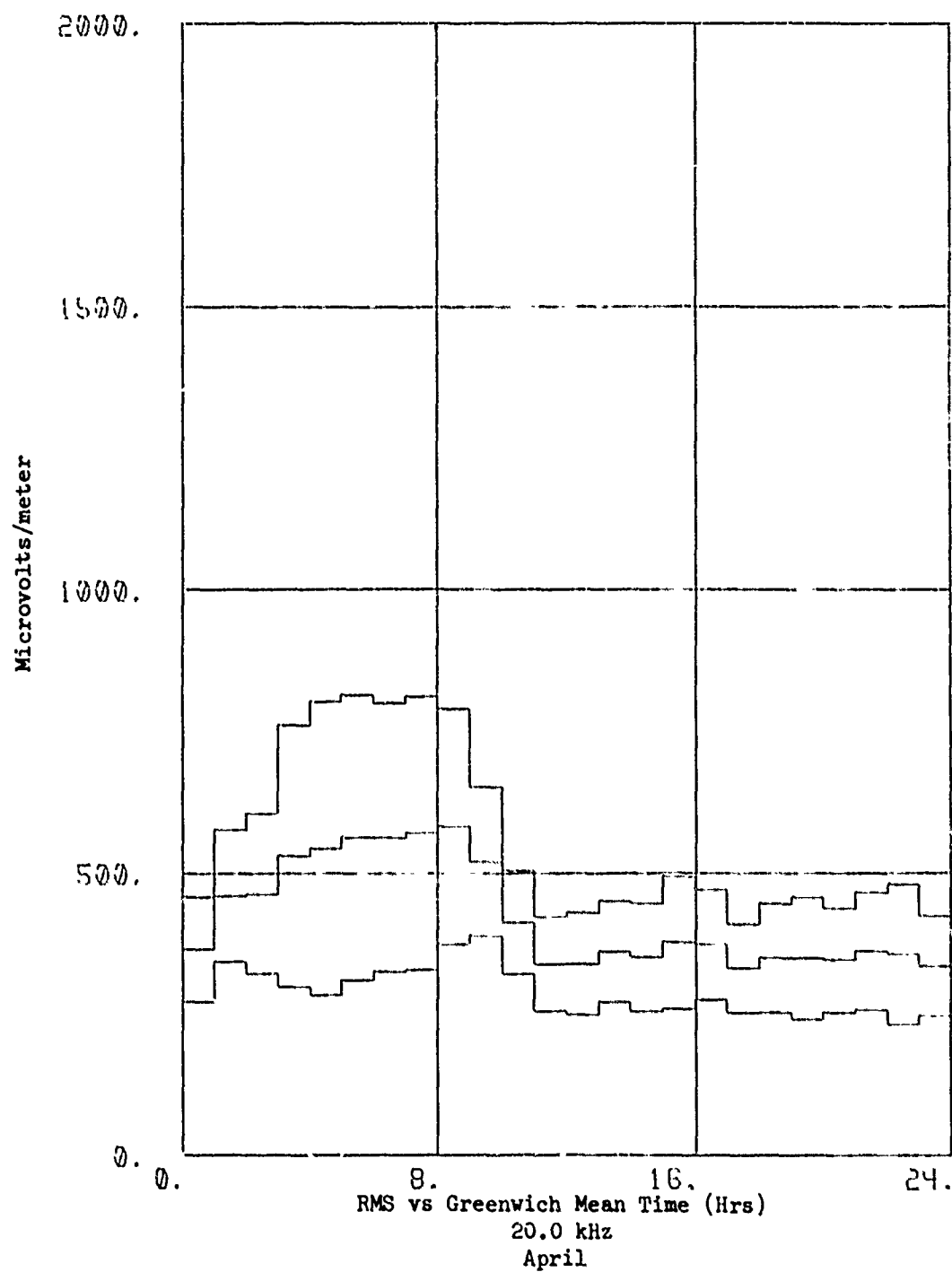


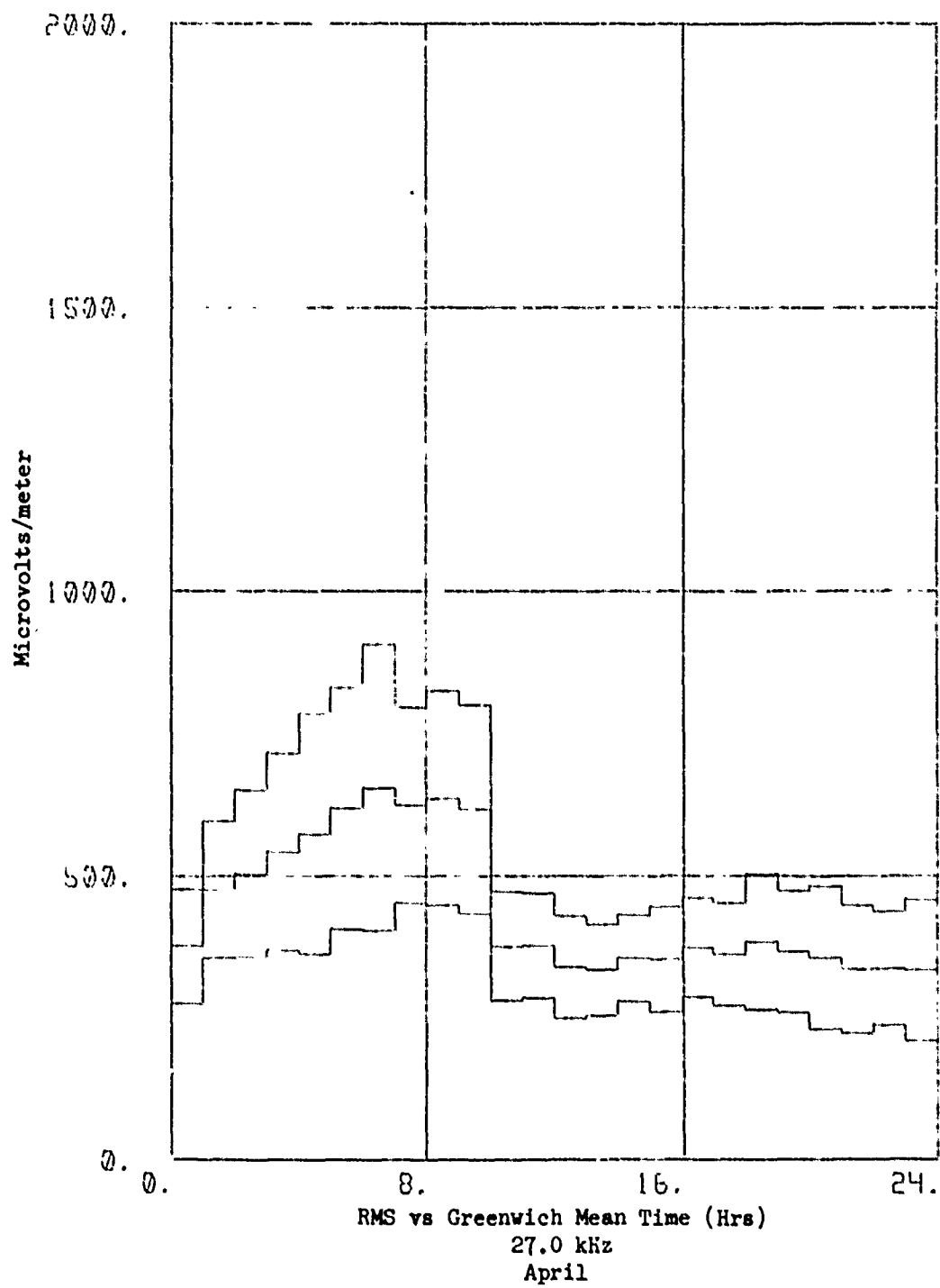
5.9 - ERMS vs TIME (@ FREQS. - FOR APRIL)

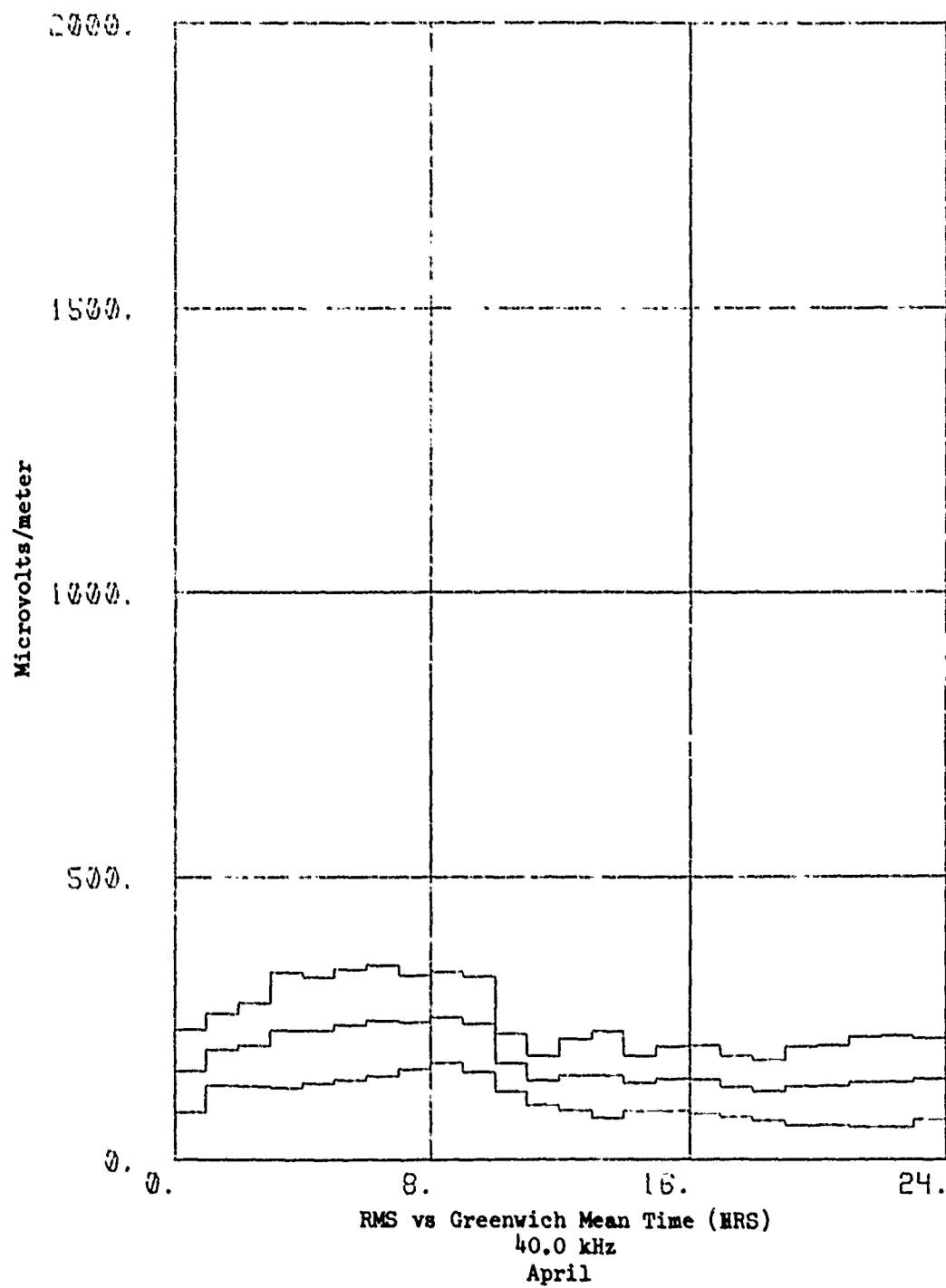


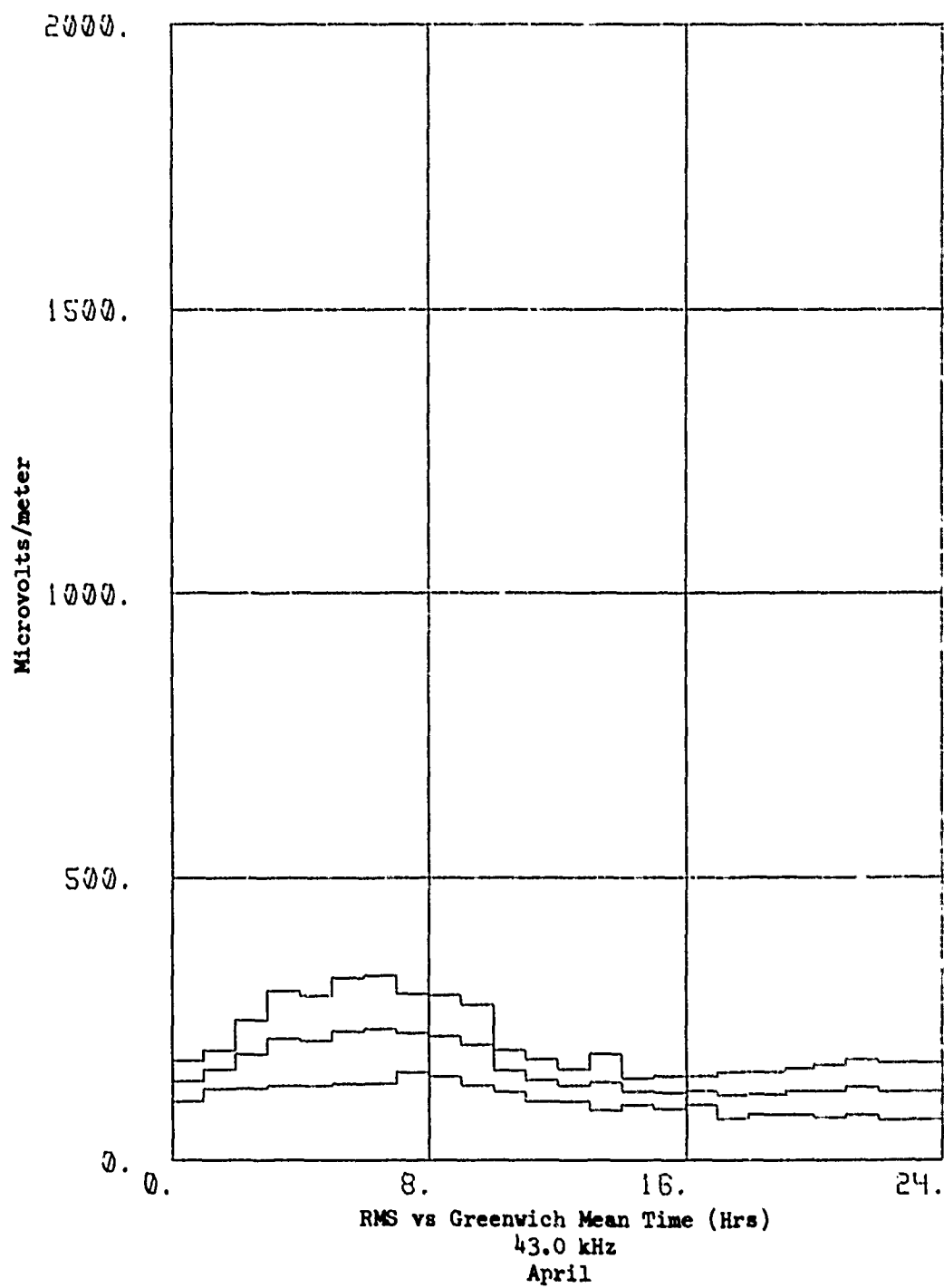




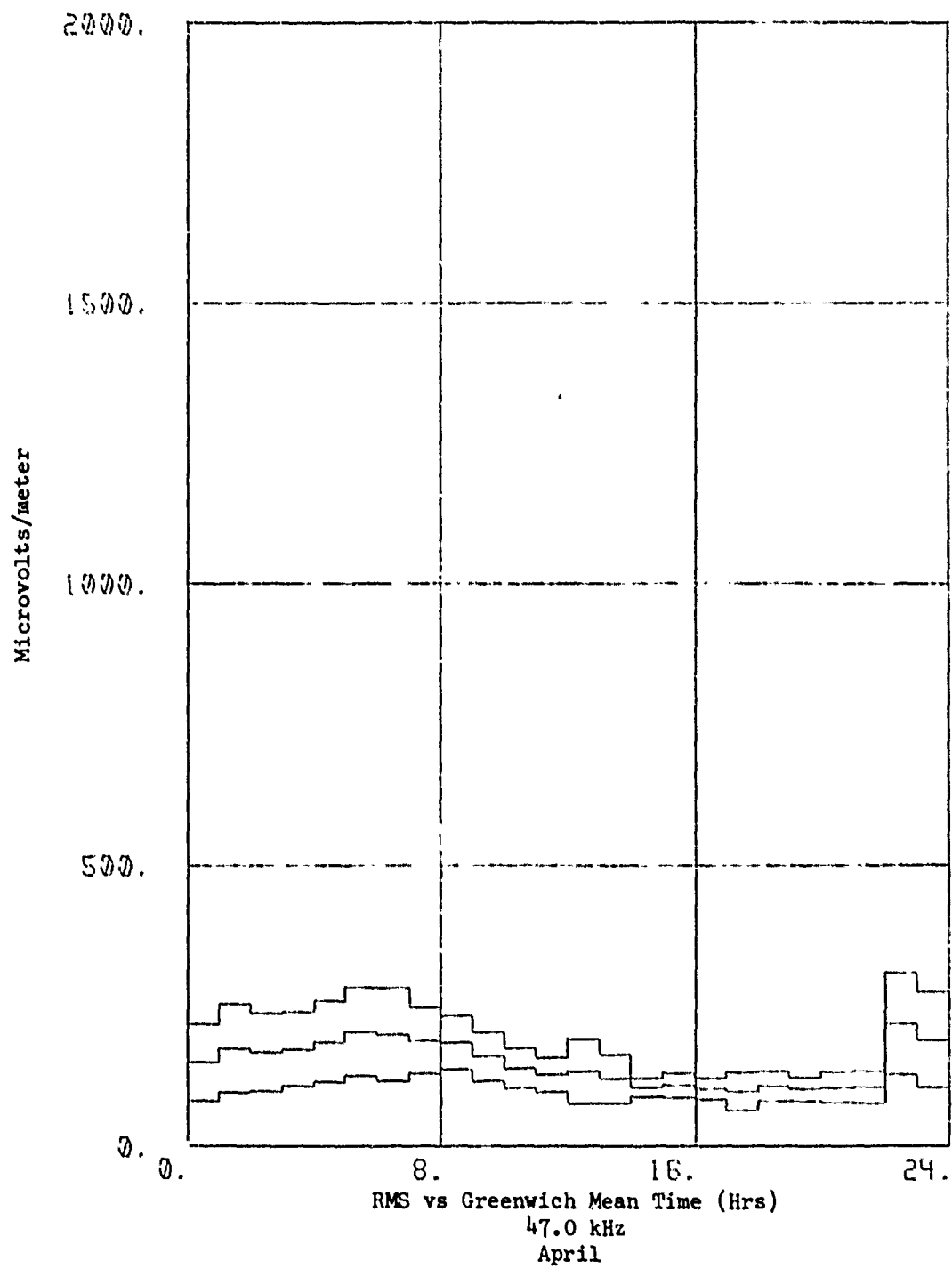


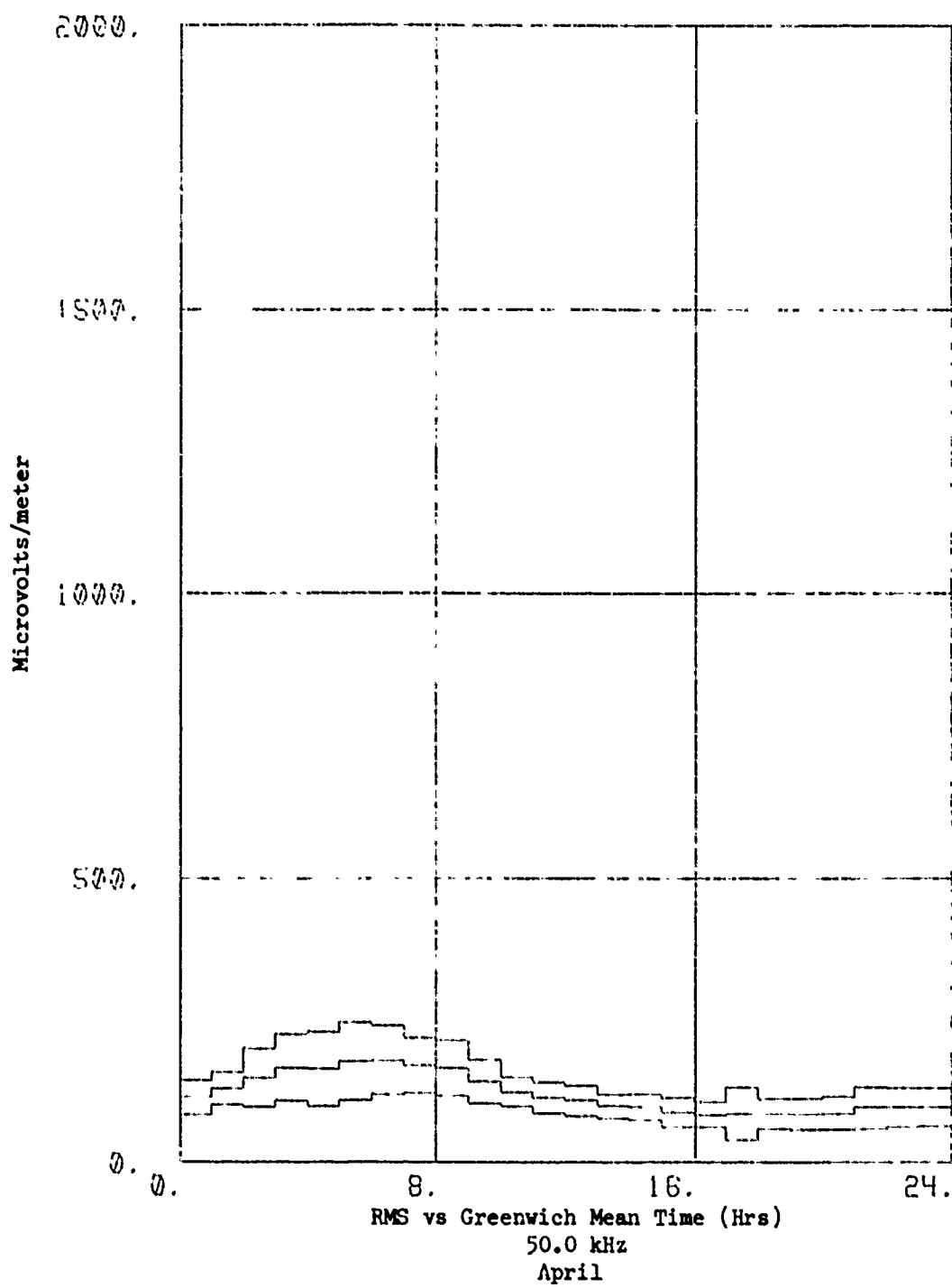


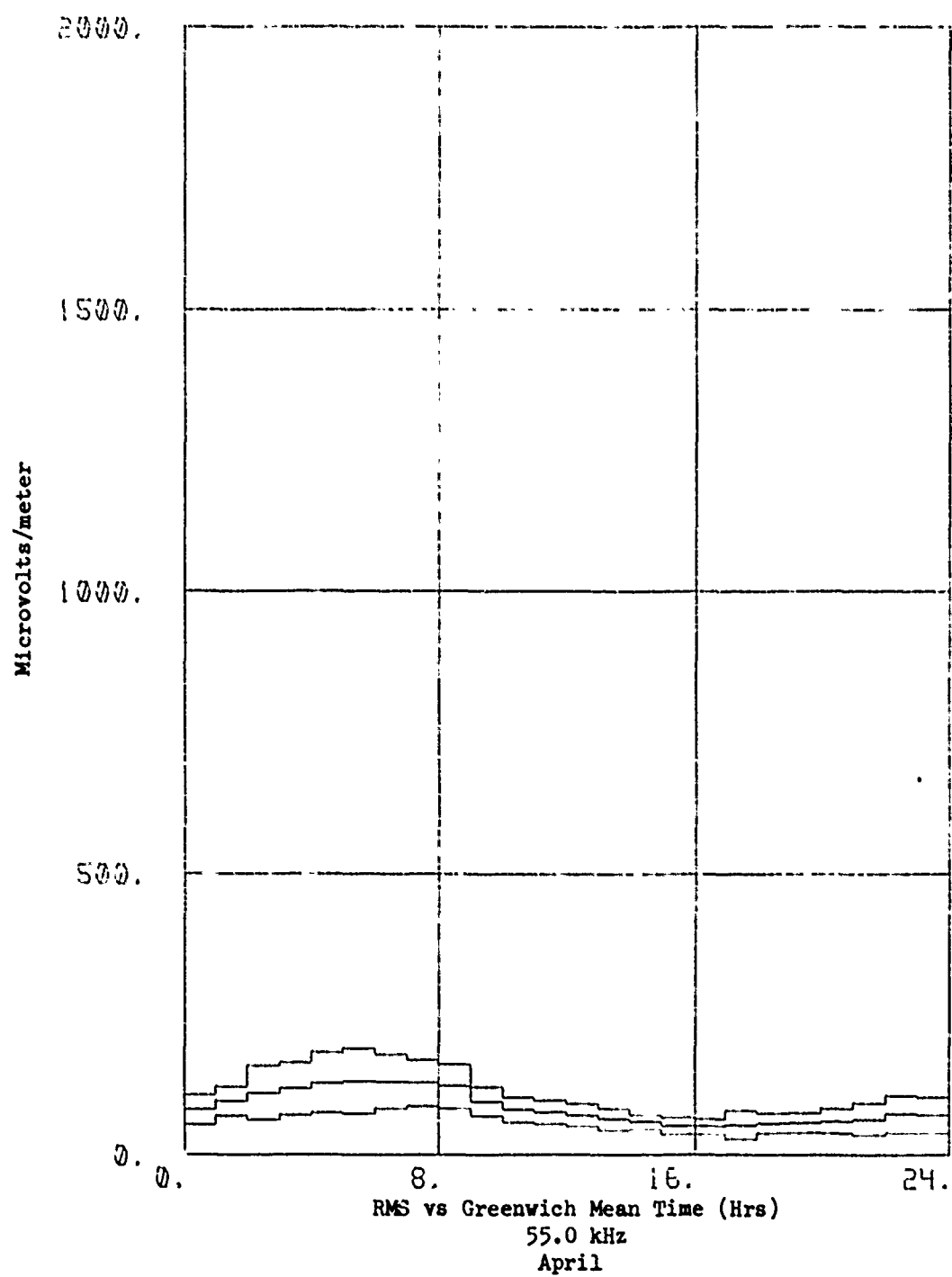




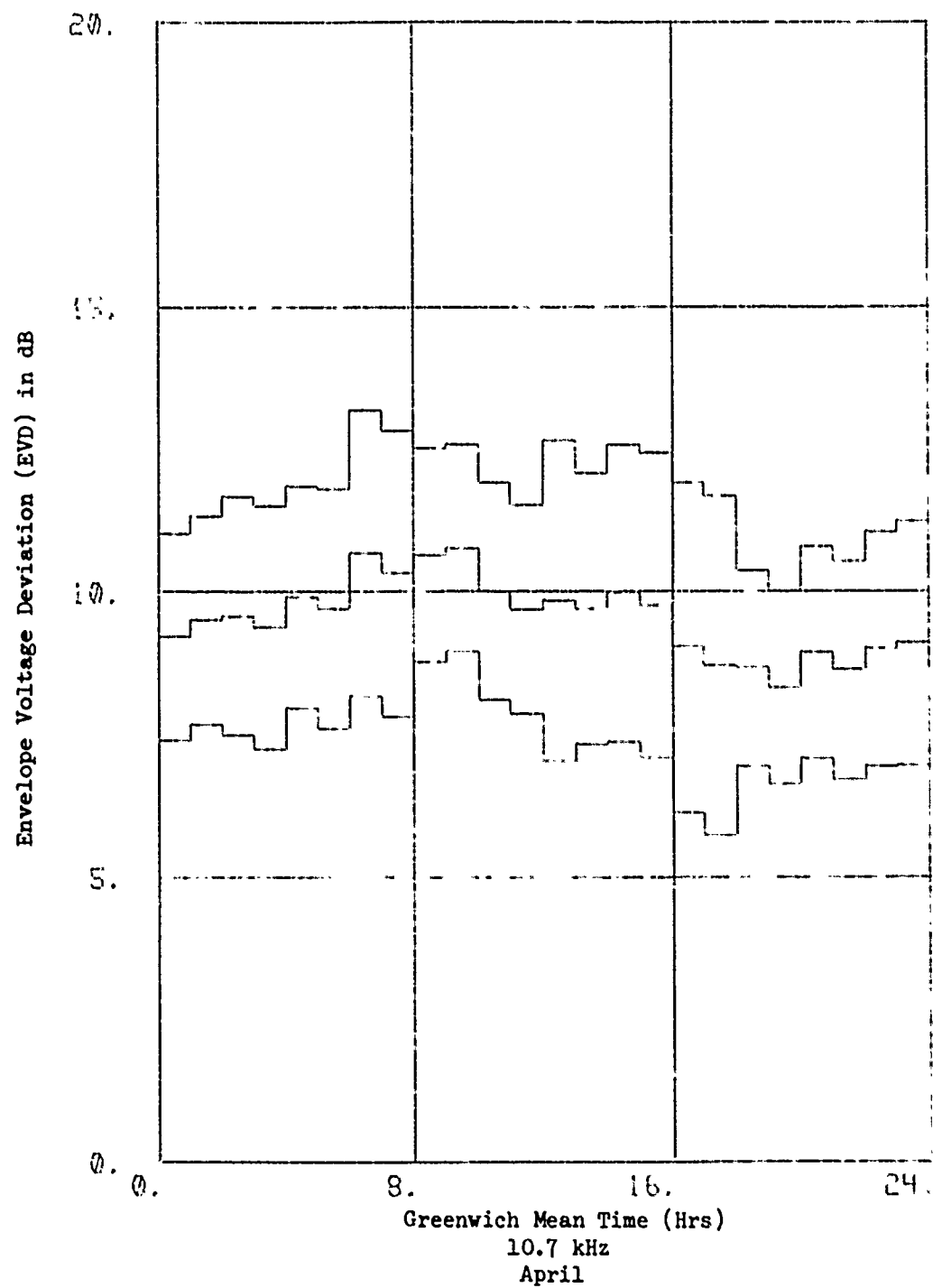


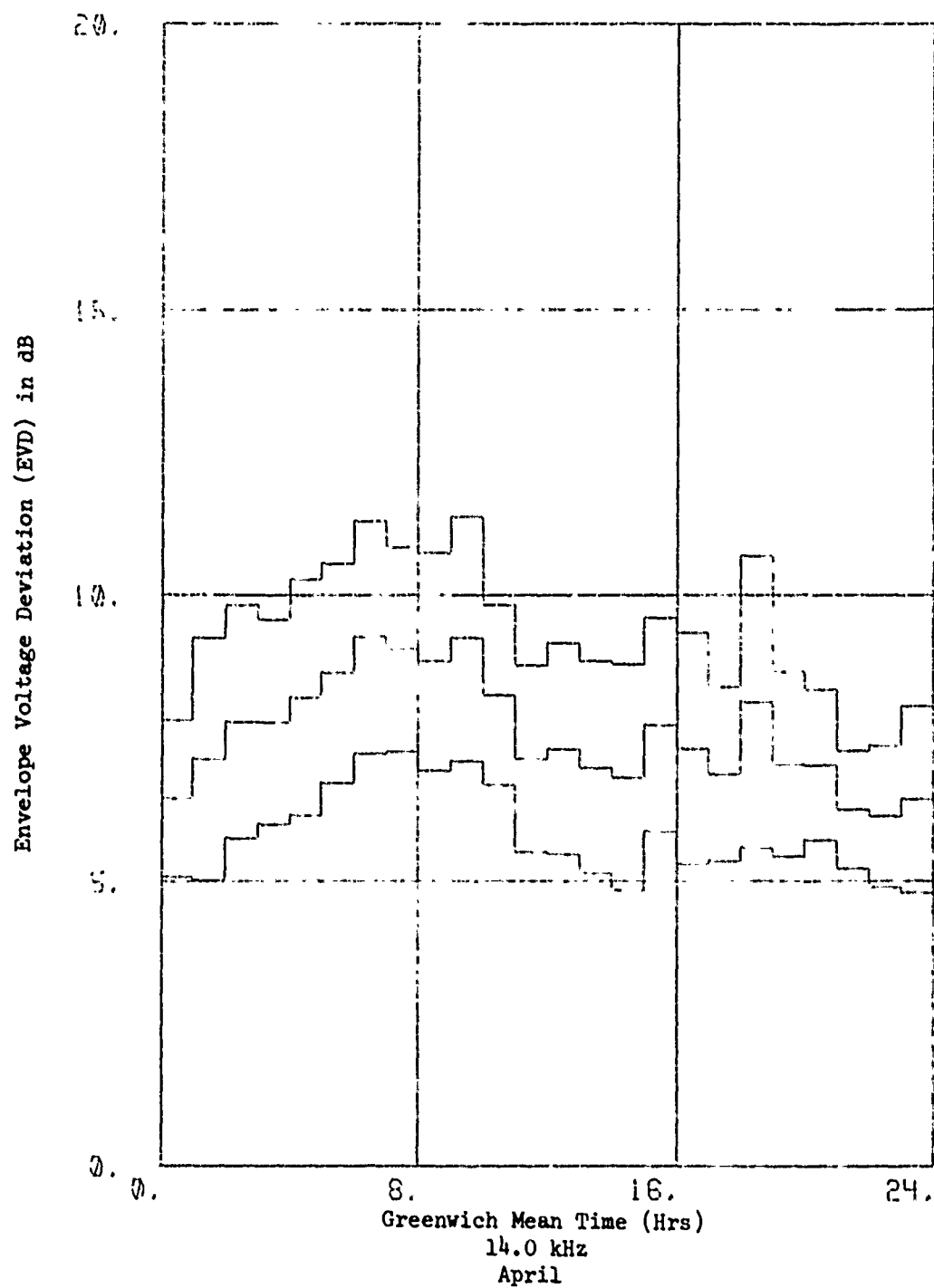


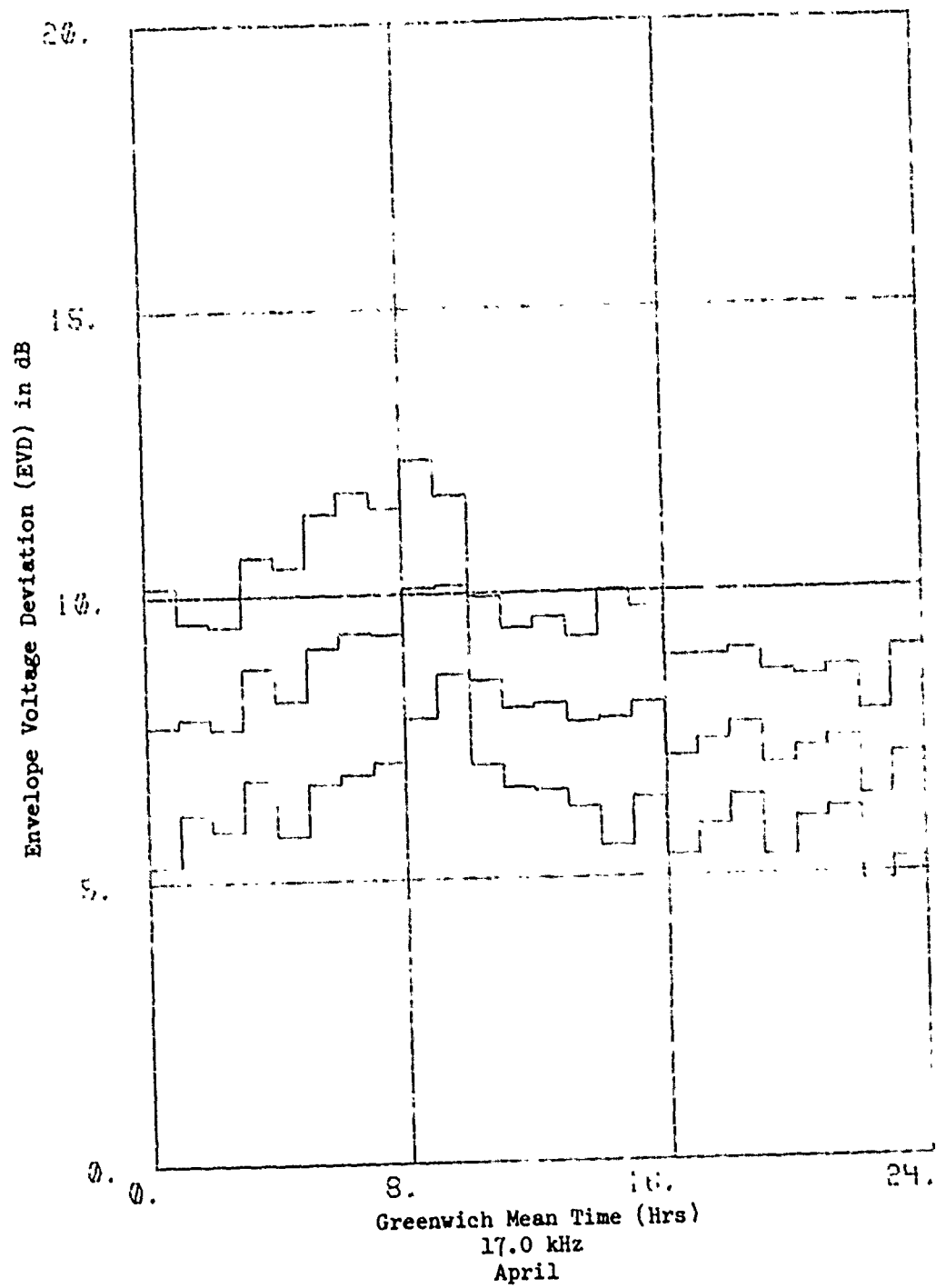


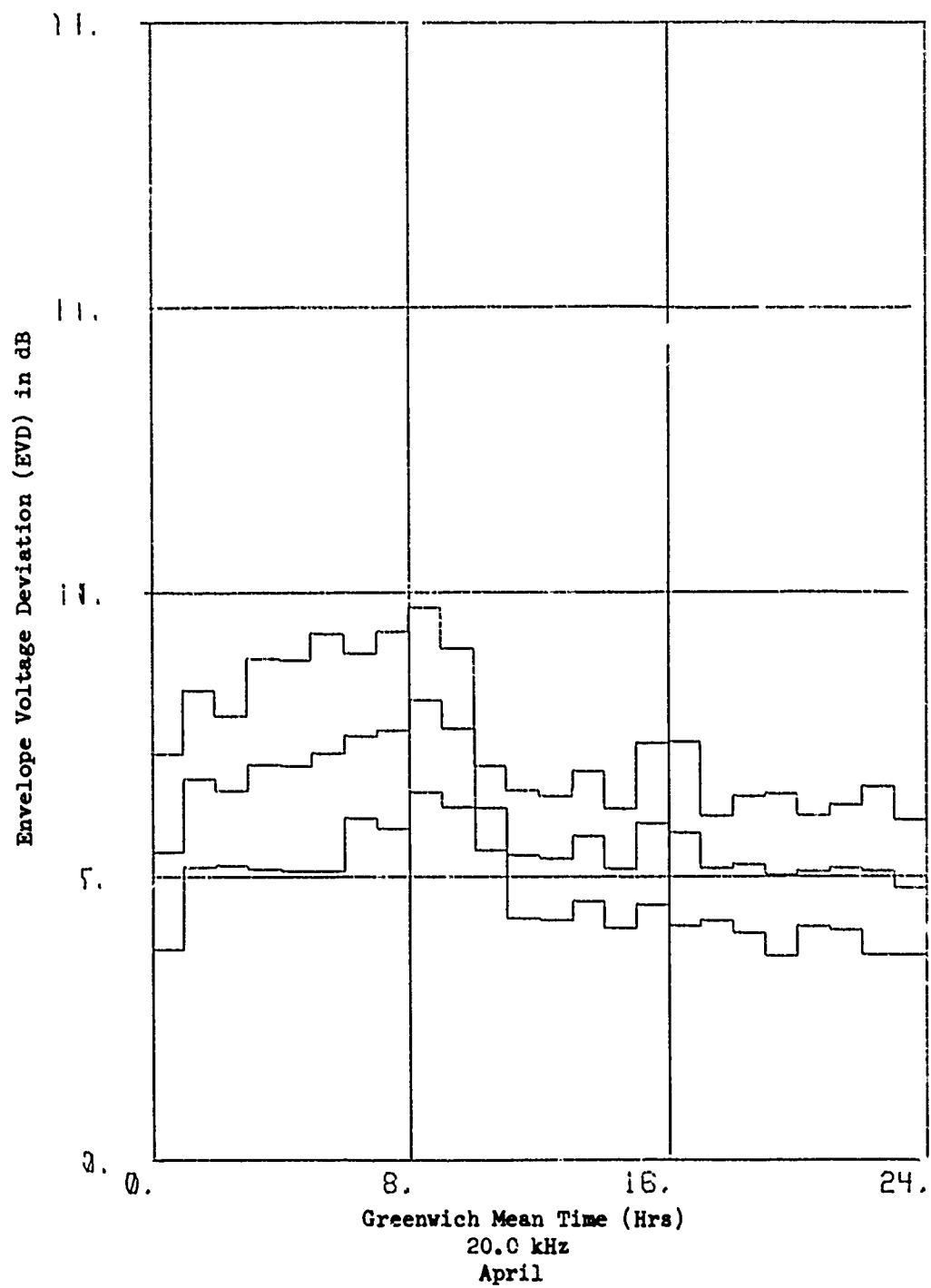


5.10 - EVD vs TIME (@ FREQS. - FOR APRIL)

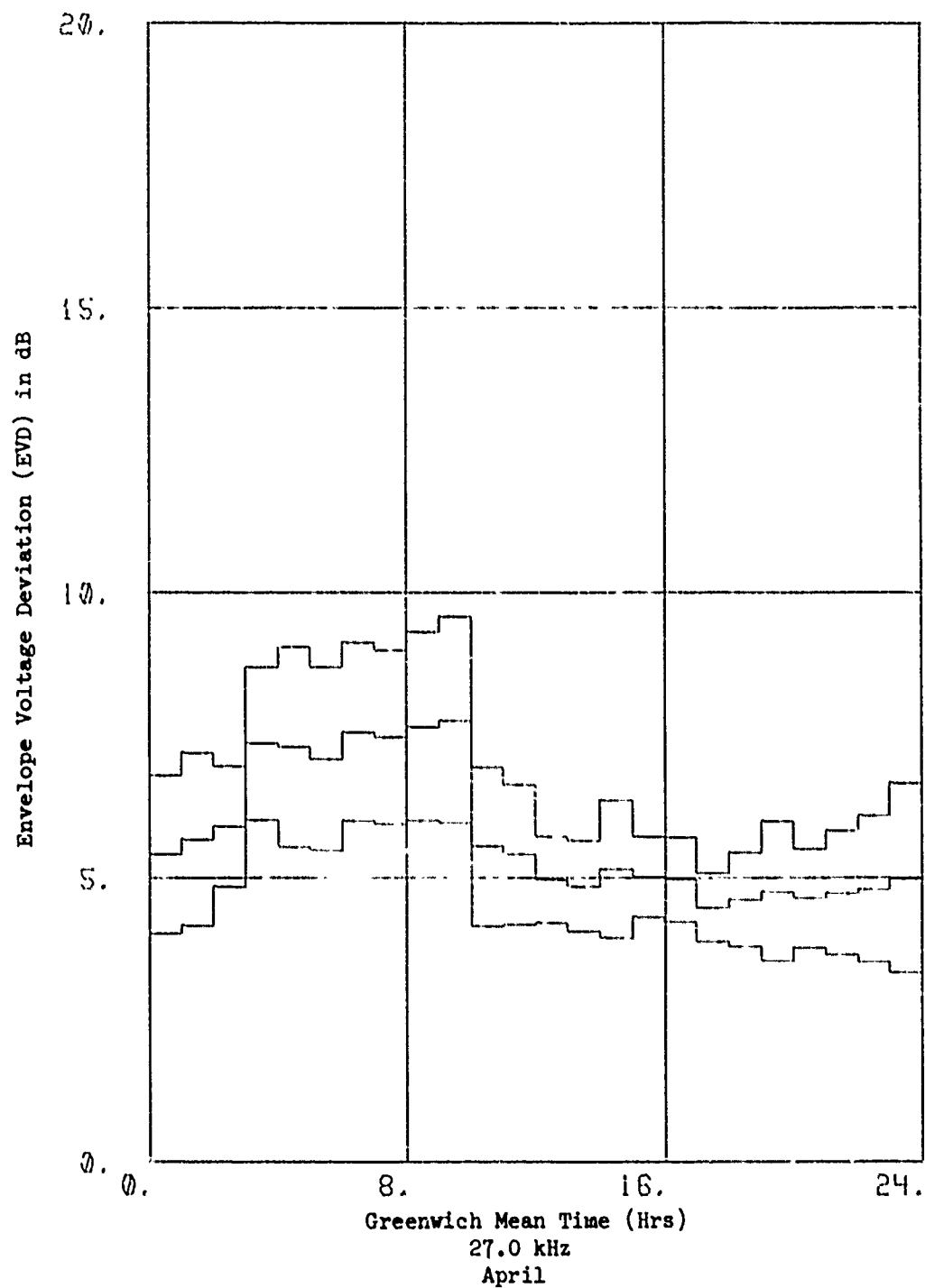


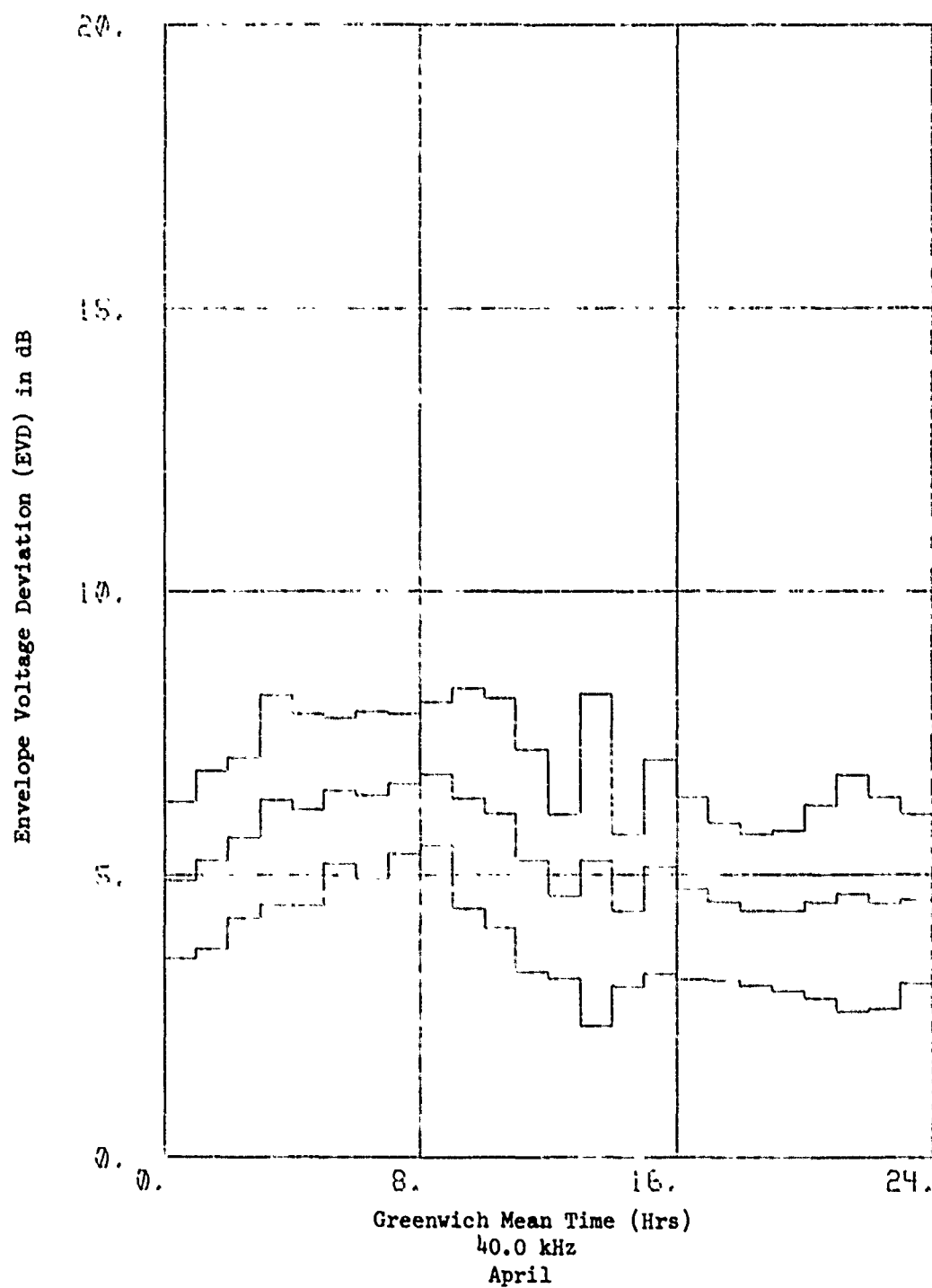


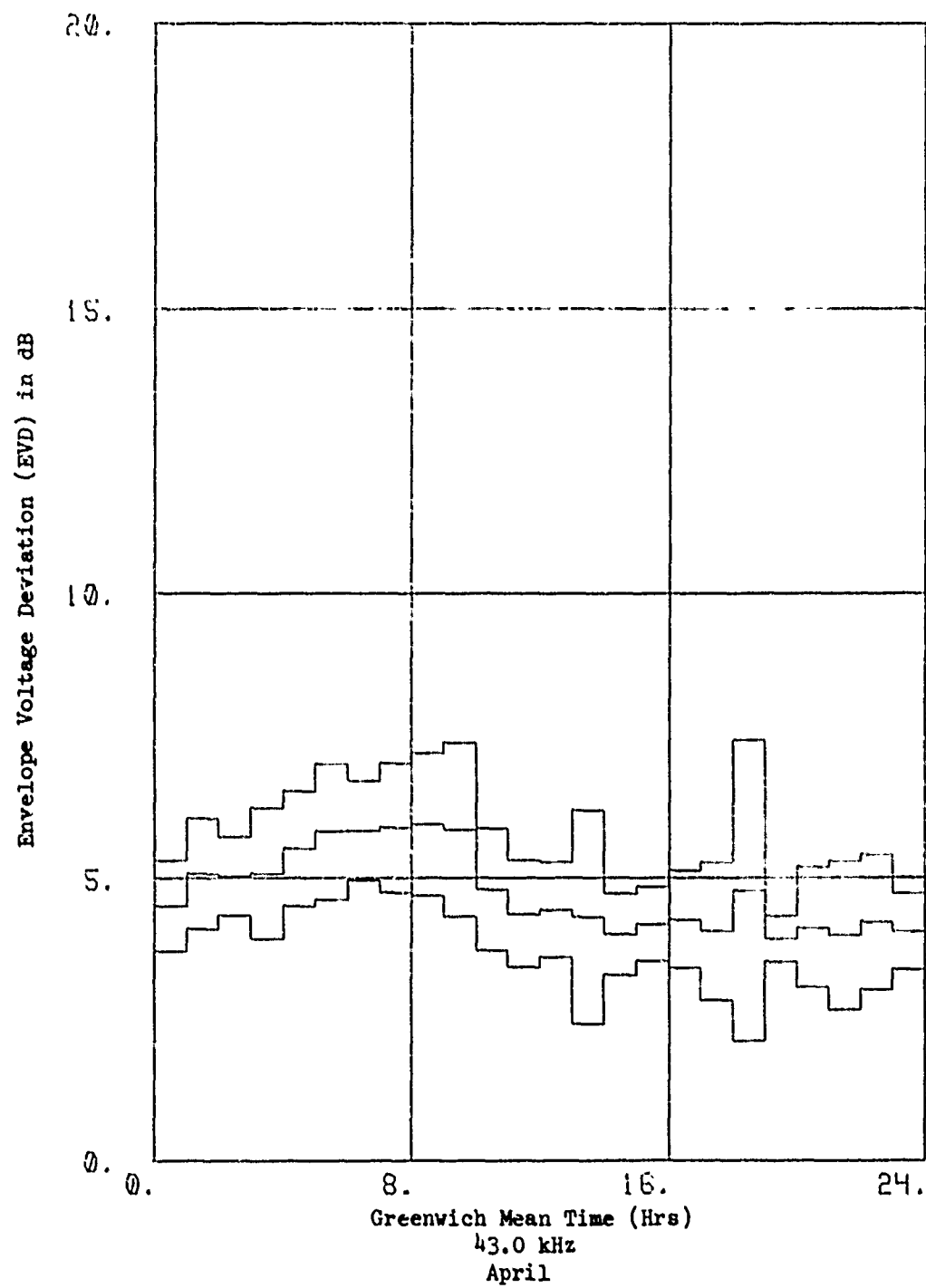


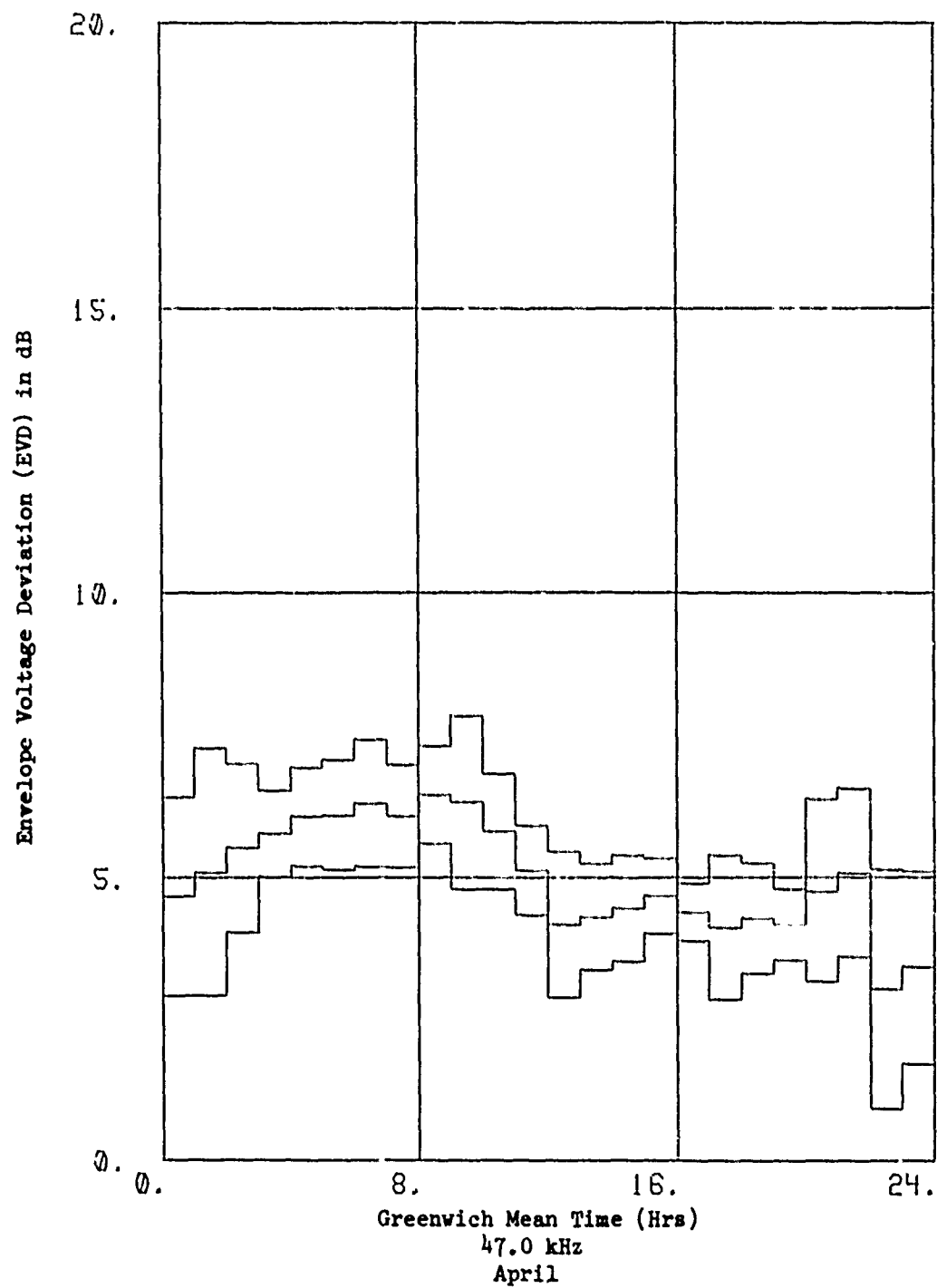


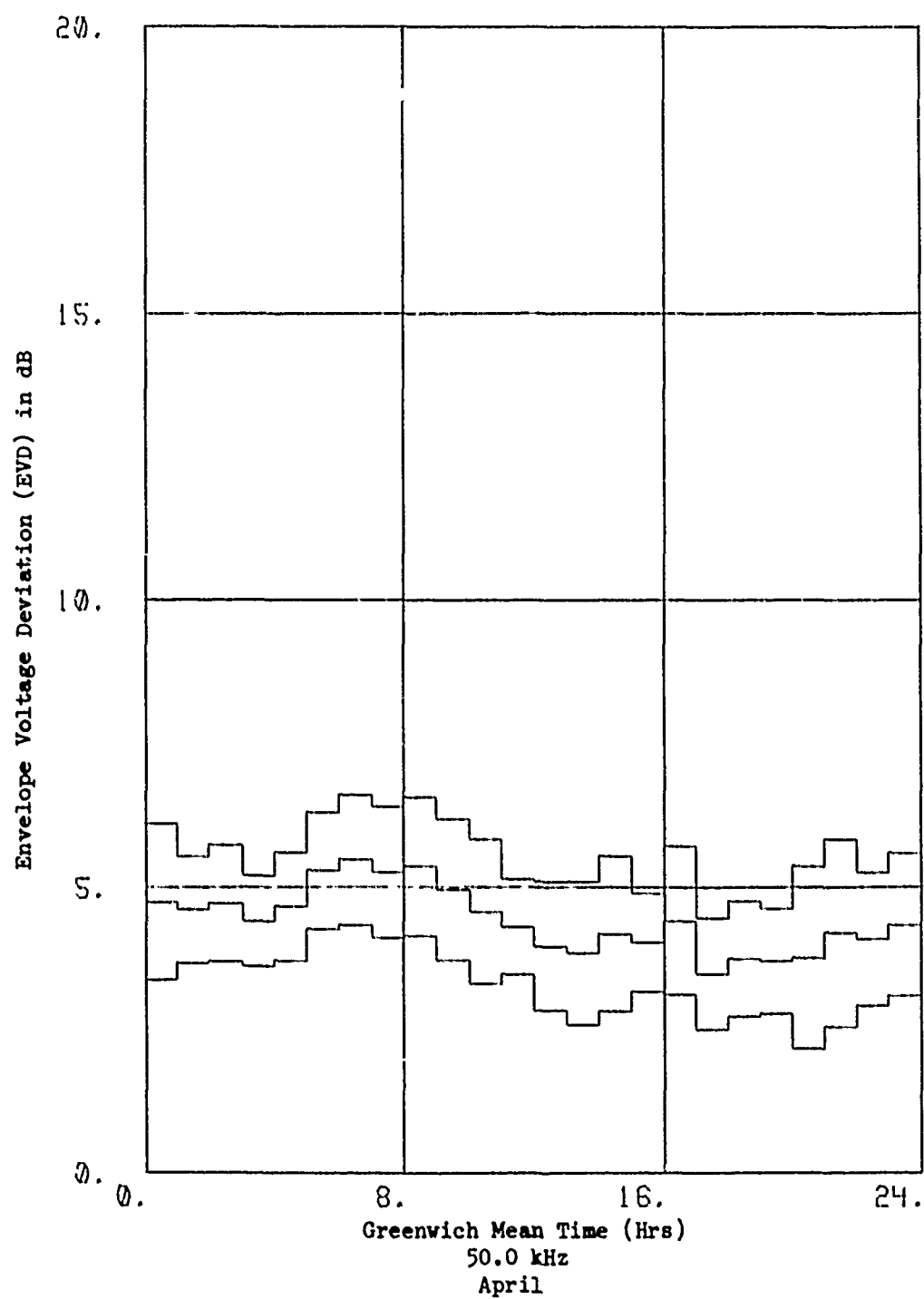


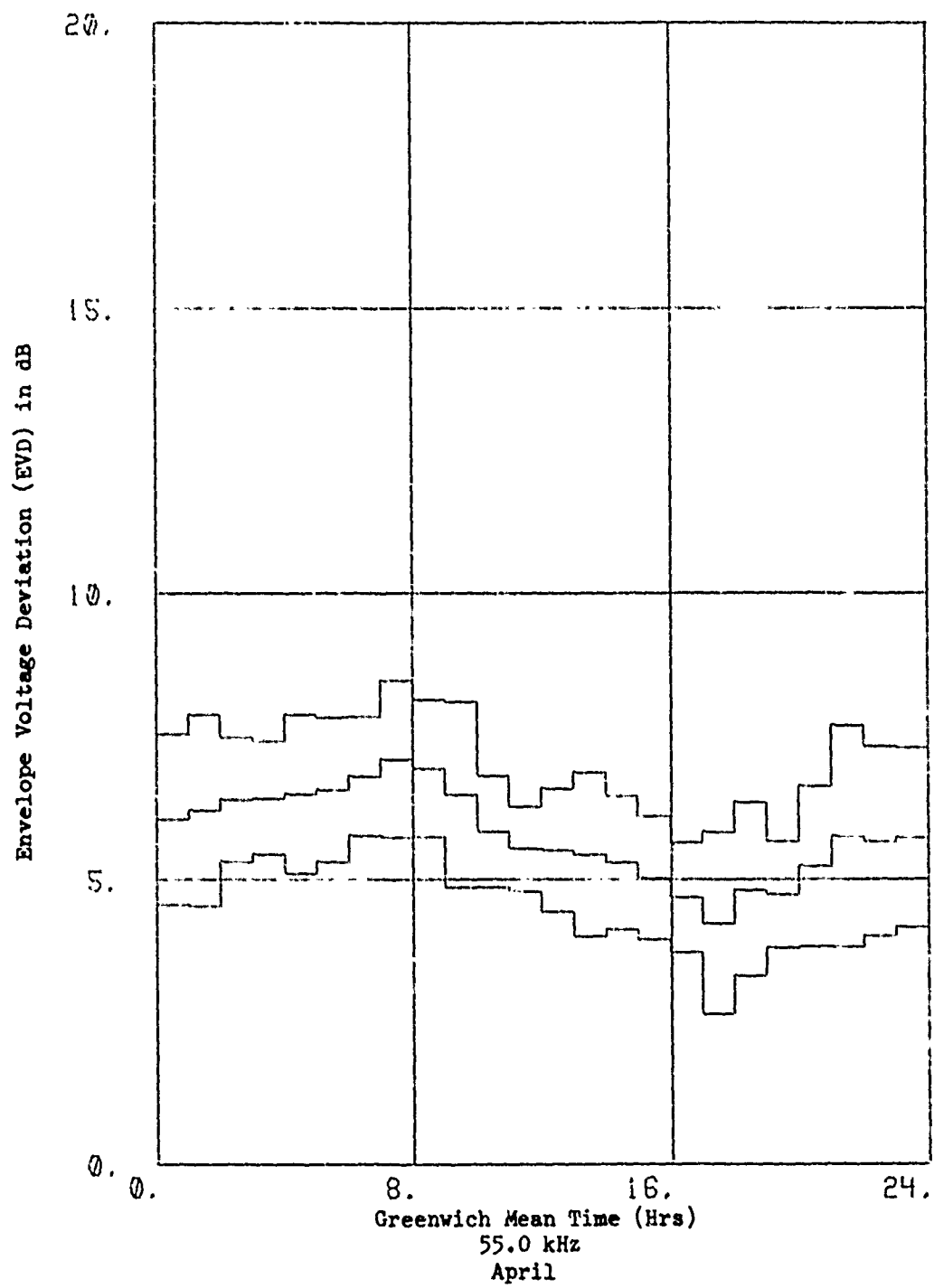




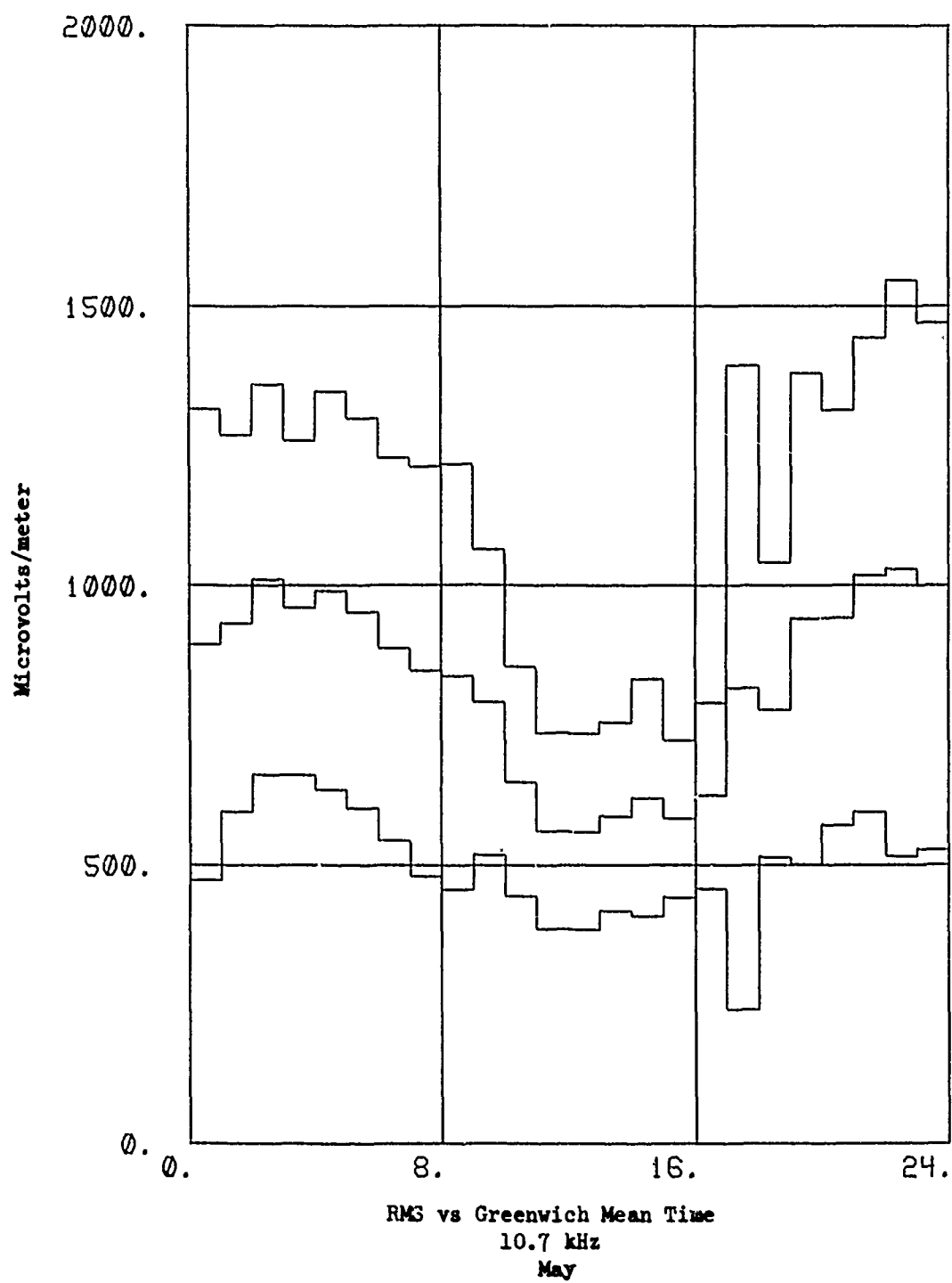




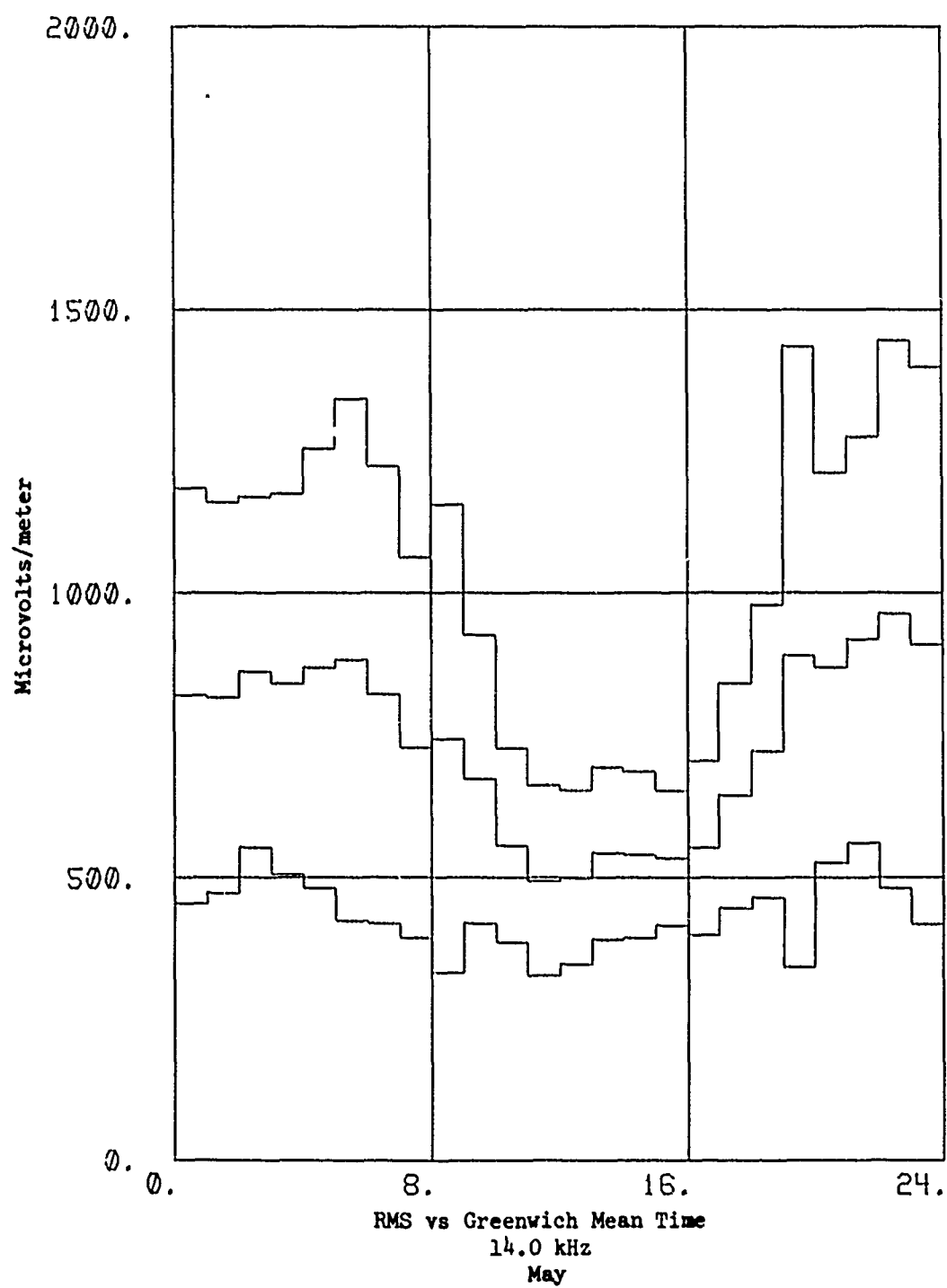


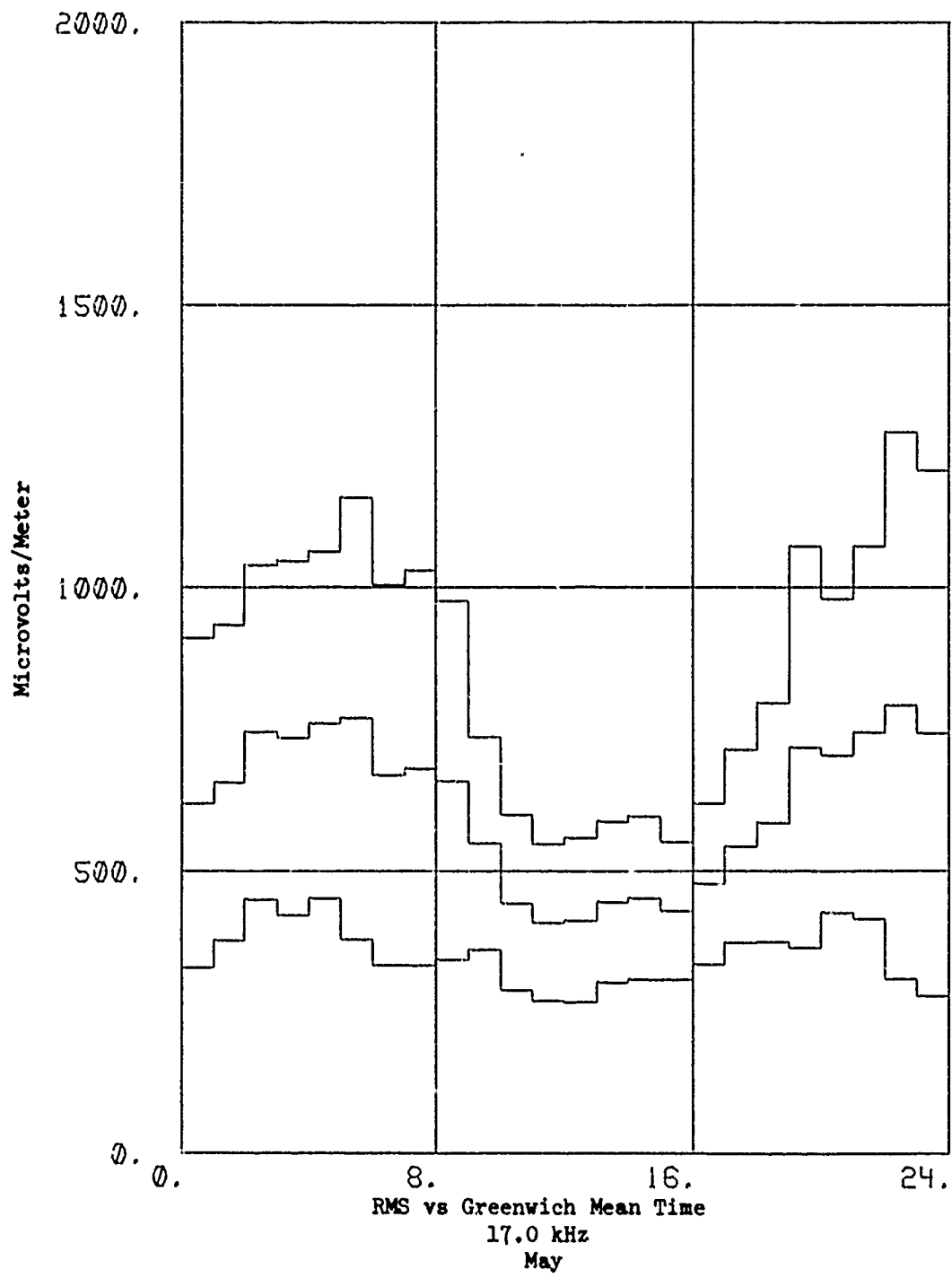


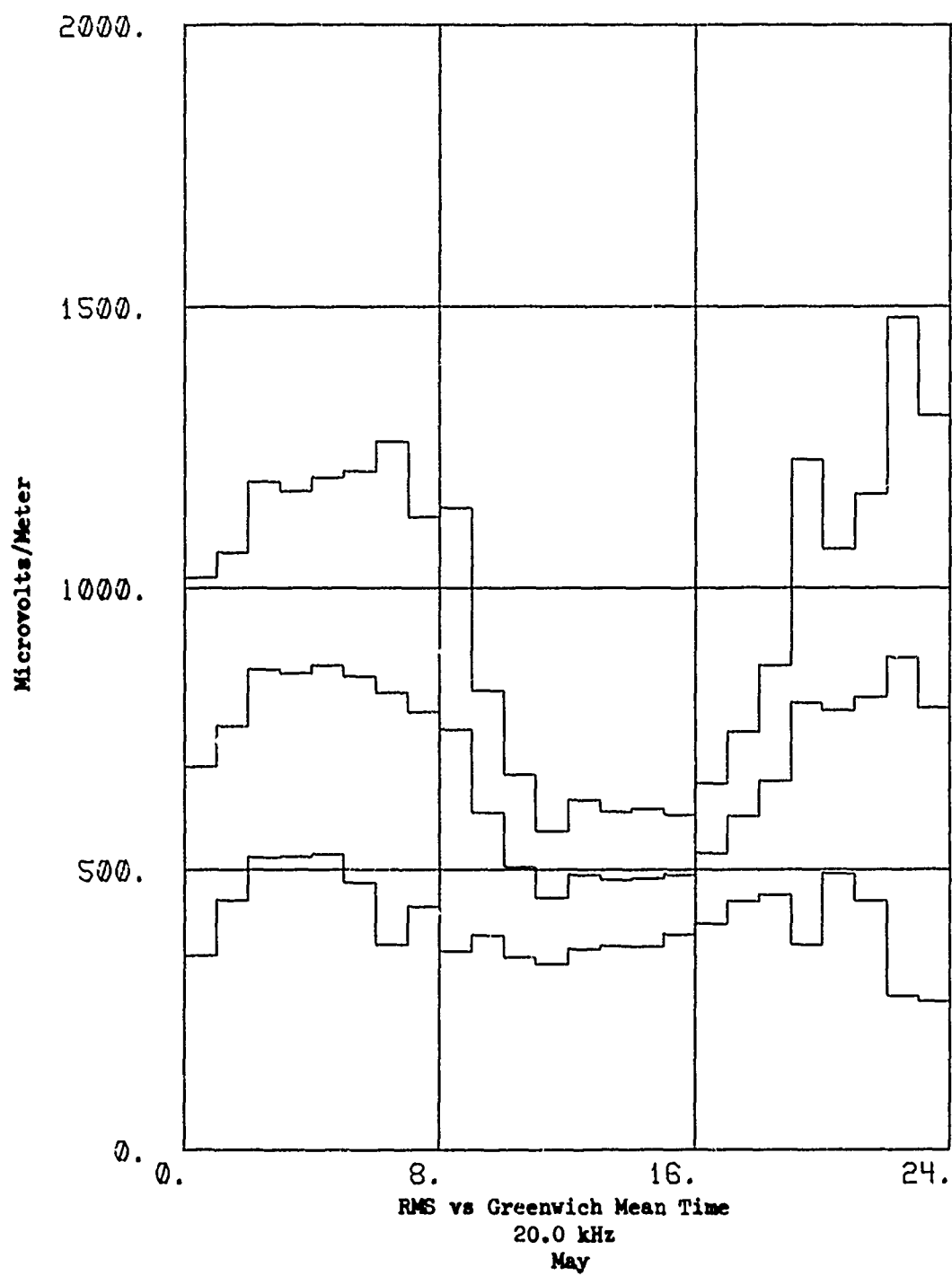
5.11 - ERMS vs TIME (@ FREQS. - FOR MAY)

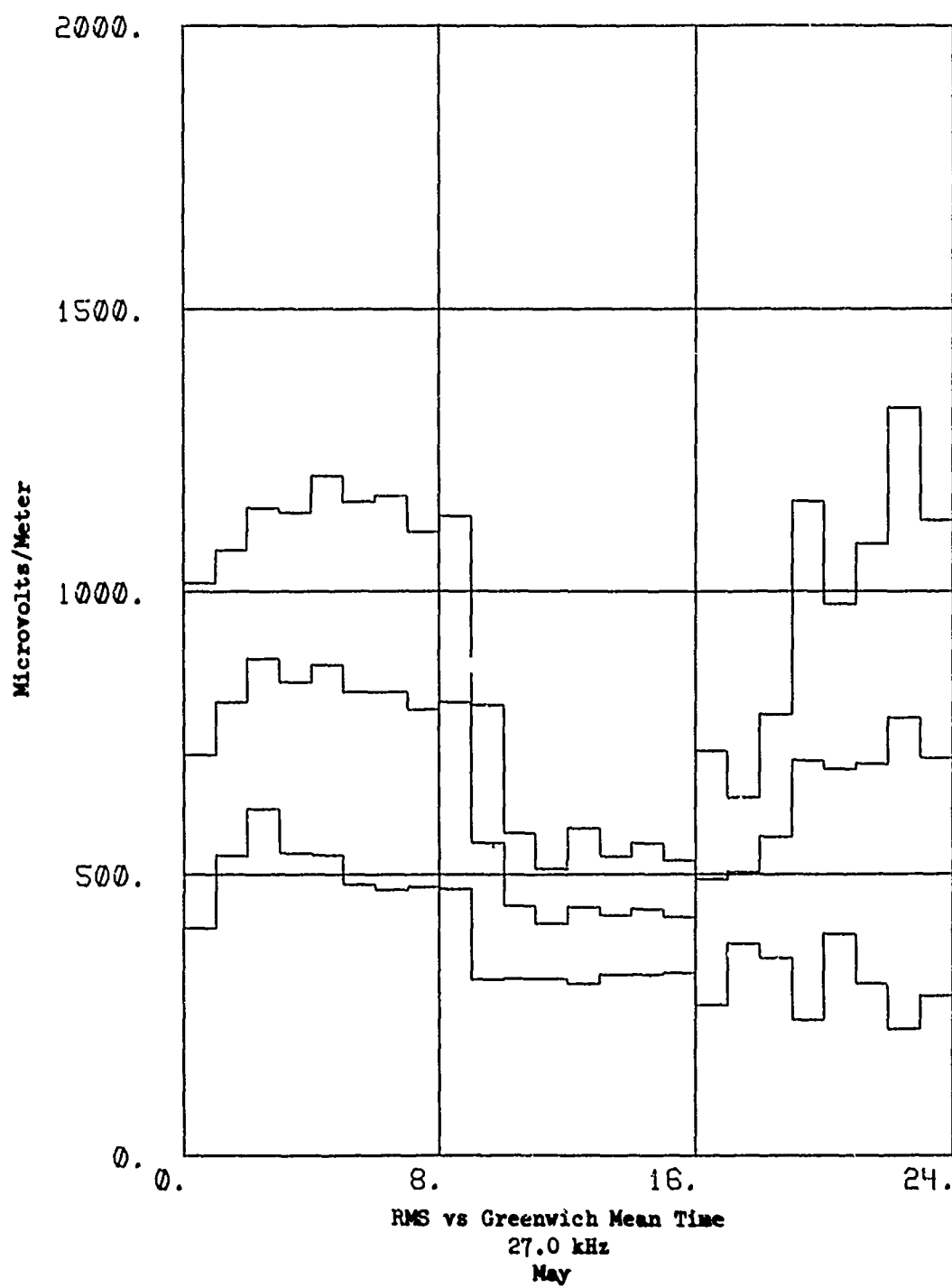


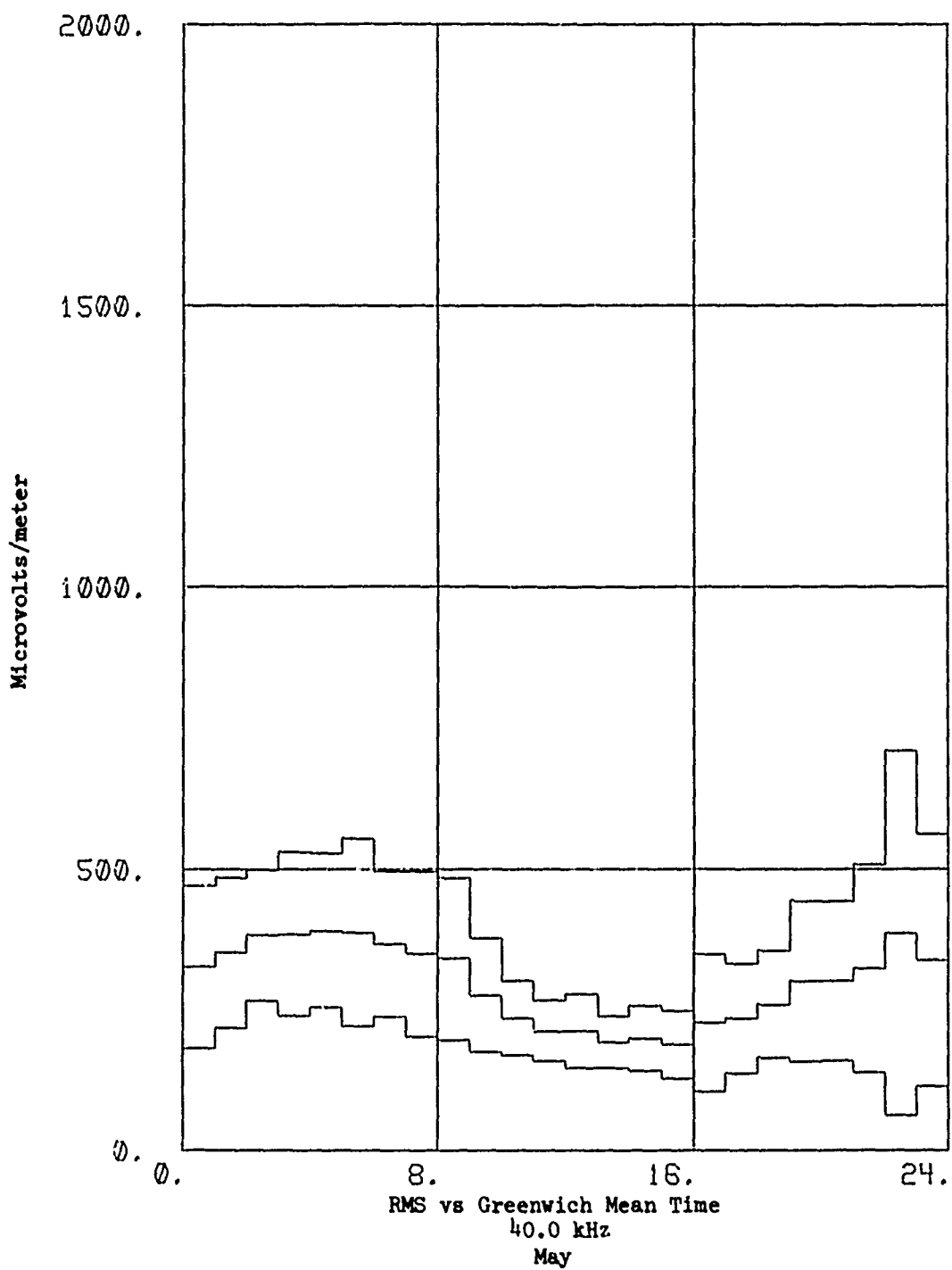


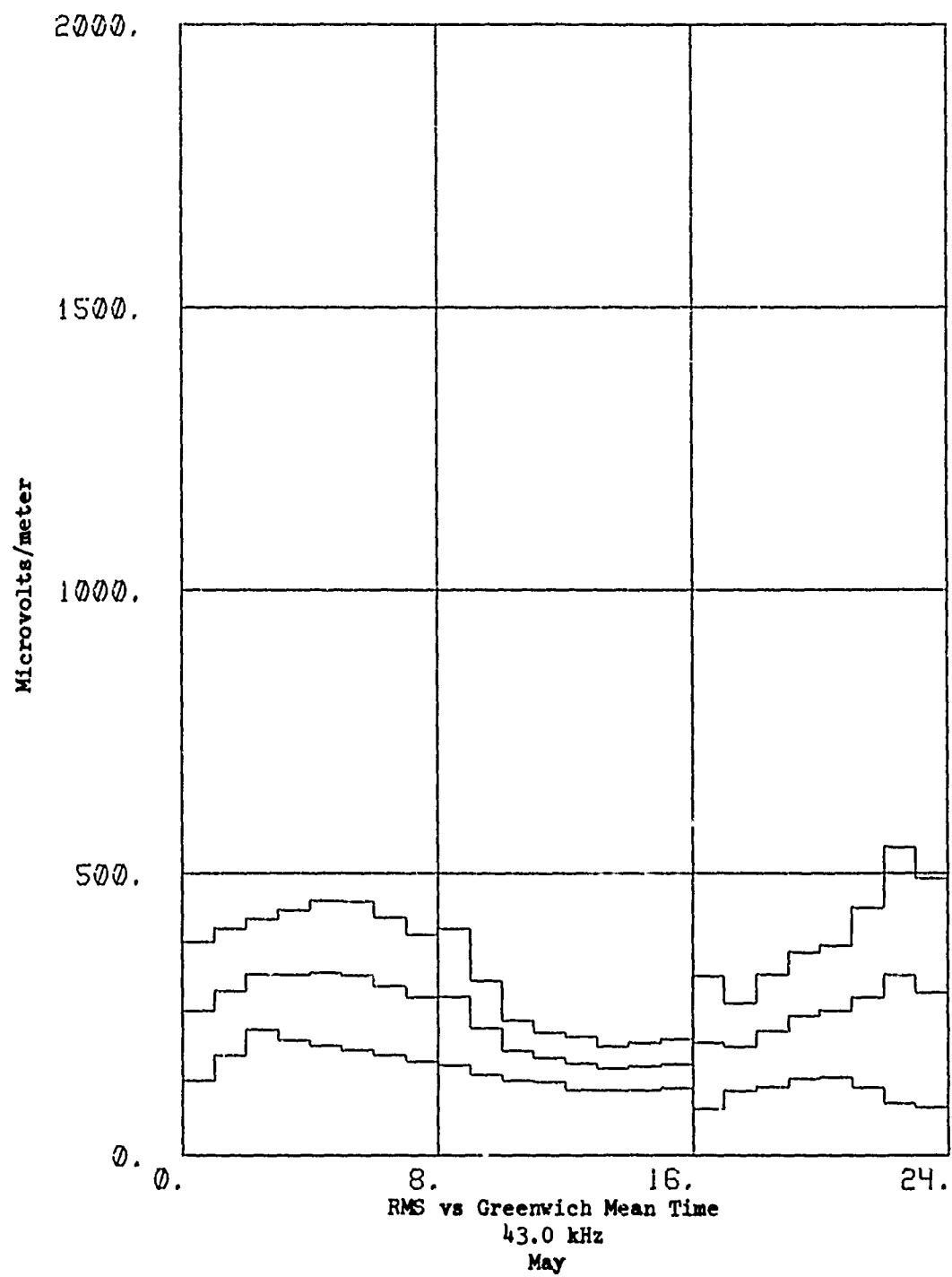


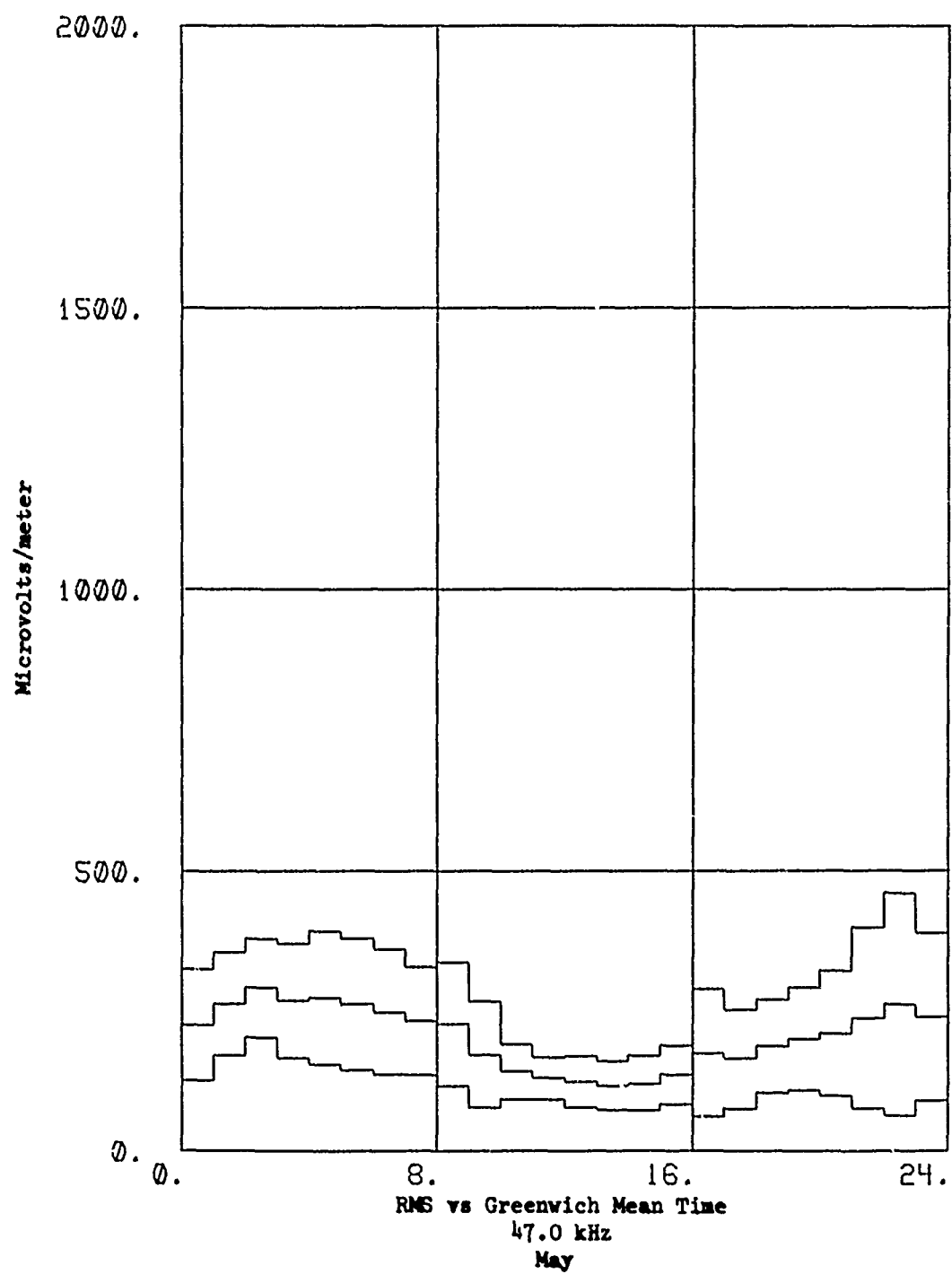


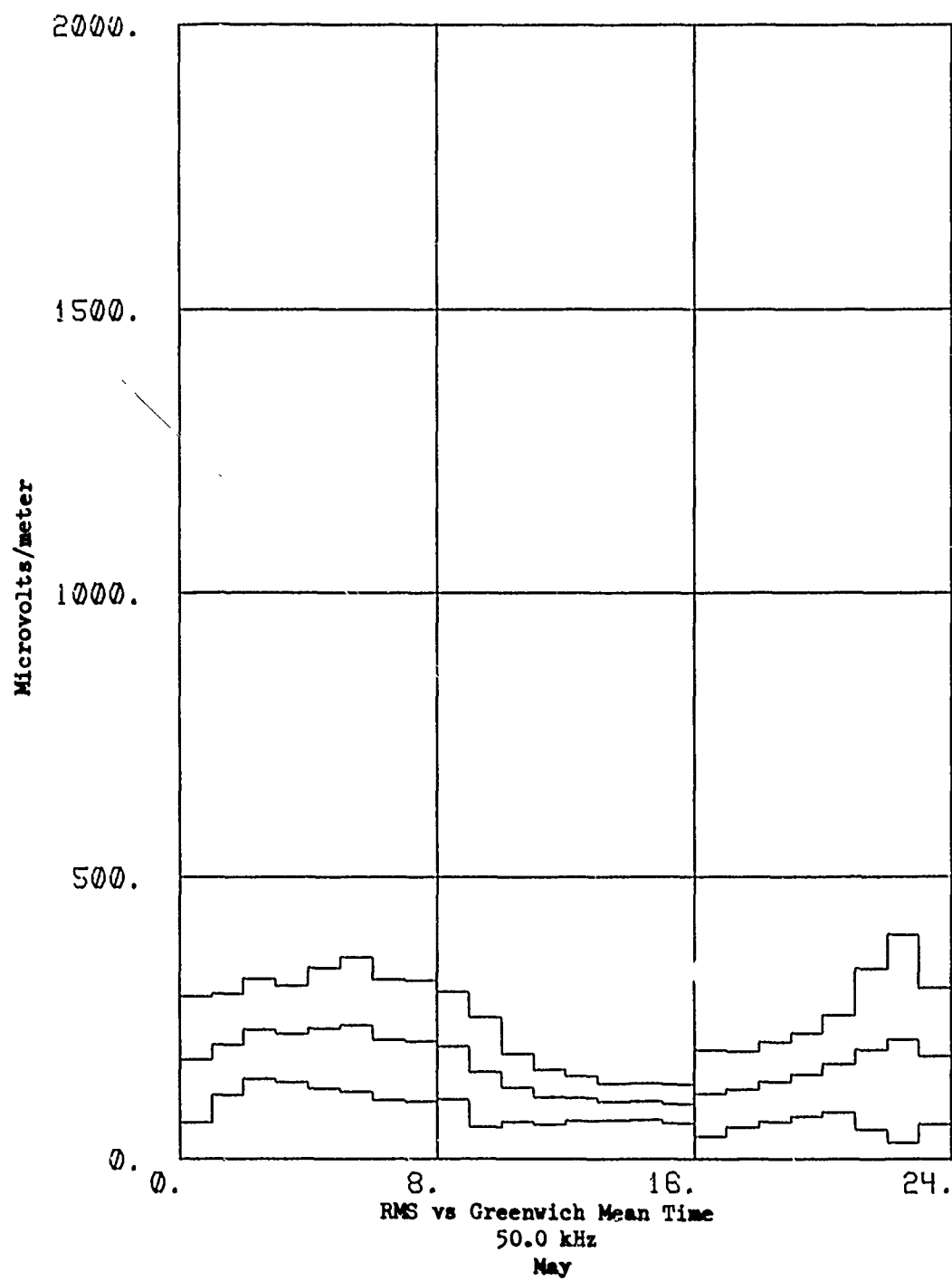




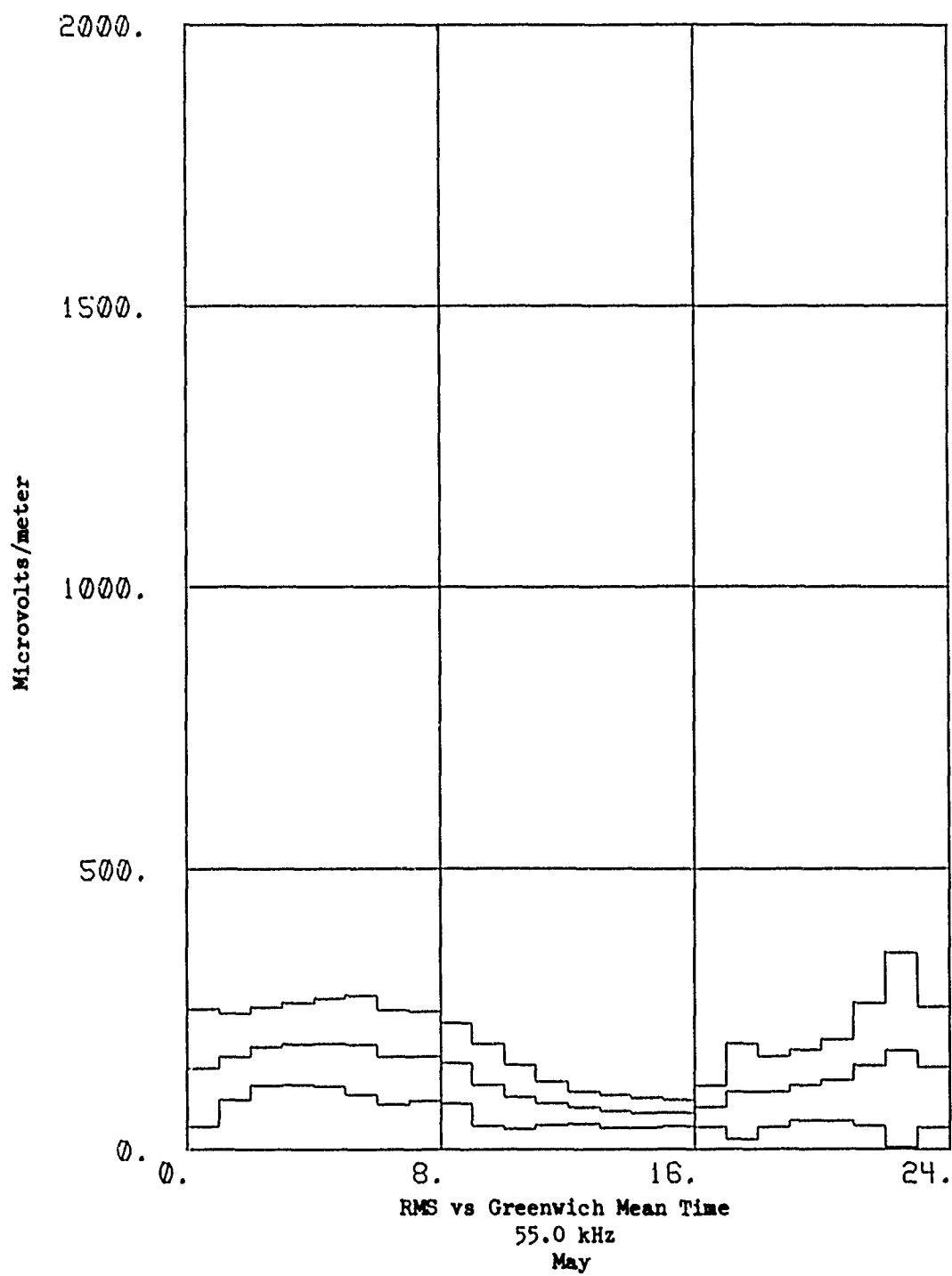




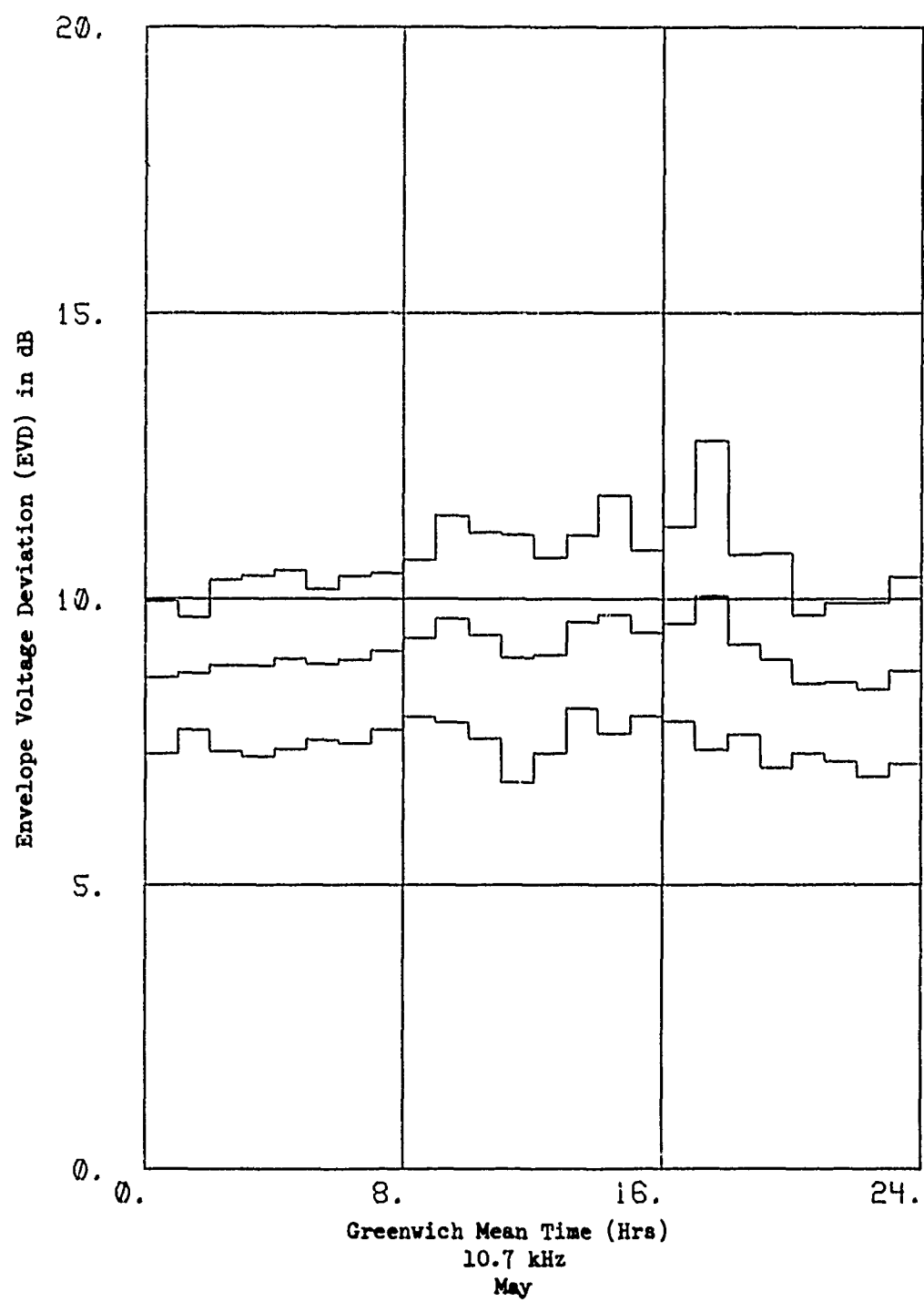


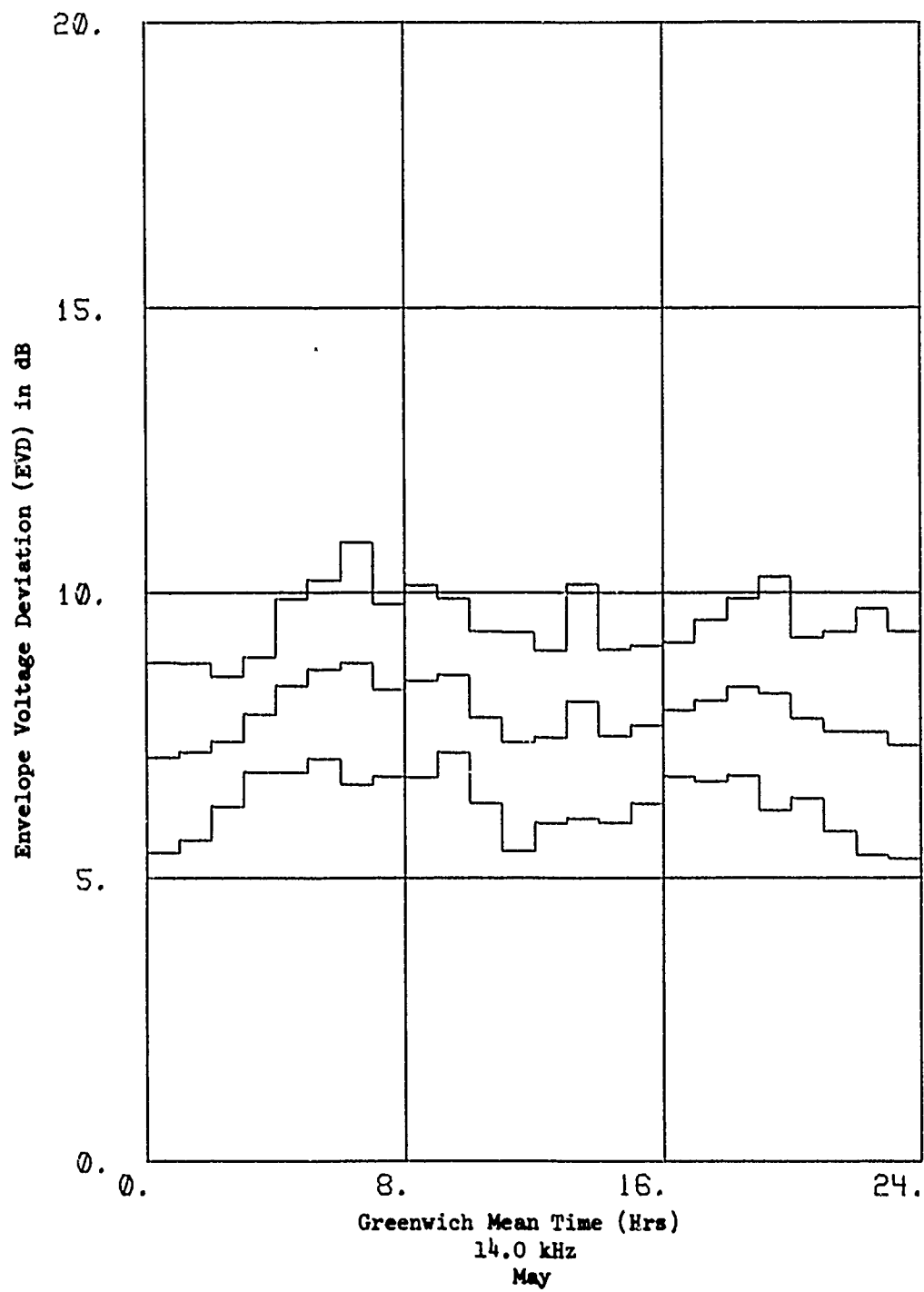


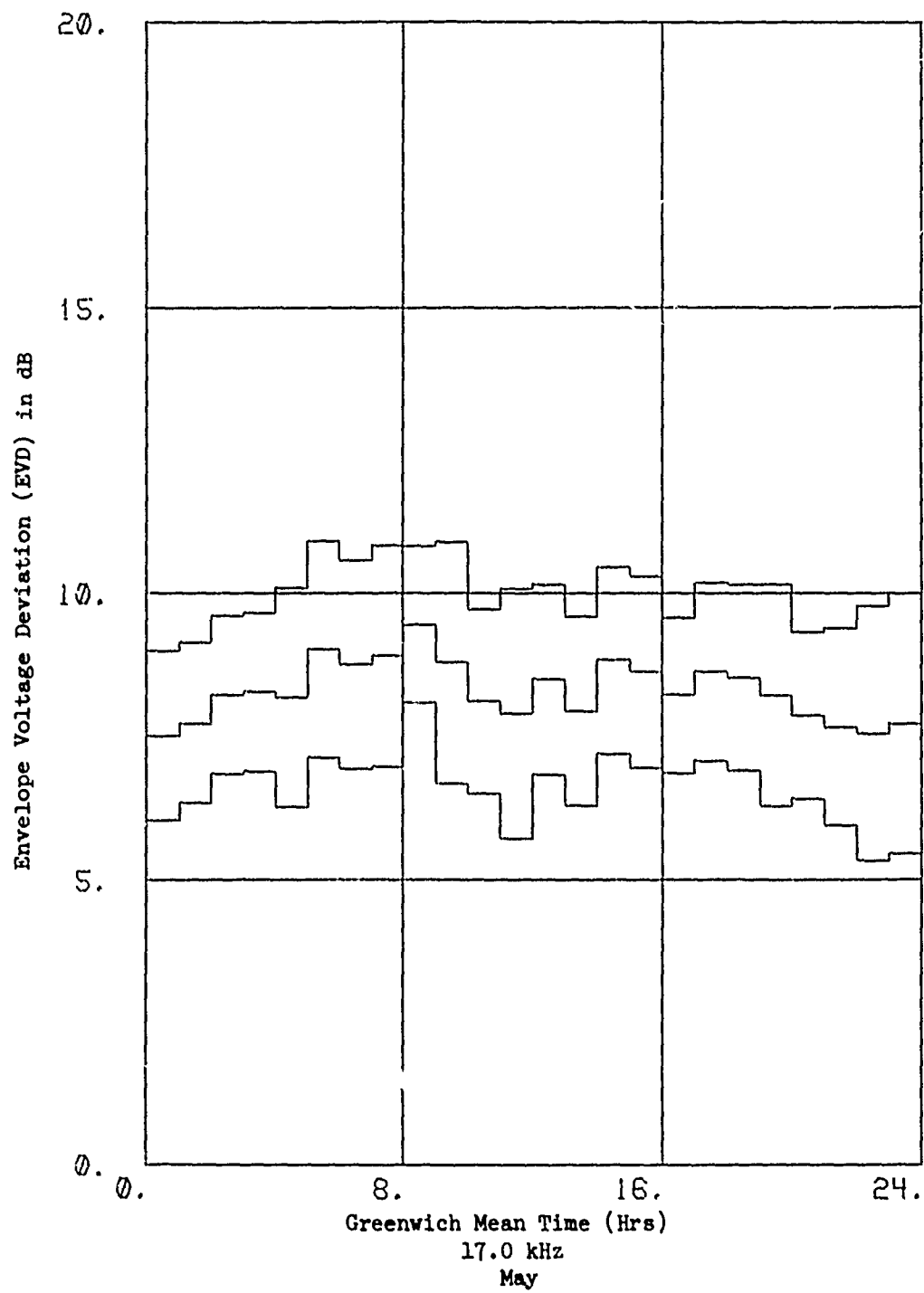


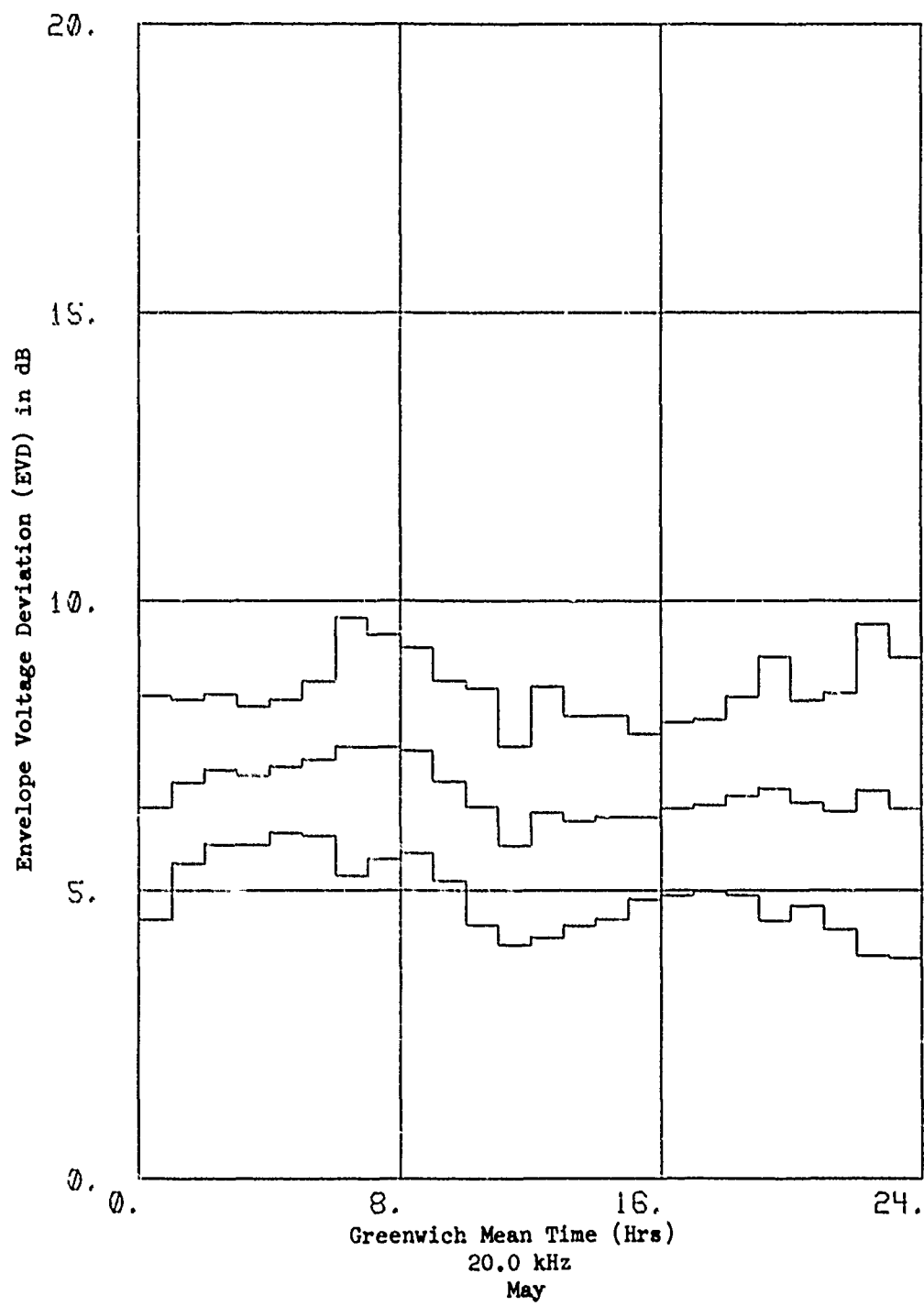


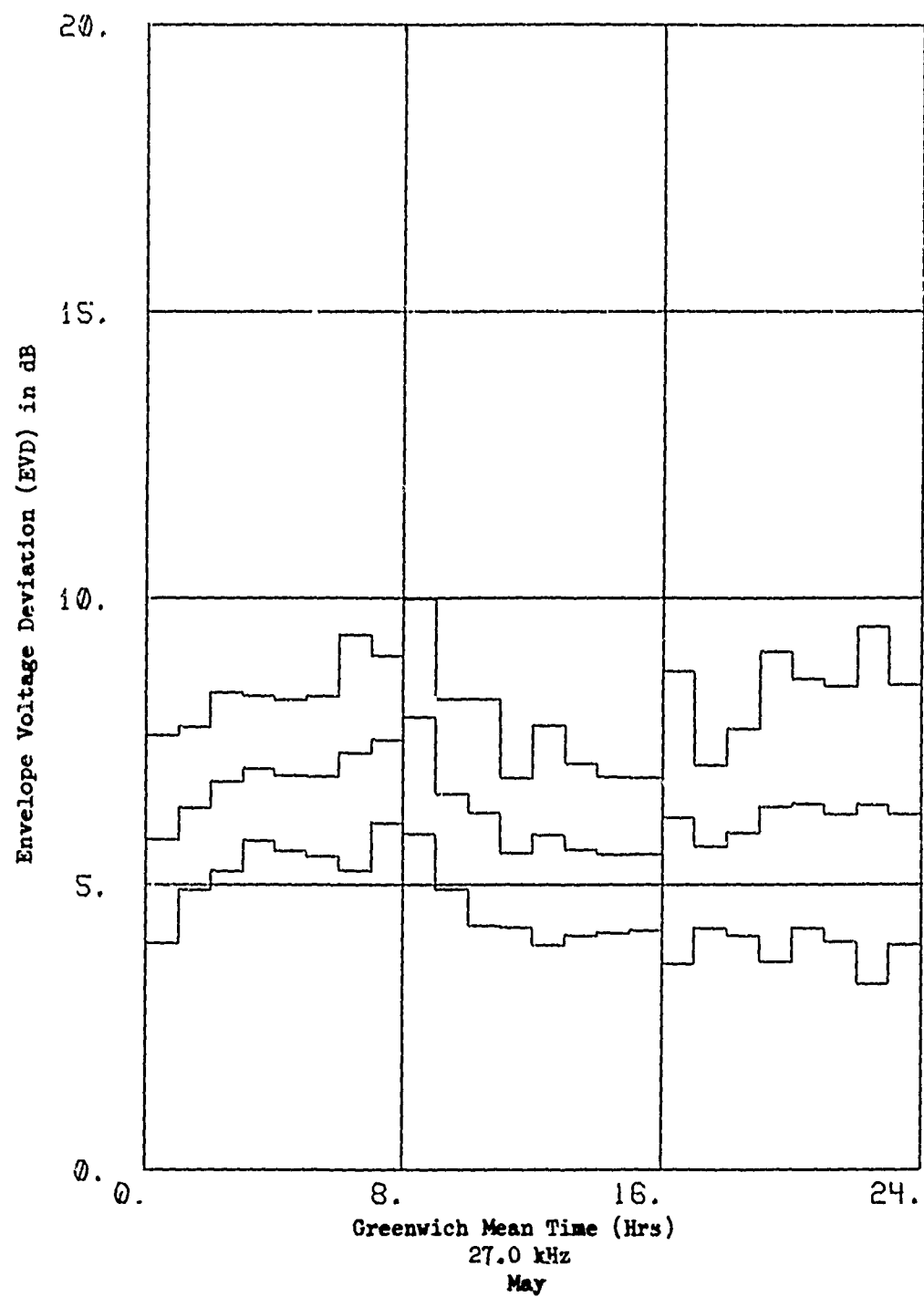
5.12 - EVD vs TIME (@ FREQS. - FOR MAY)

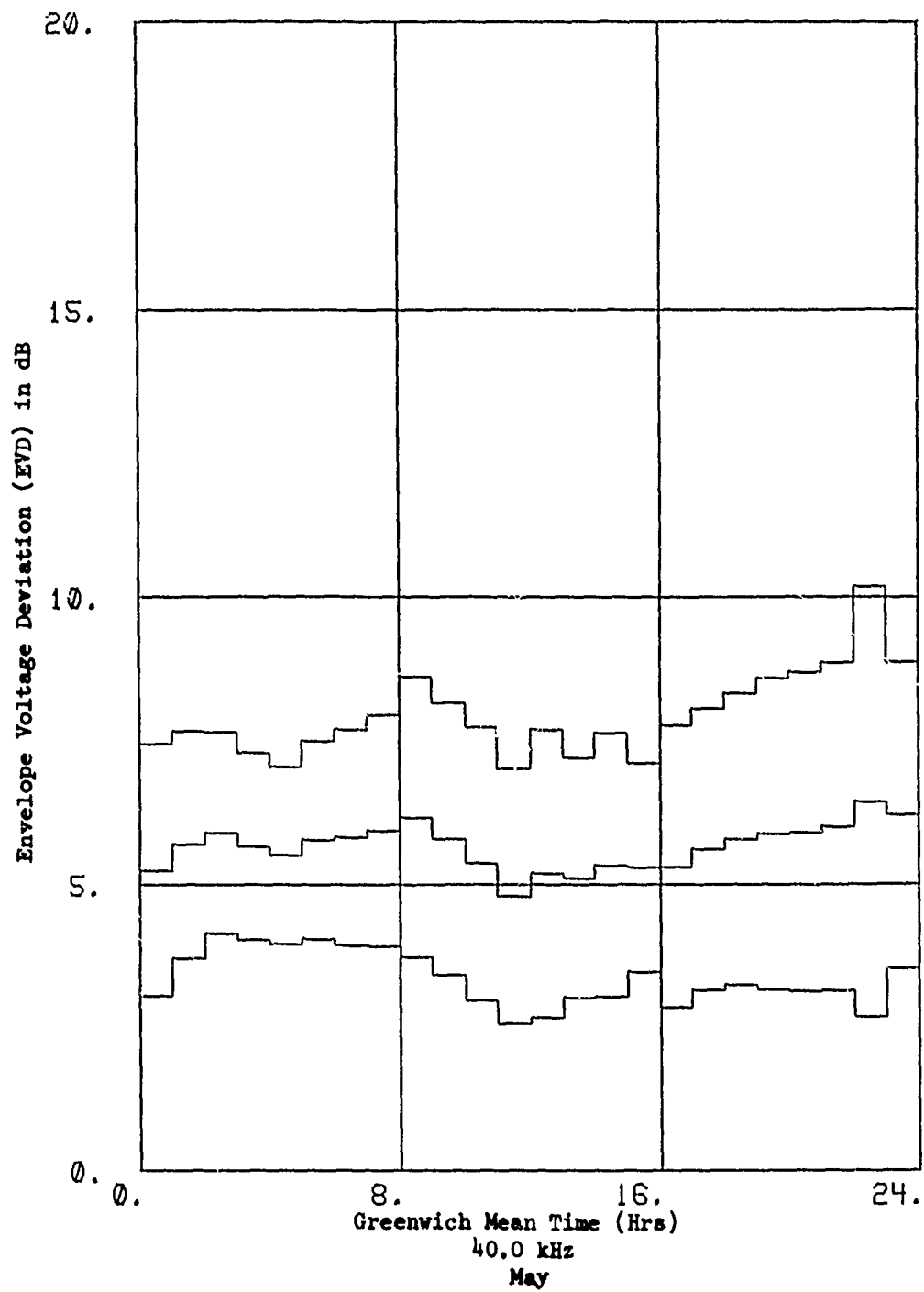




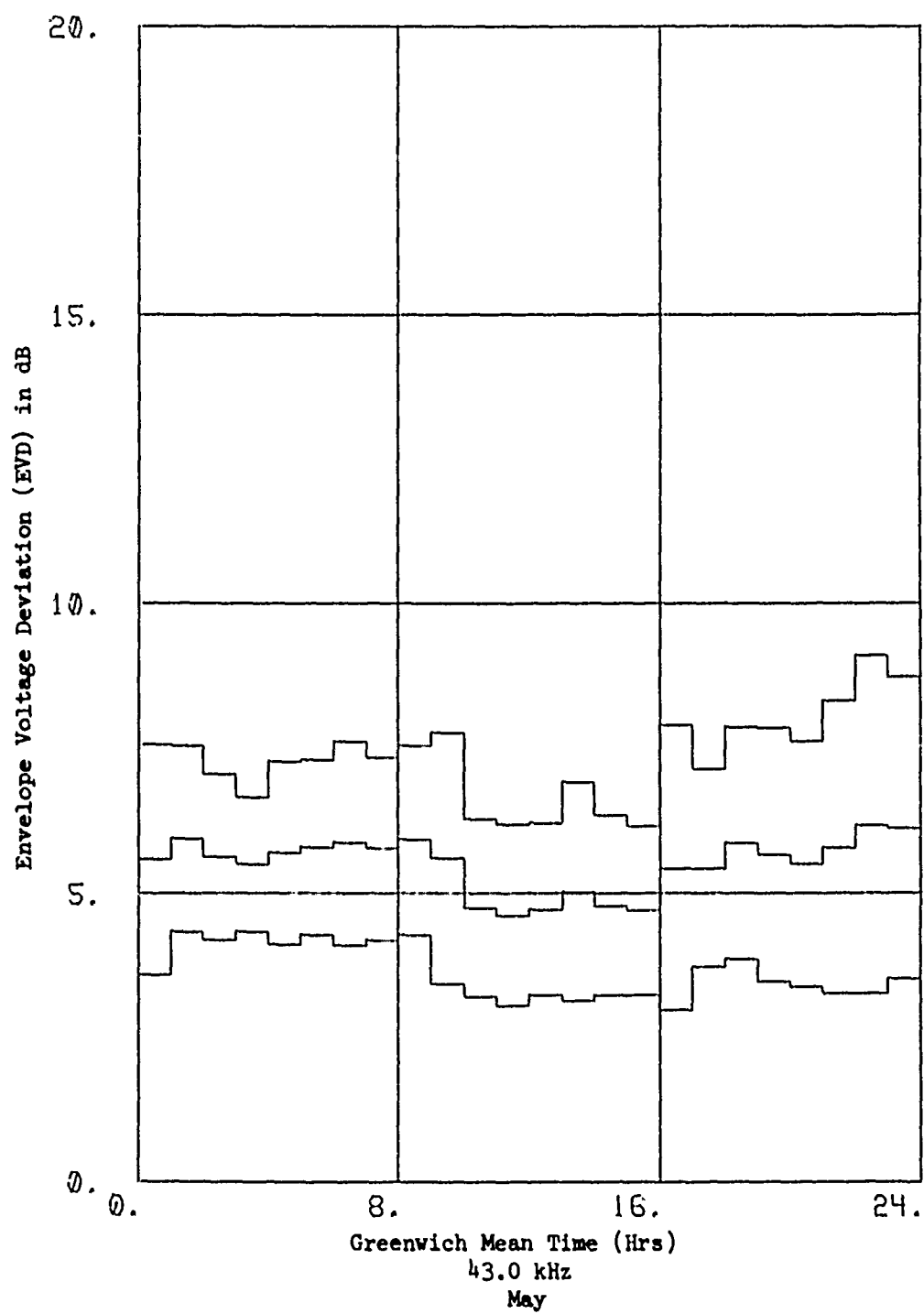


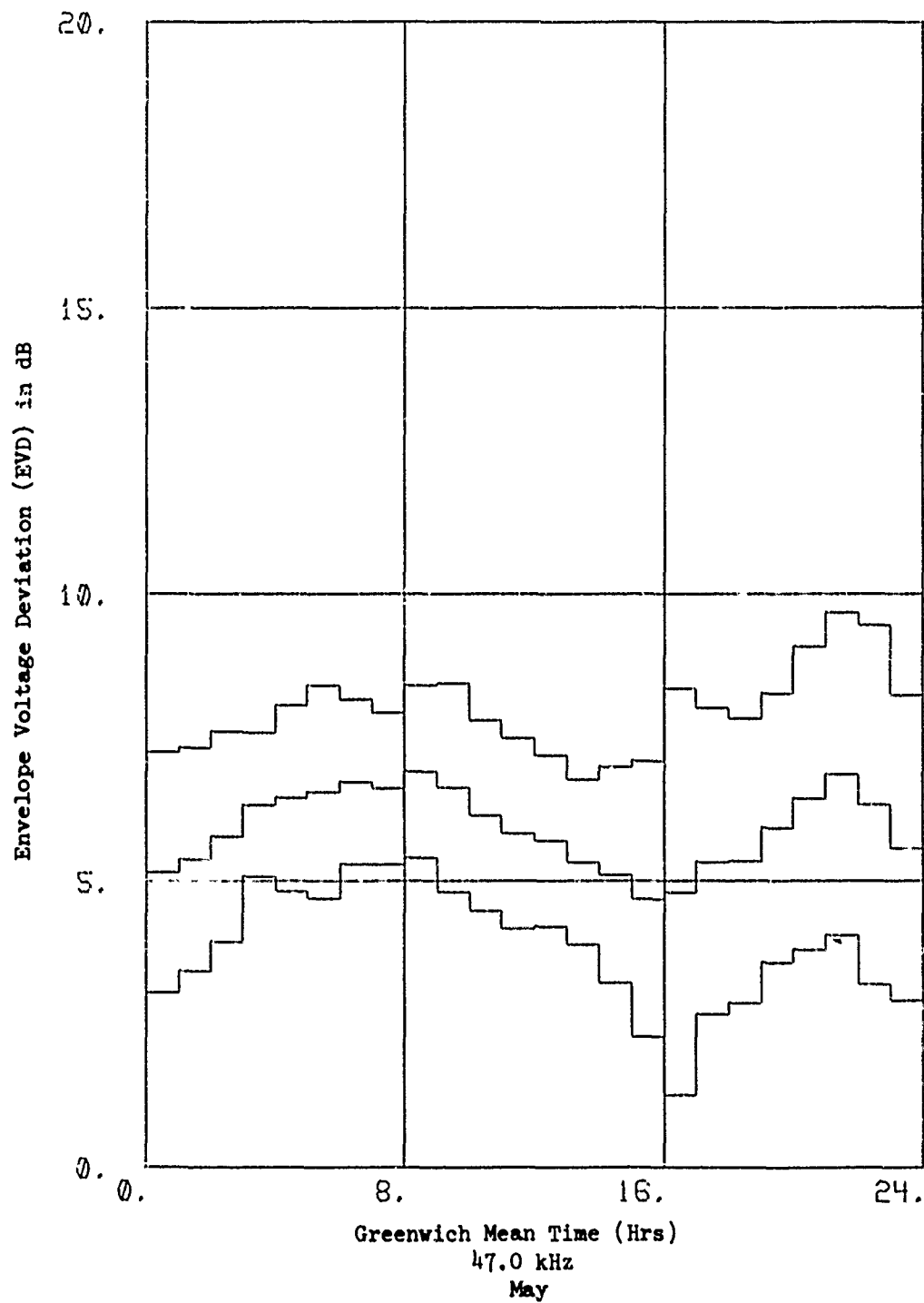


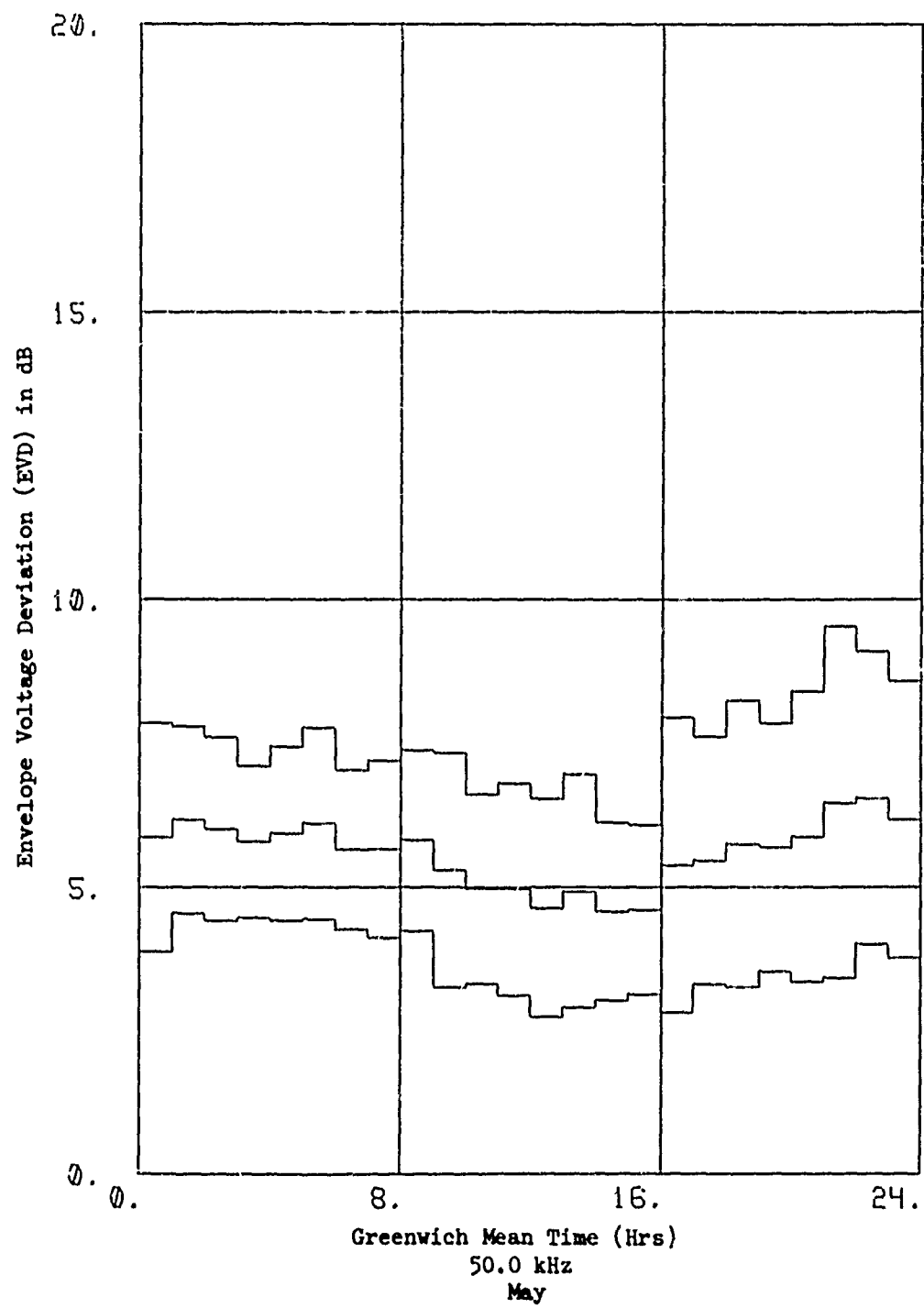


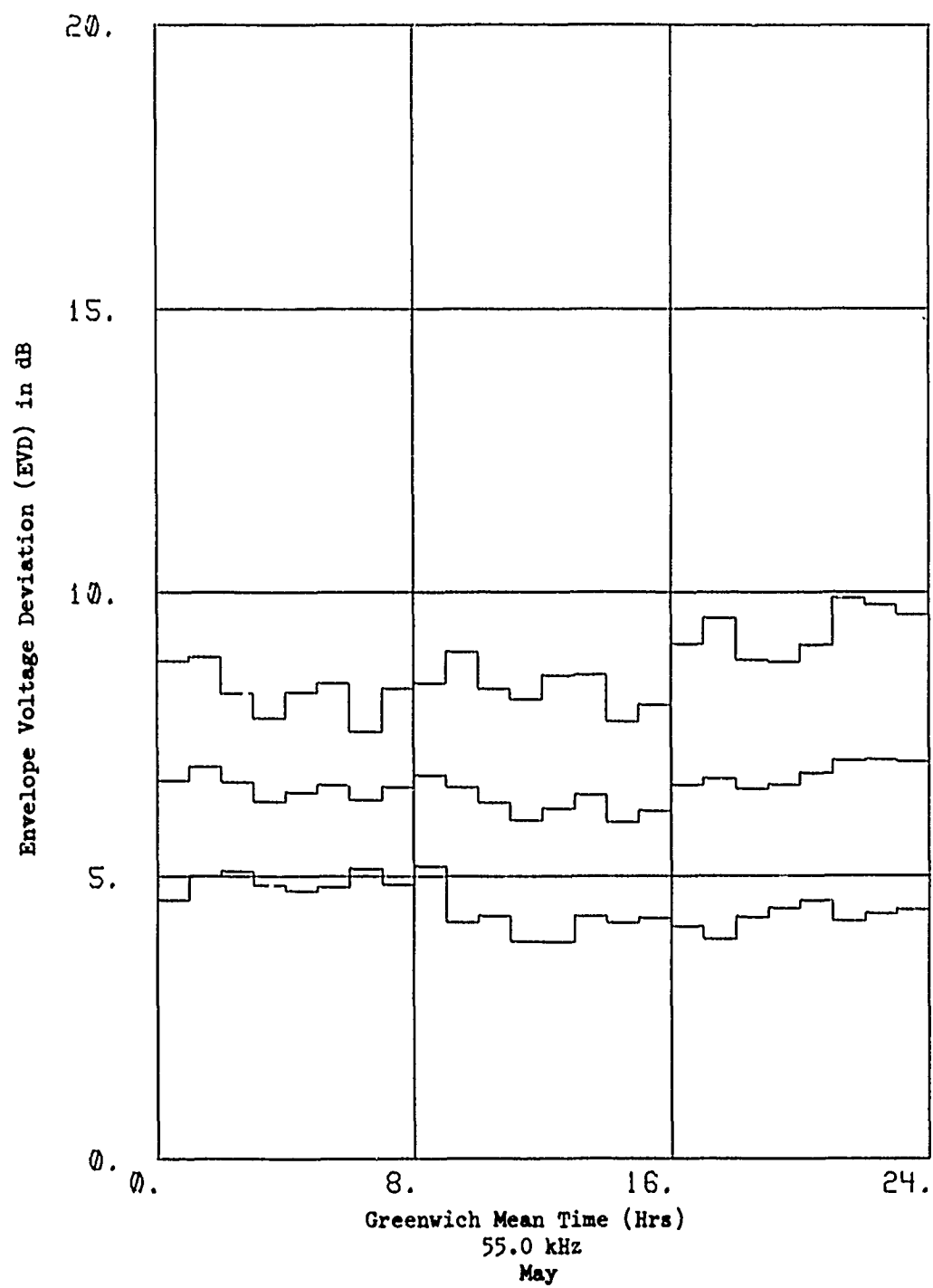




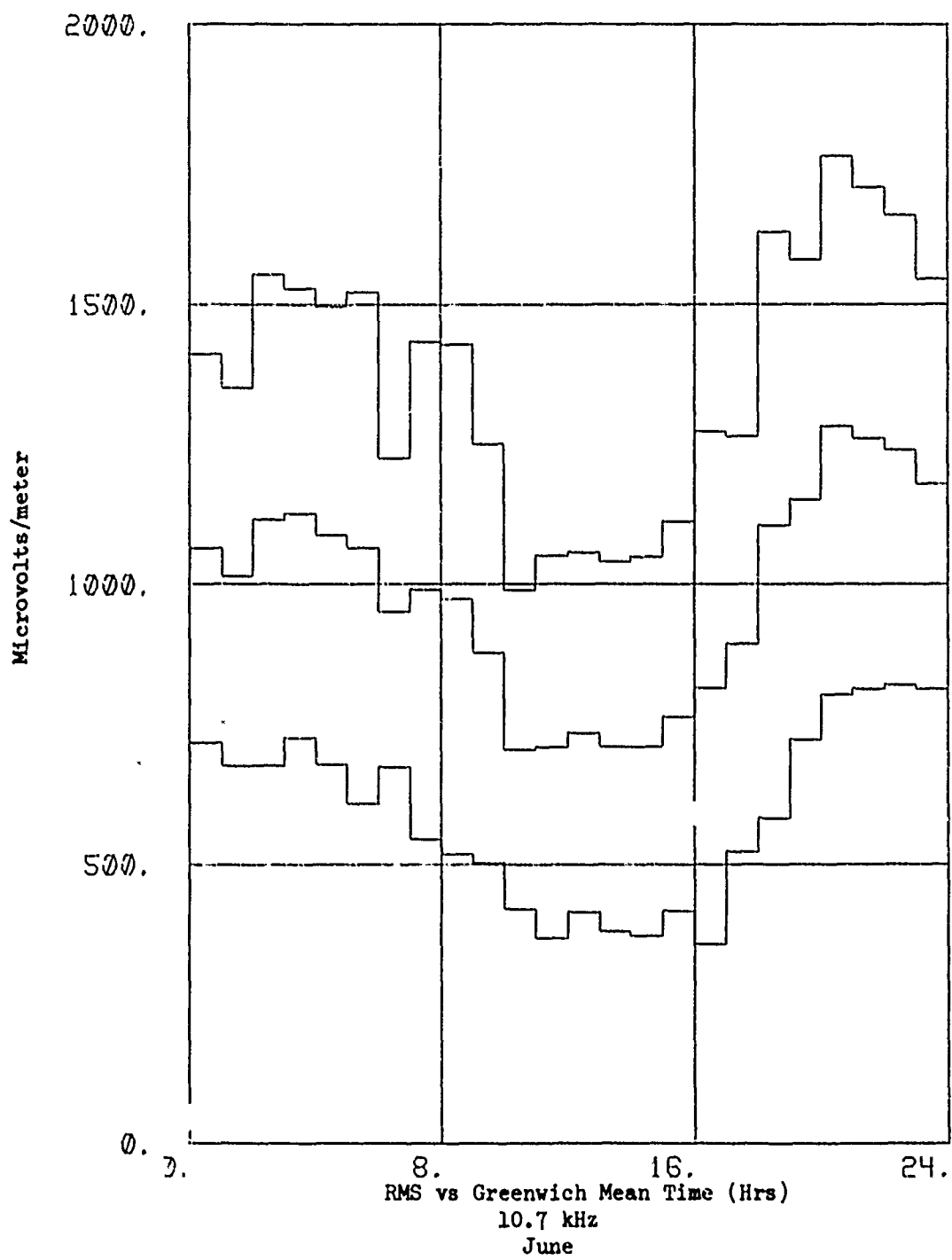


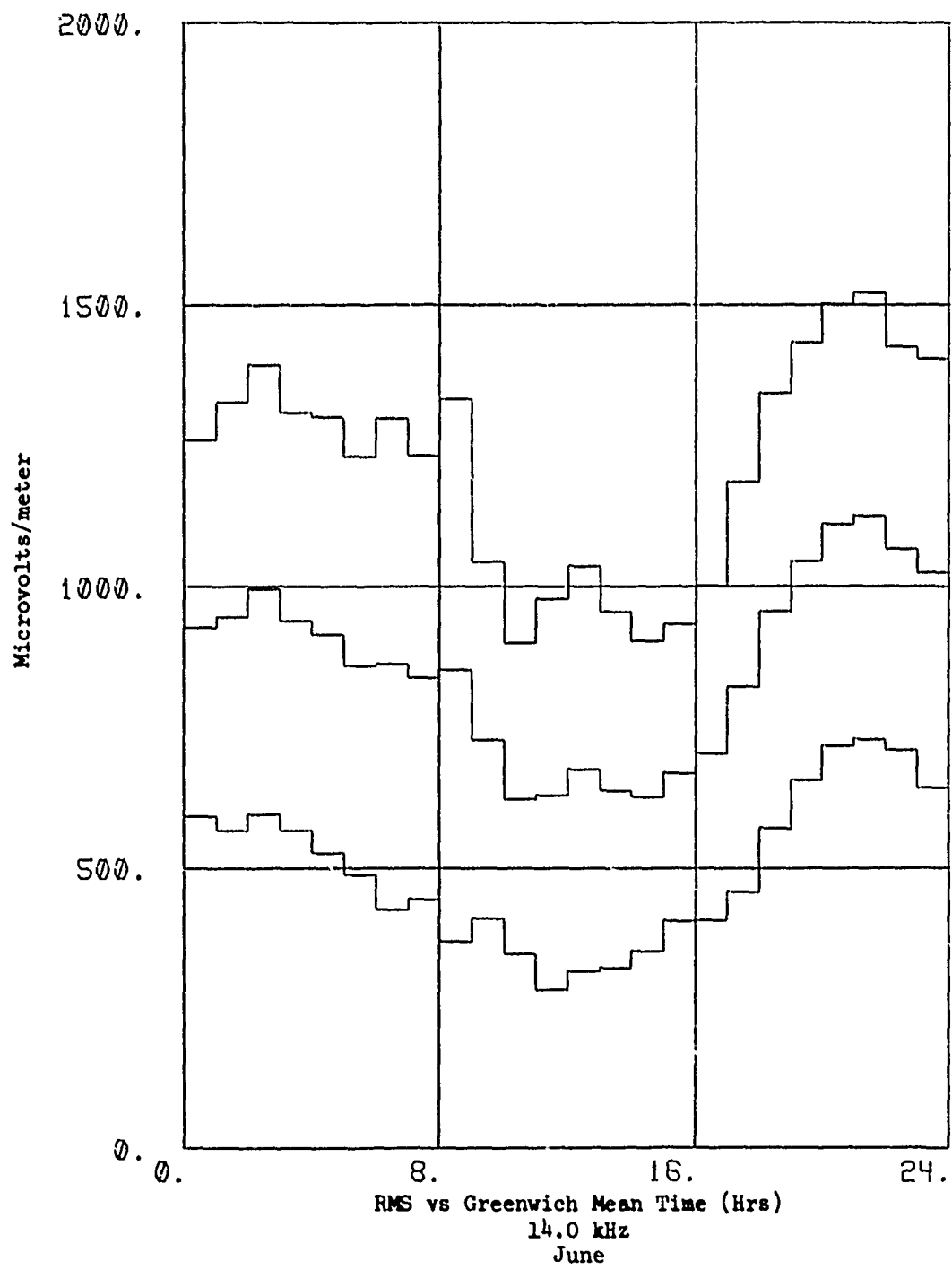


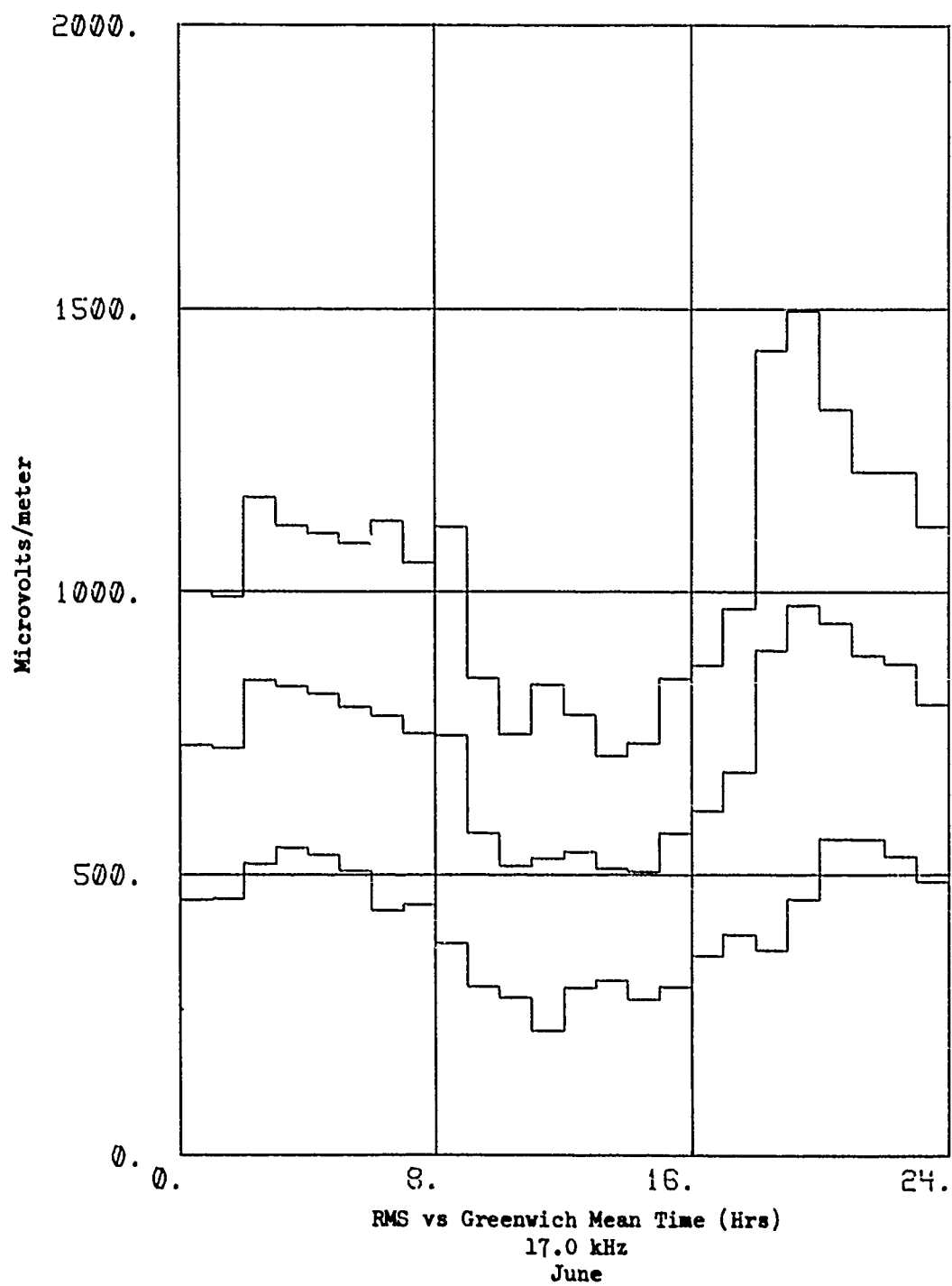




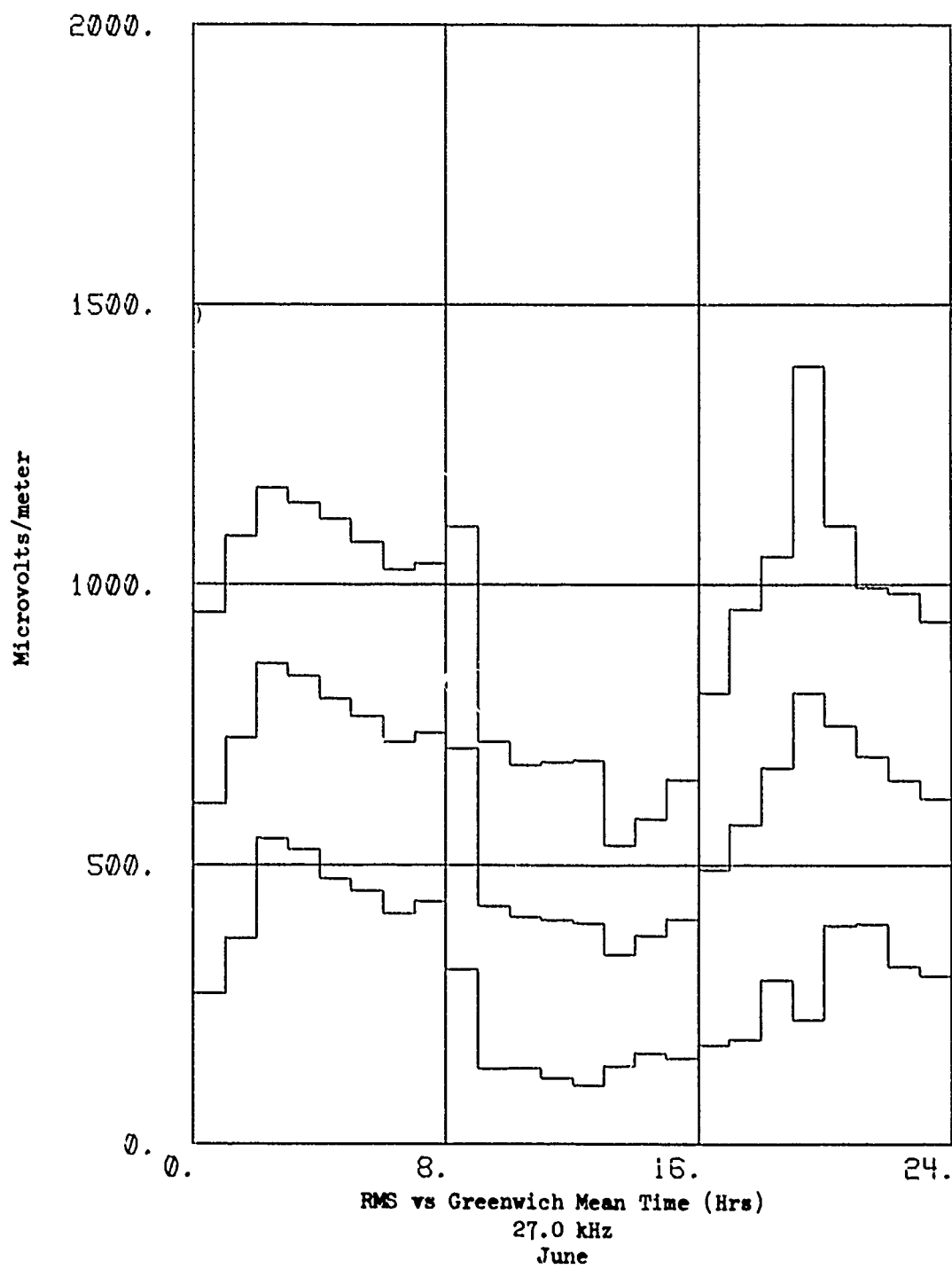
5.13 - ERMS vs TIME ( @ FREQS. - FOR JUNE)

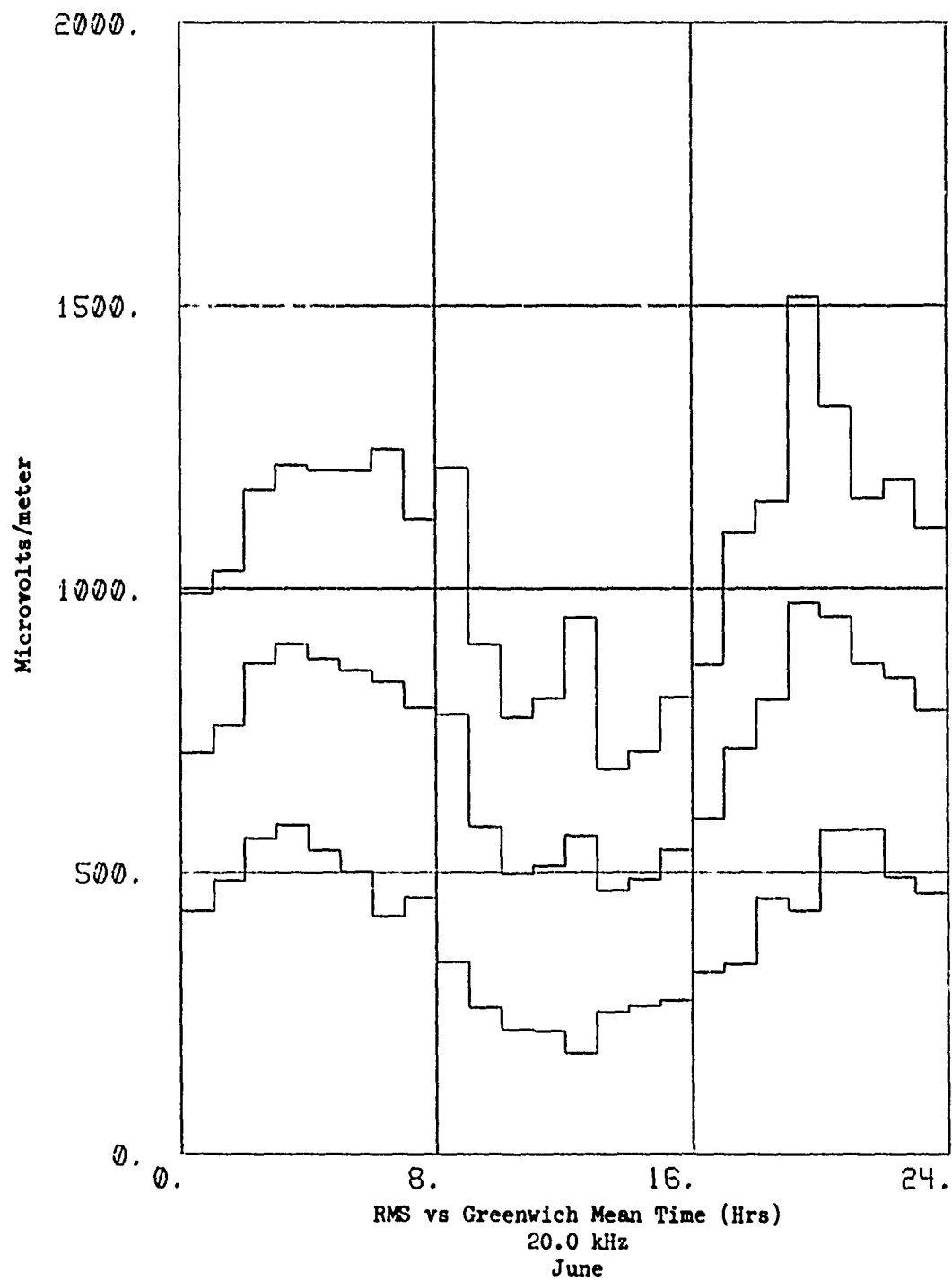


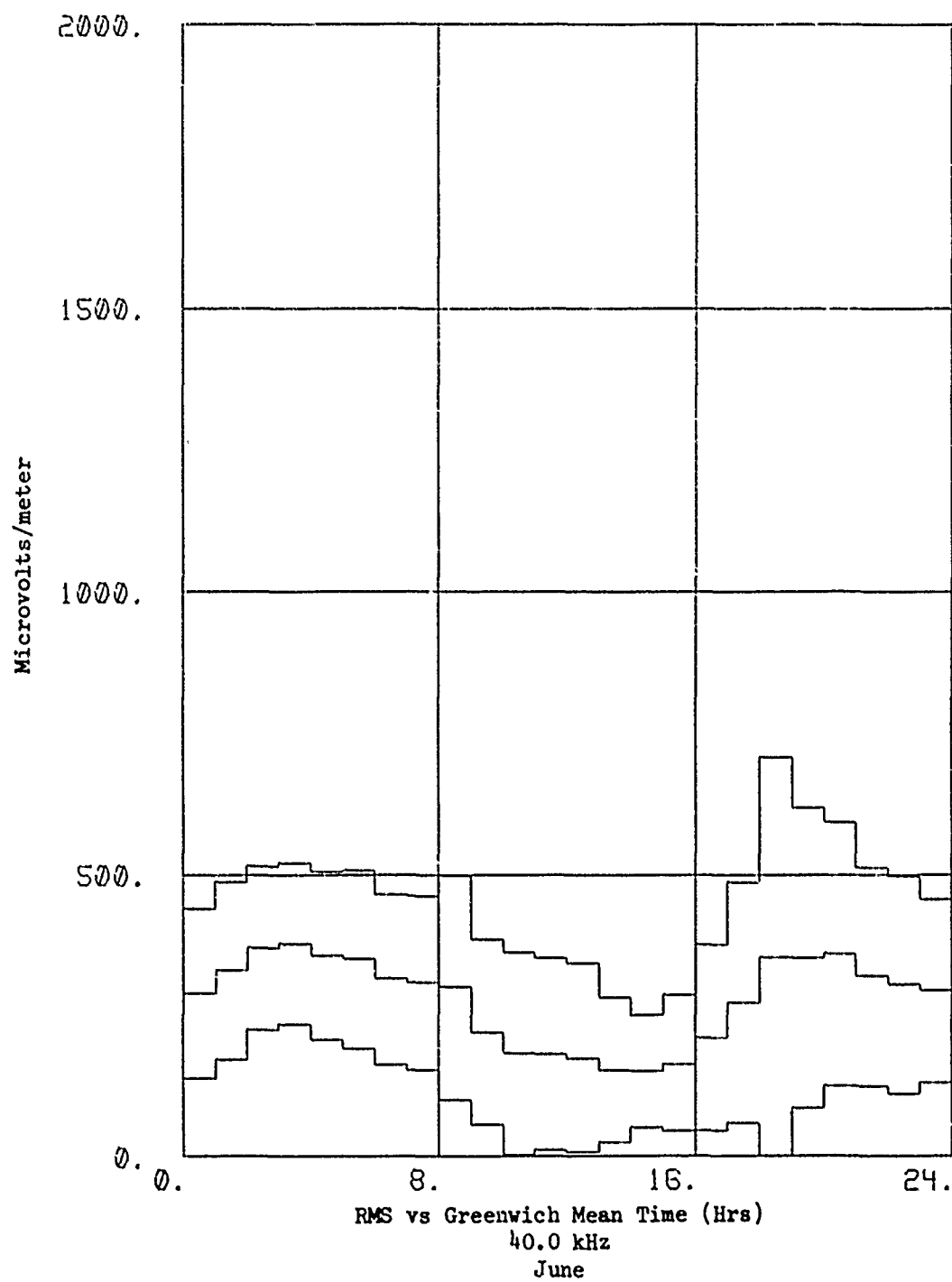


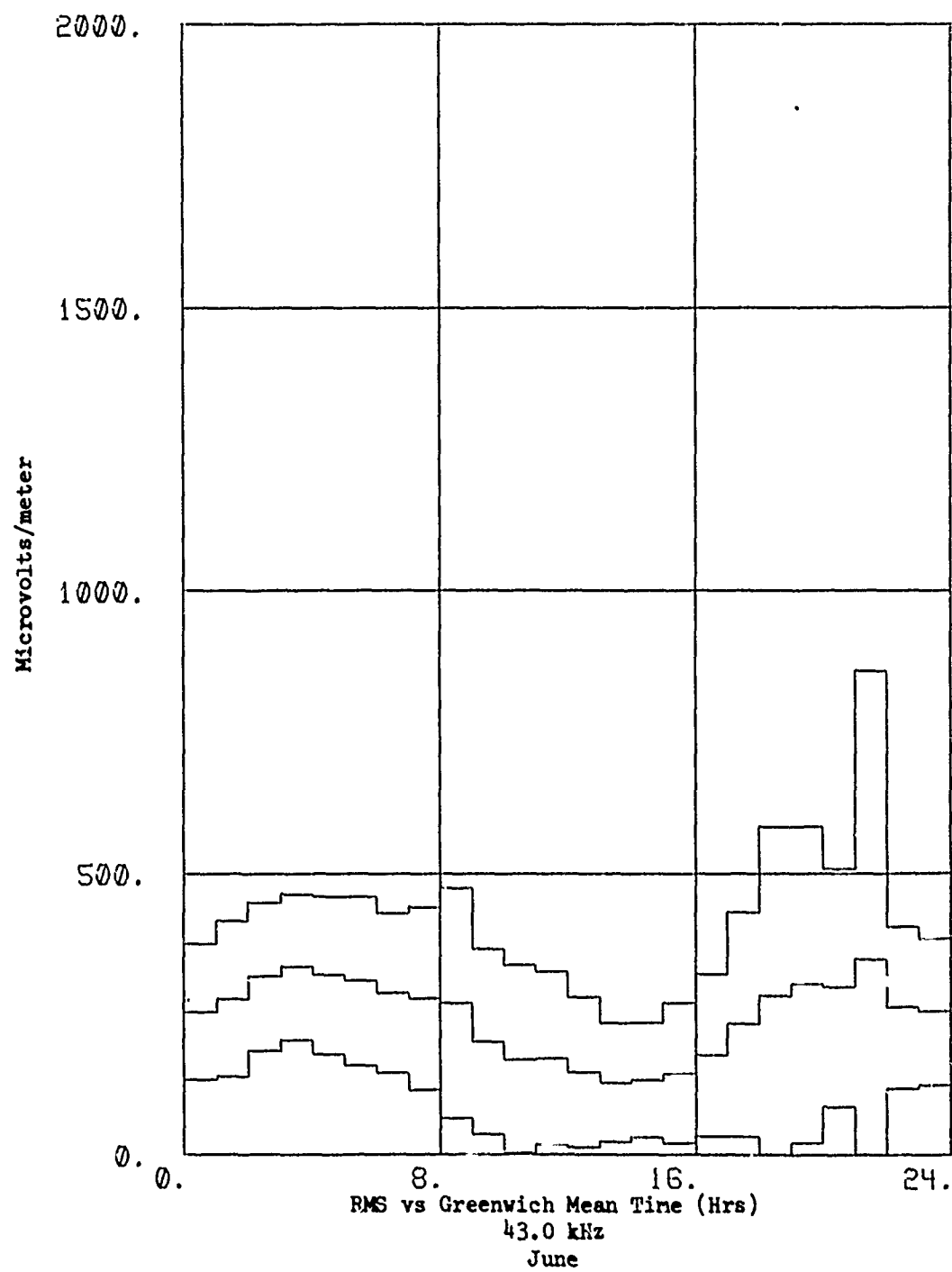


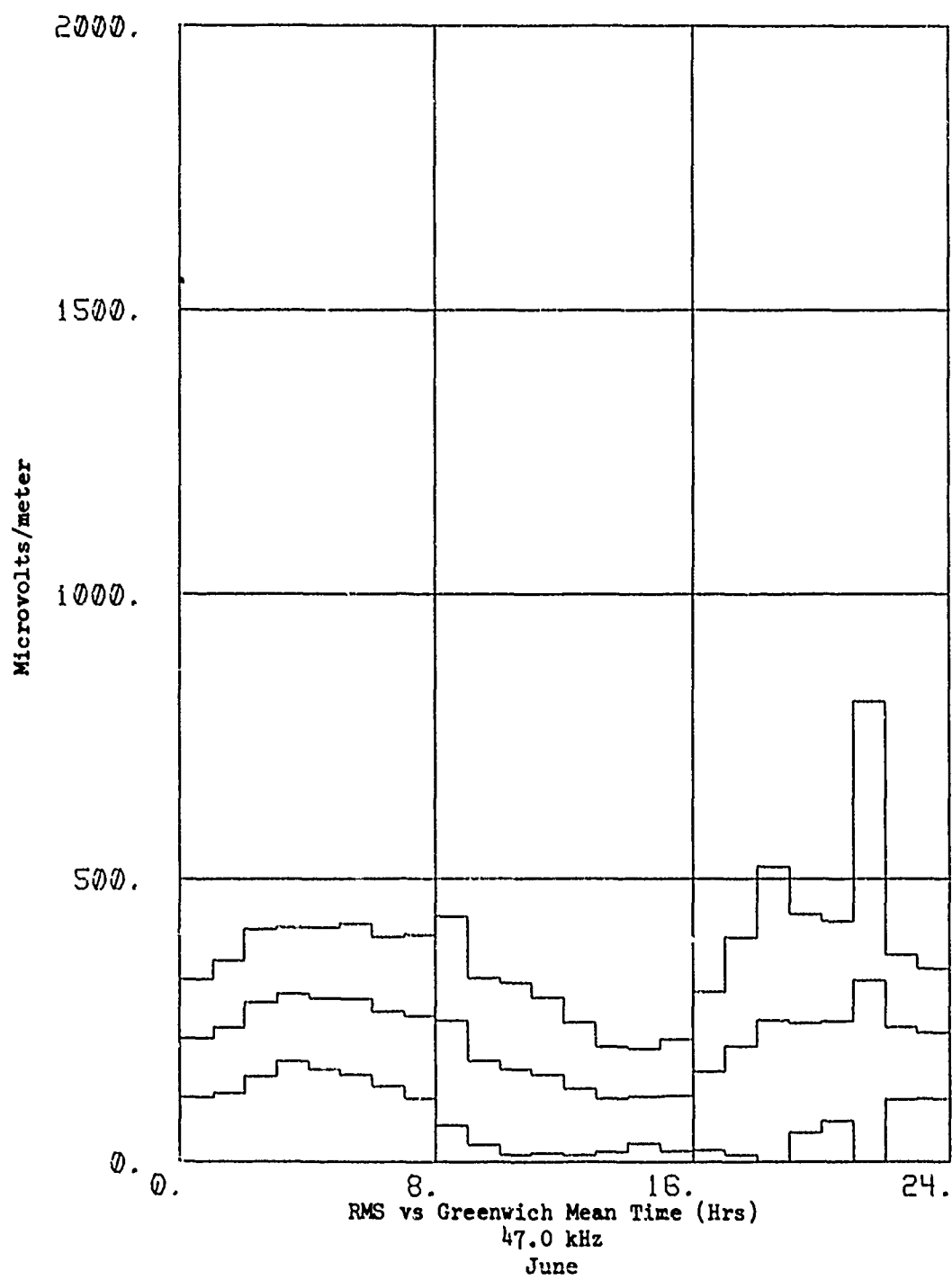


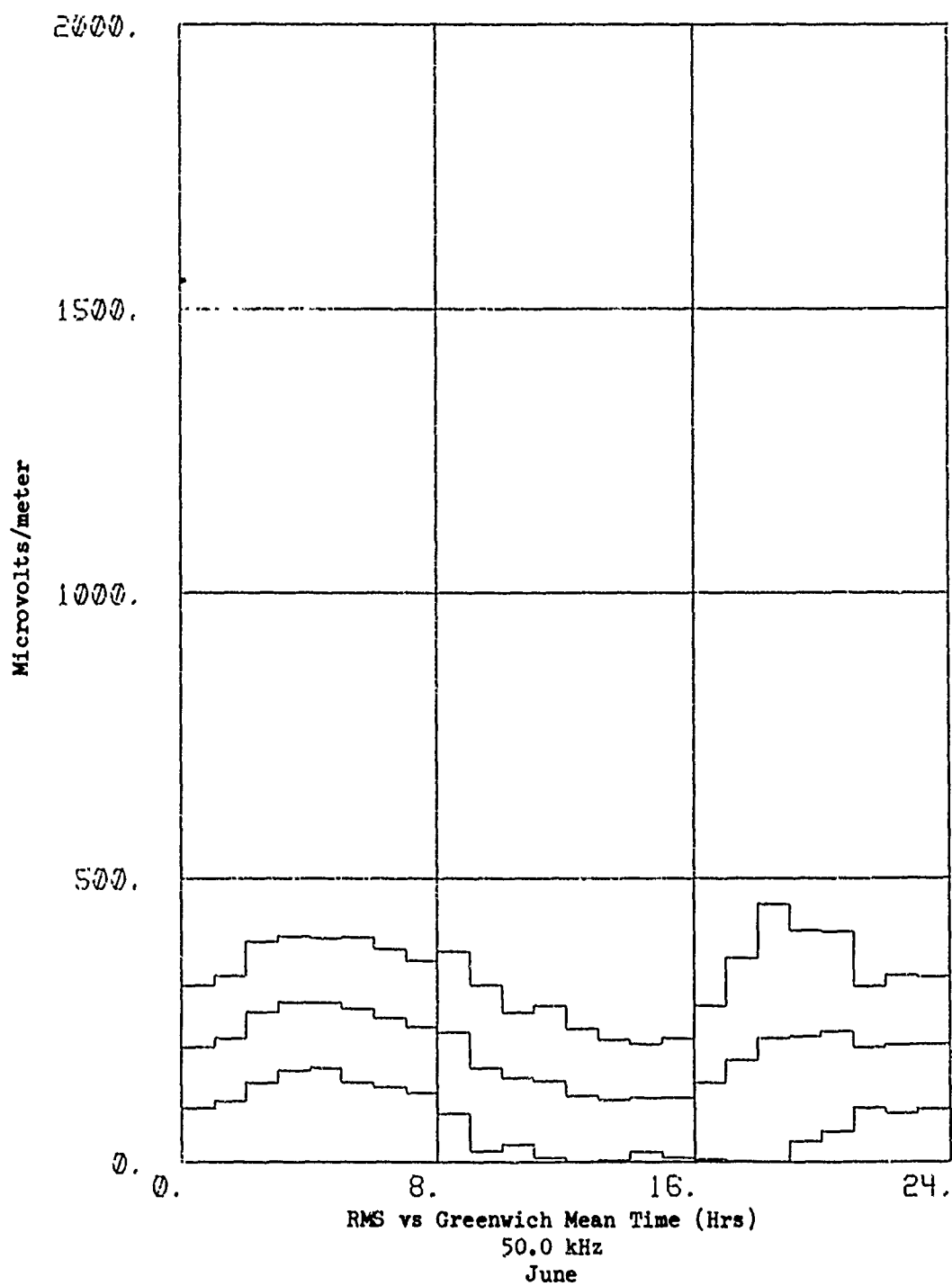


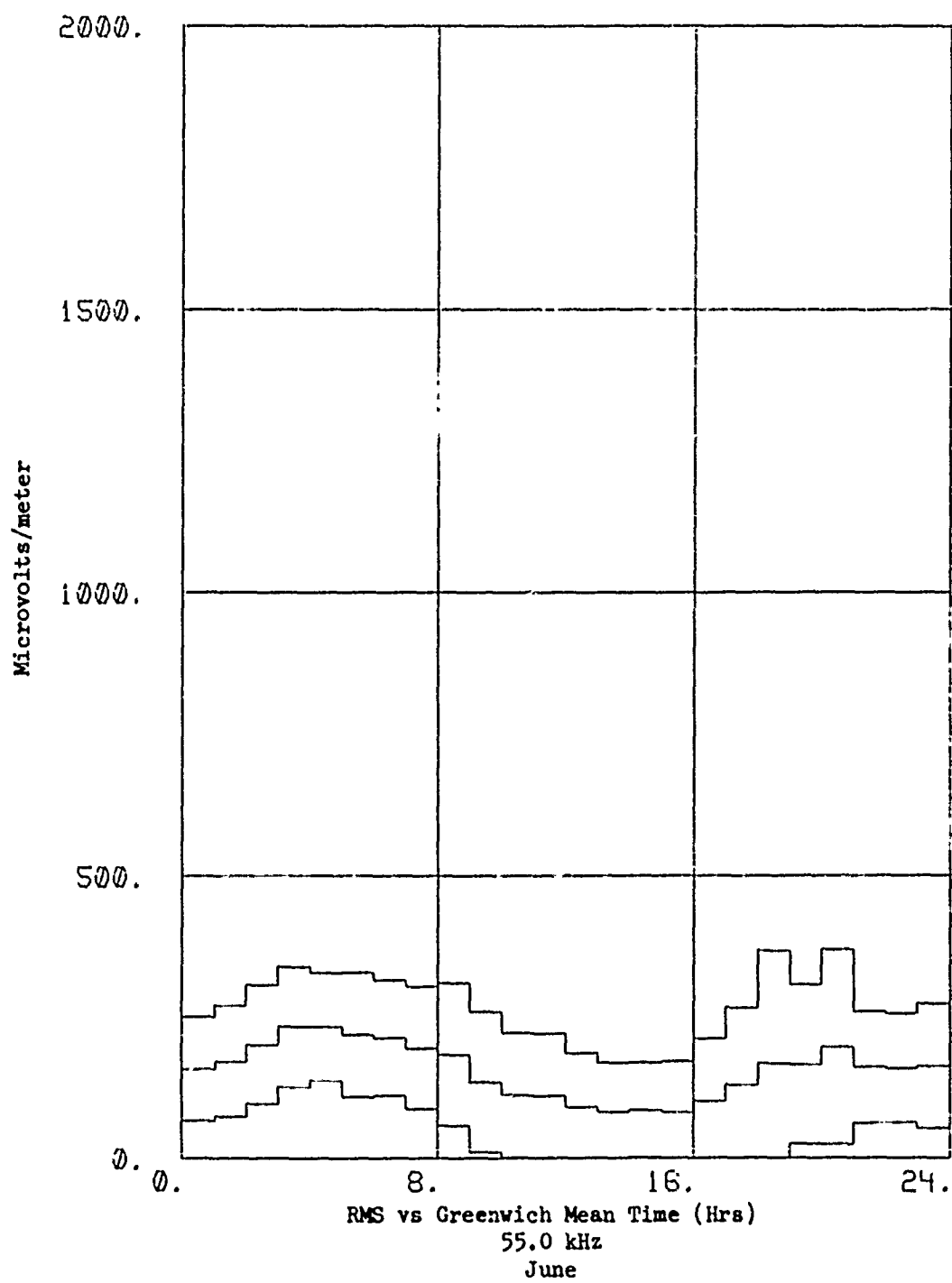






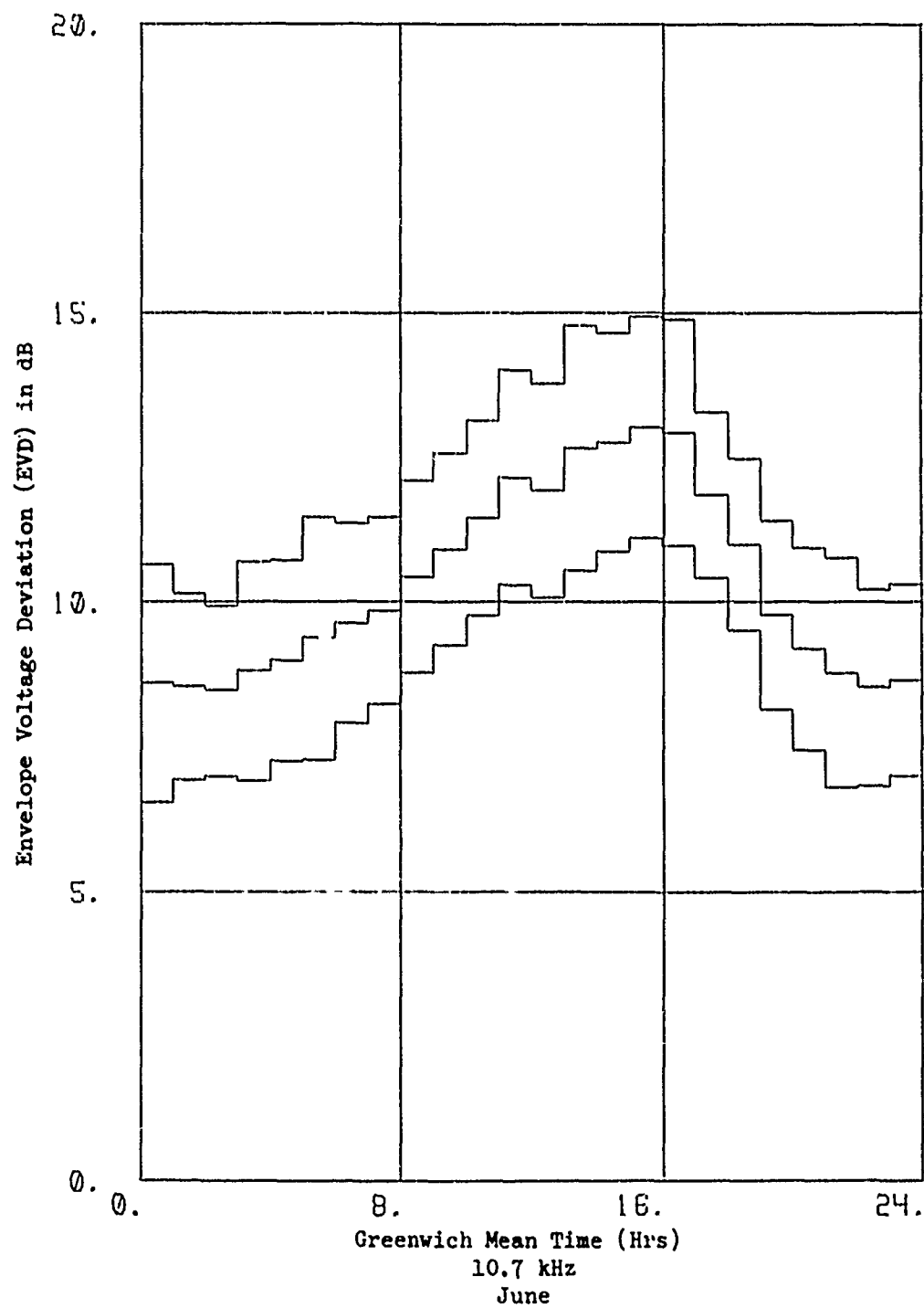


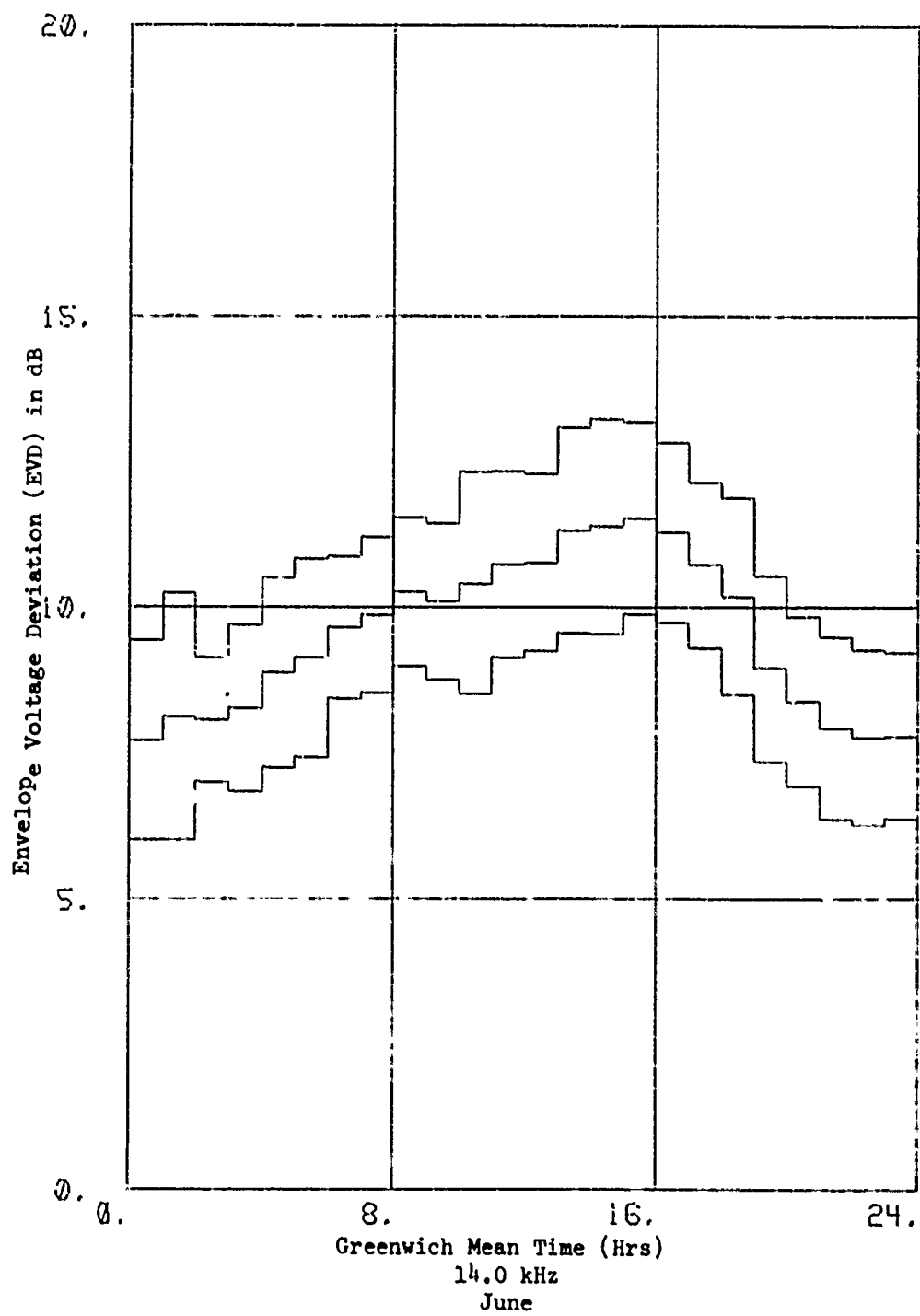


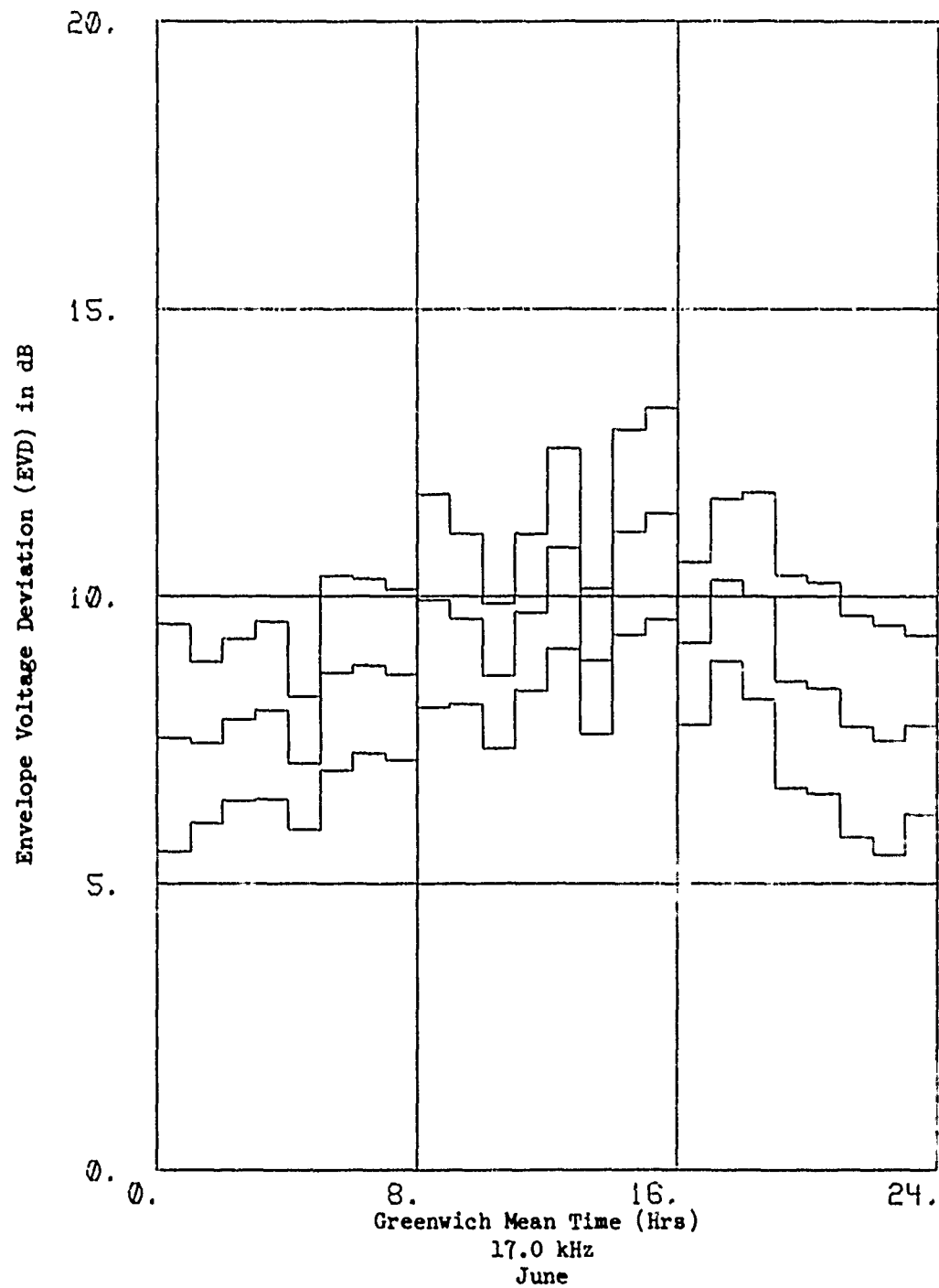


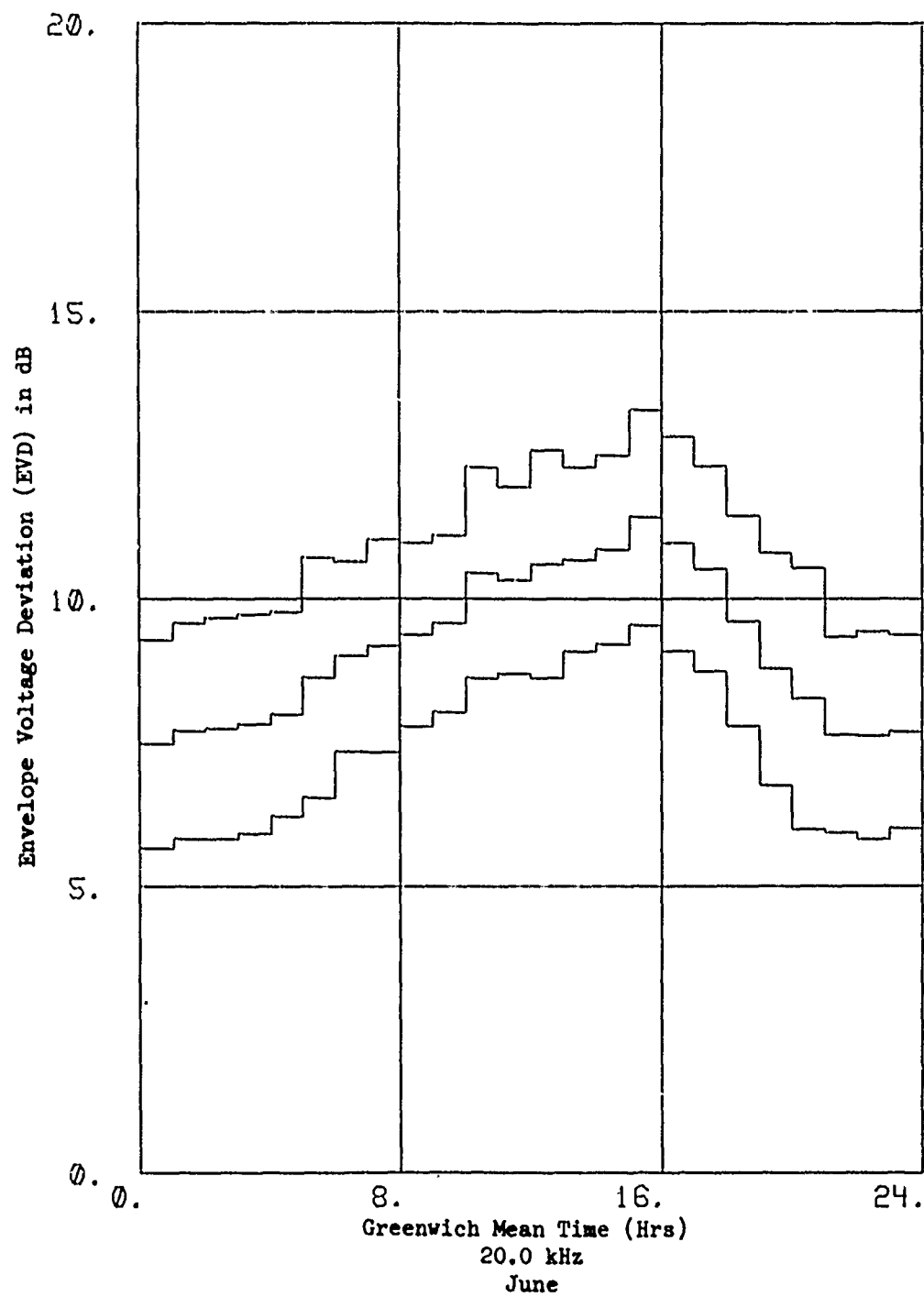
5.14 - EVD vs TIME (@ FREQS. - FOR JUNE)

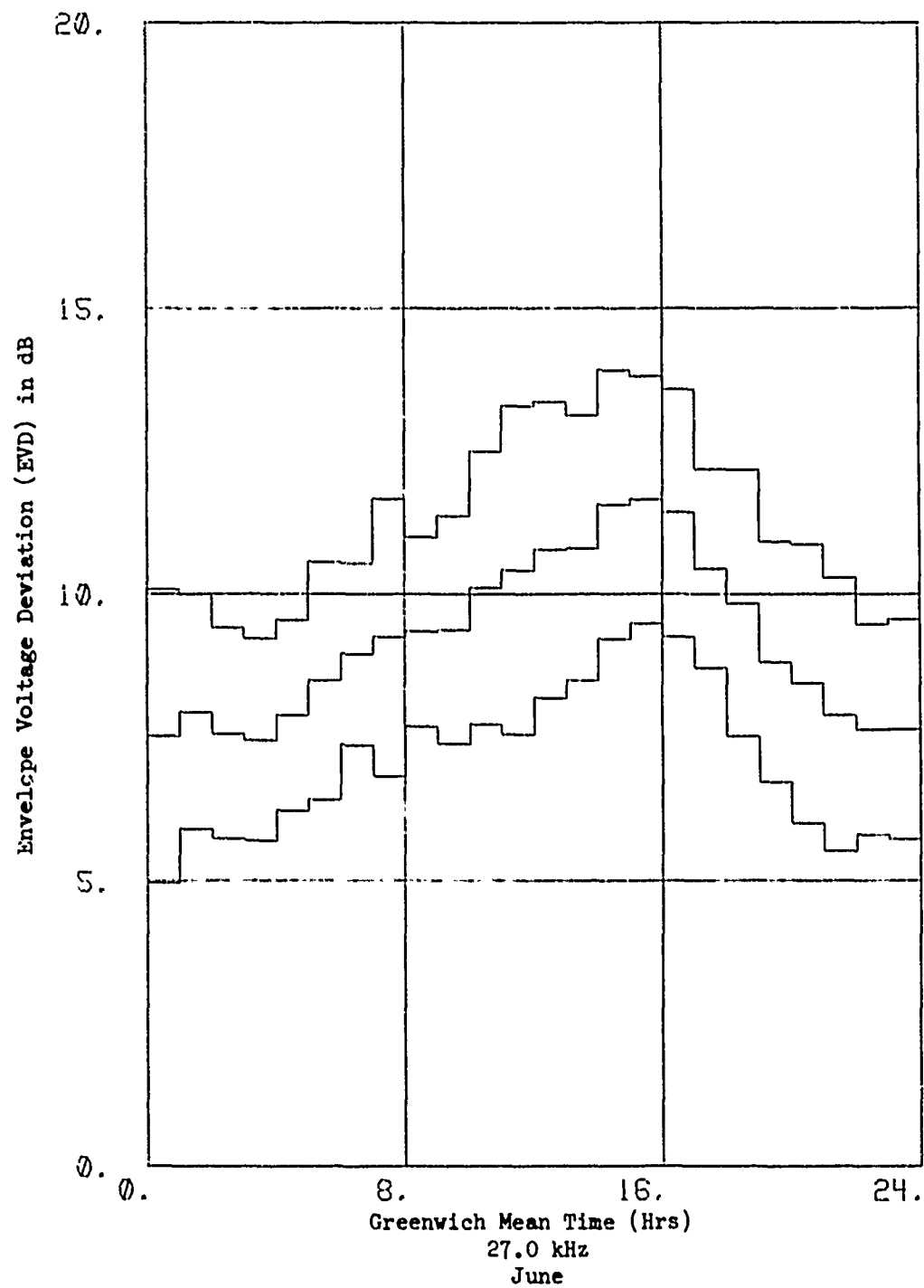


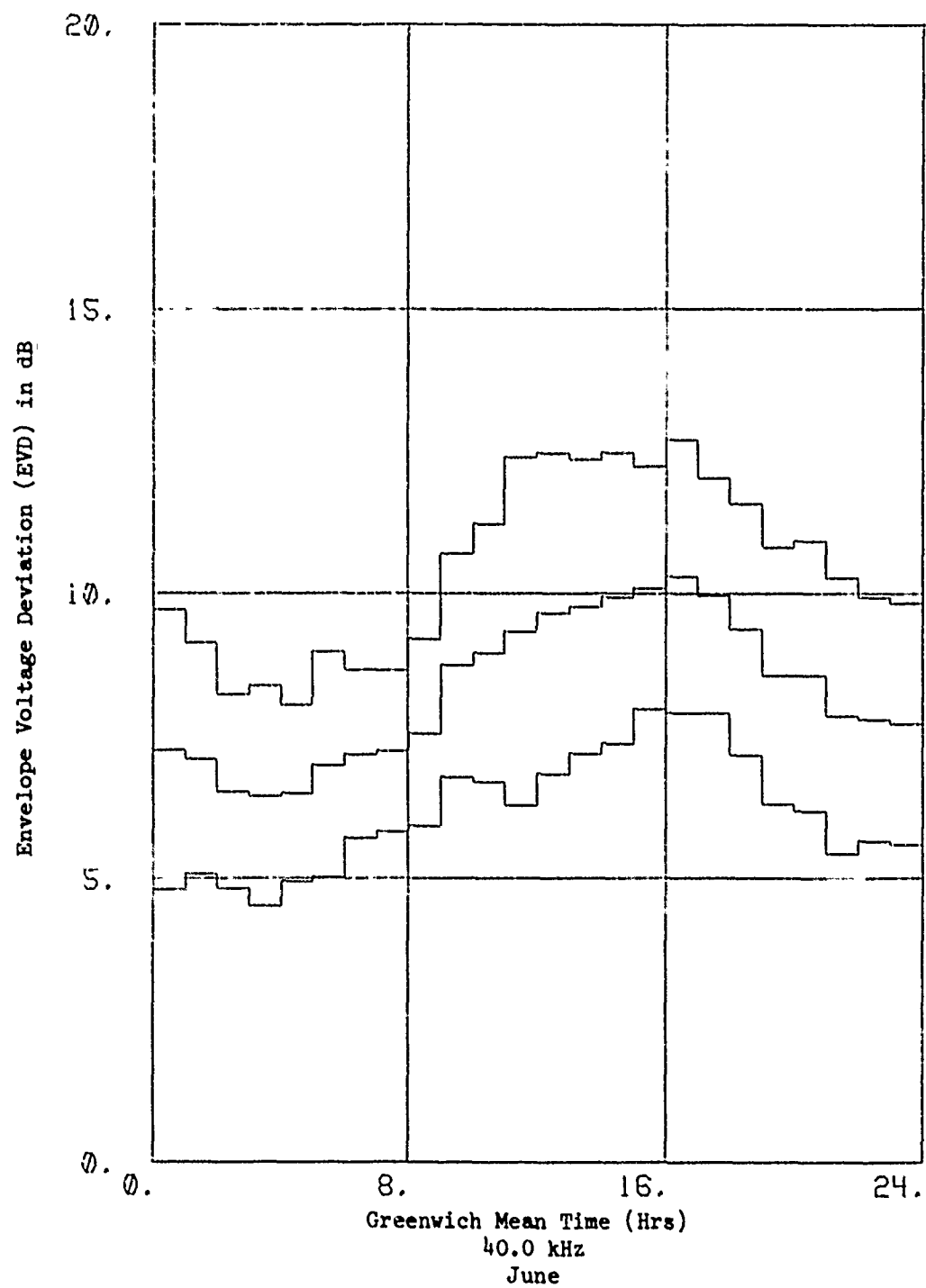


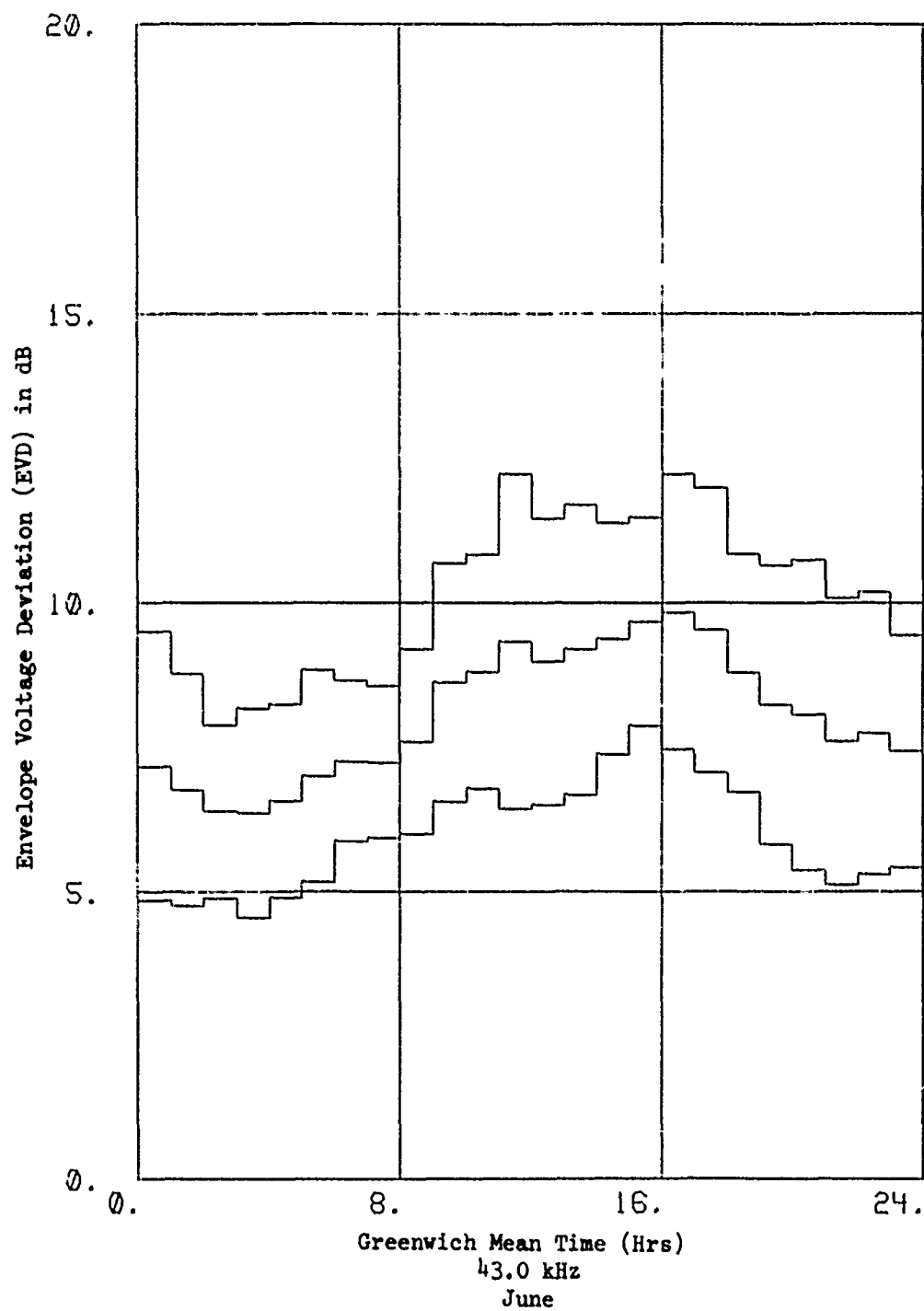


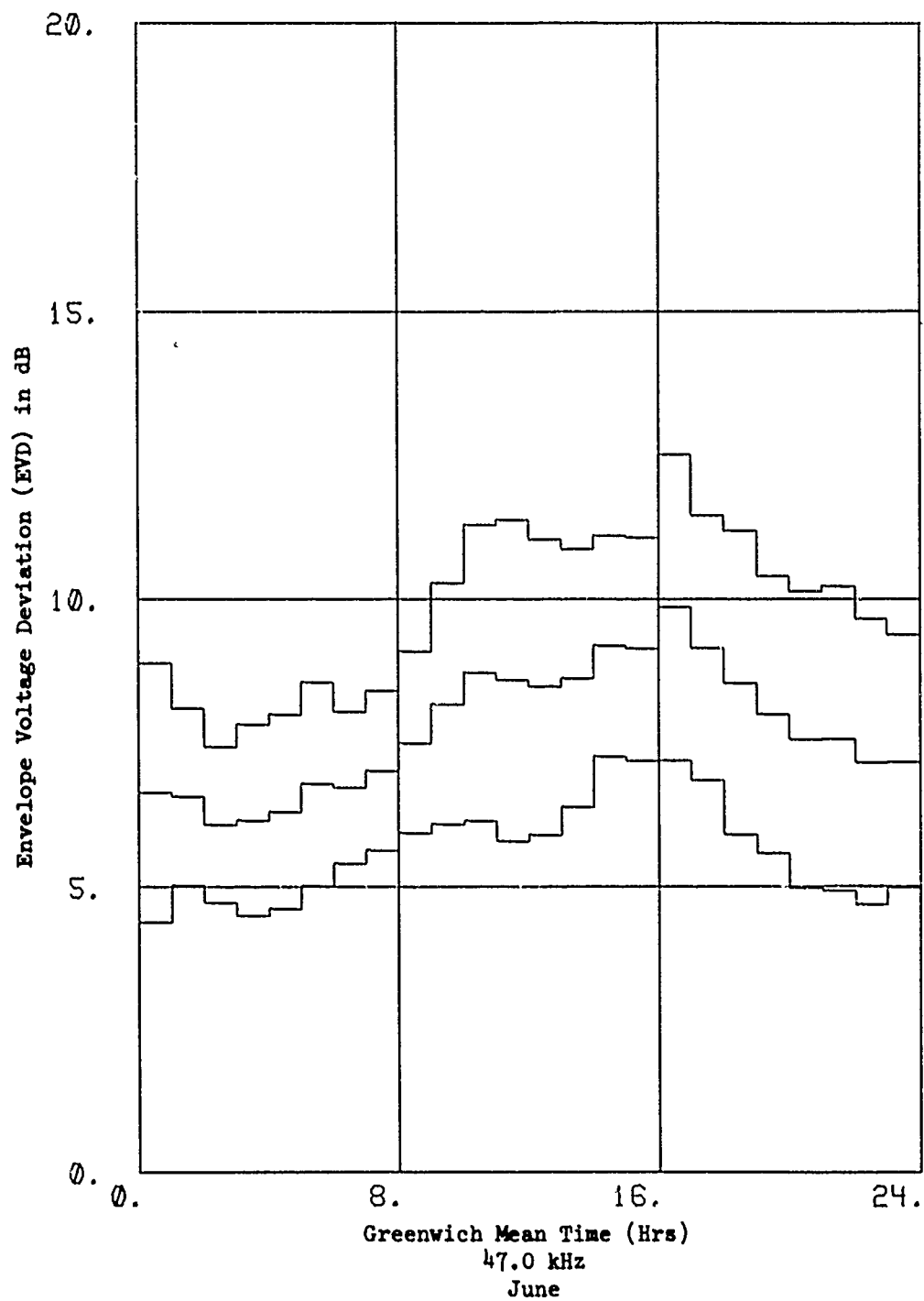




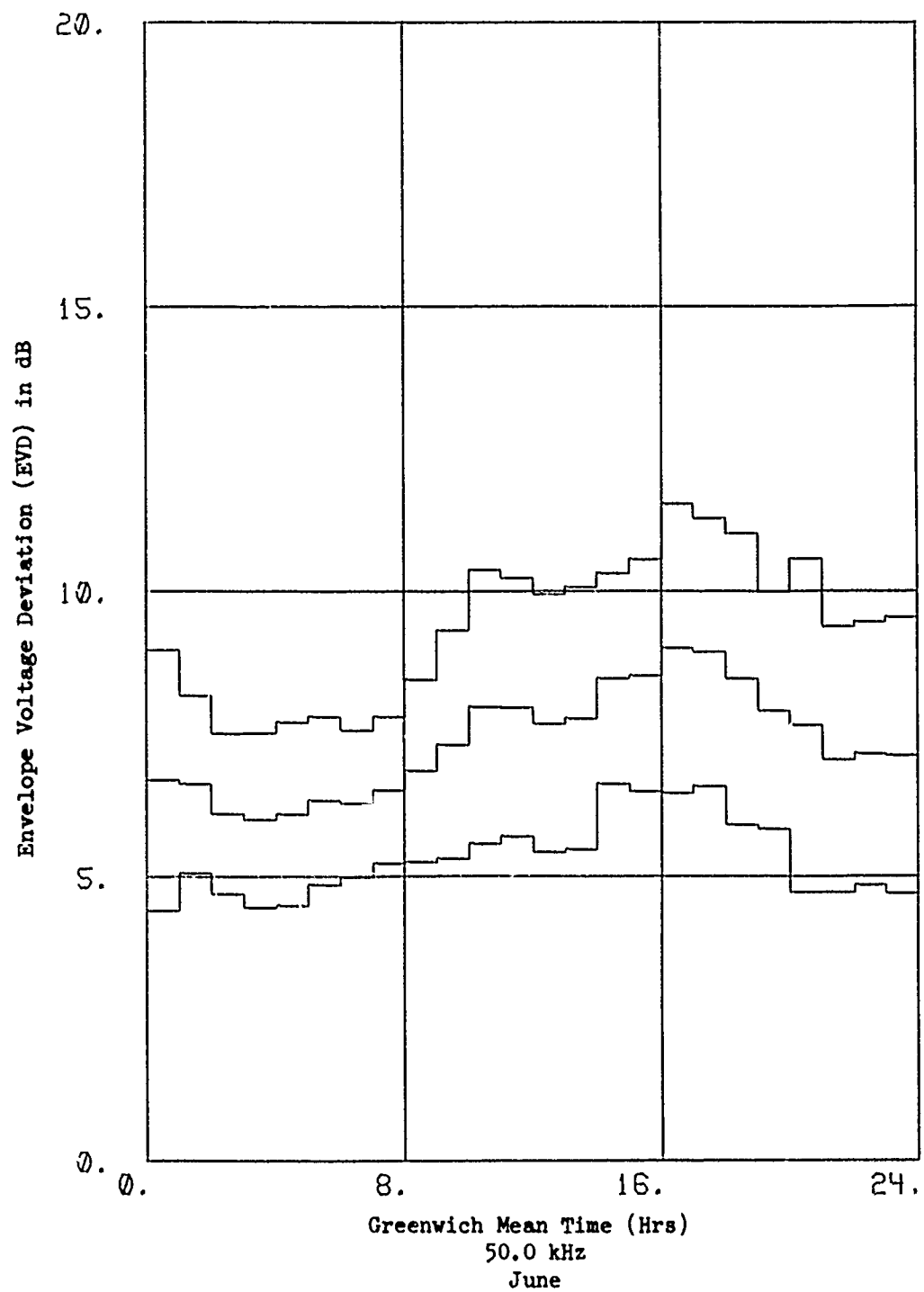


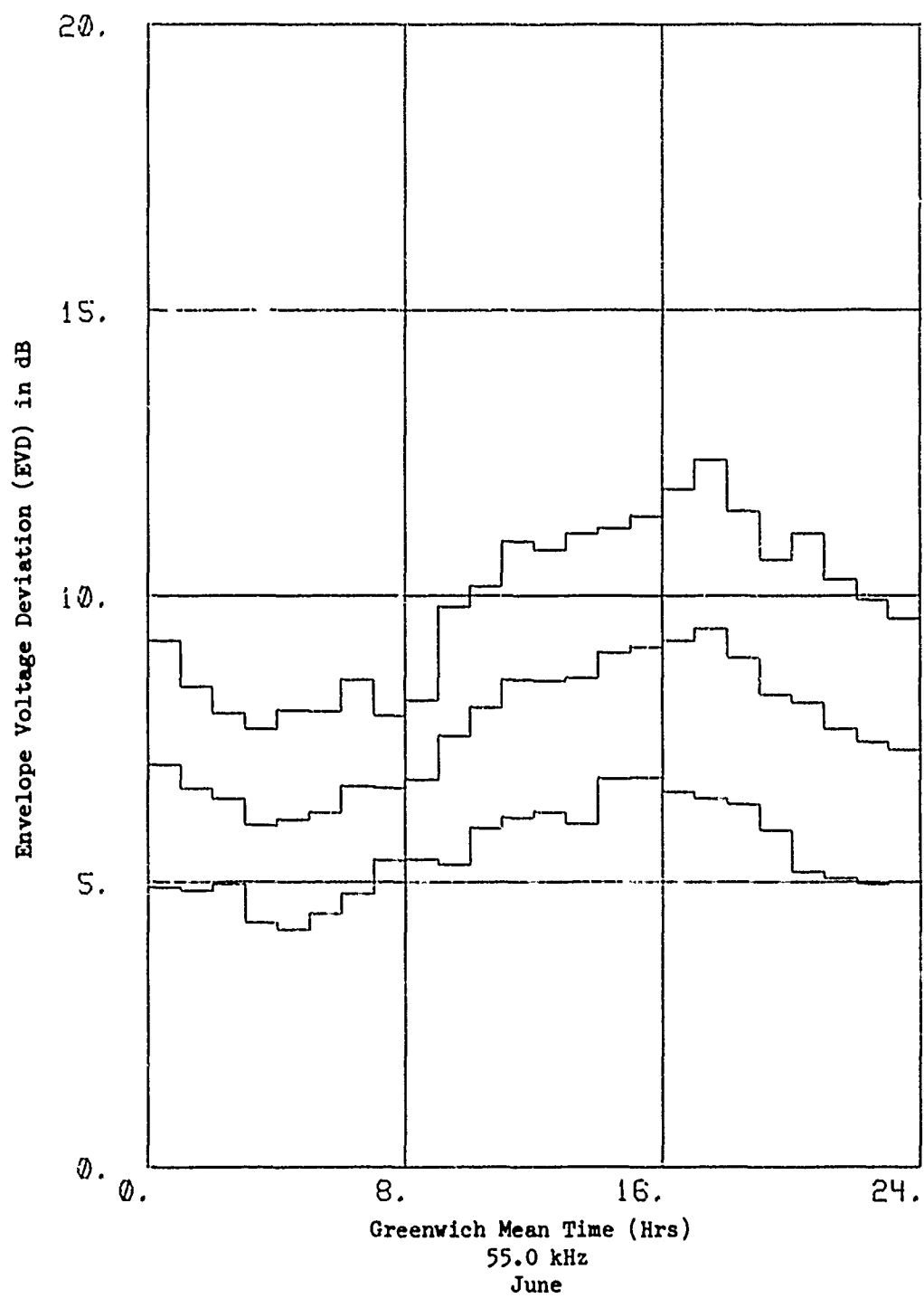












## CHAPTER VI

### SUMMARY AND PROJECTIONS

#### 6.0 RESULTS OF VIENNA TEST RUN

From this limited data we still can discern the variation with frequency, time of day, diurnal effects, and the periods within a season of the average (RMS) atmospheric noise value and its impulsiveness. The RMS values of noise can be seen decreasing rapidly with increasing frequency (Section 5.1), and increasing during the night (Section 5.6). The impulsiveness (EVD) increases during certain periods during the day depending on the period within a season (Sections 5.7 - 5.14). The impulsiveness is seen to increase significantly during the day as the summer season commences. (Note the June plots for EVD - Sections 5.4 & 5.14). The RMS values for noise can be seen consistently increasing during the Spring Season (Section 5.3). Although substantiating data is not presented in this report, indications from the extremely limited data for Jan & Feb lead to the interpretation that the noise floor remains fairly constant during the Winter season and is slightly lower than that of March.

Amplitude Probability Densities were plotted against CCIR APD curves for corresponding EVD values and the coherence was fairly good. This is one statistic which will be carefully monitored during the collection effort and data analysis. Distinct changes in the APD and EVD curves can reveal the presence of local interference.

#### 6.1 PROJECTED EFFORT

Now that all three Statistical Noise Analyzers are in place and operating at their remote sites, the data tapes are beginning to be returned to RADC for reduction and correlation. Preliminary indications lead us to believe that the theoretical APD curves, as developed by Rayleigh, Weibull, and Crichlow, may not be valid for the Northern Area of the world.

The data will be collected from these sites until September 1977. This will complete one full seasonal year and two summer seasons (when Equatorial storms are most prevalent). These units will then be moved to other sites where collection is necessary to fill in the data base, yielding a complete set of "real-world" data for an entire year for the Northern Area.

## 6.2 GOALS

It is the intent of the entire portion of the Tri-Service Propagation Program to establish an accurate data base from which the noise tables in the present propagation prediction models may be corrected to accurately characterize the "real" Northern Area atmospheric noise environment.

It is also expected that this data base will enable the accurate synthesis of new noise curves for the areas above the 50th parallel.

The Amplitude Probability Density curves will be examined closely to determine if it is necessary to reconstruct the theoretical APD curves to model the Northern Area noise. If it is deemed necessary to re-define the theoretical APD curves, this data base will supply all the necessary parameters to enable the formulation of a new set or sets of curves to accurately depict actual Northern Area distributions.

The width and space information may possibly lead to the design and fabrication of an Atmospheric Noise simulator which could be adjusted for season (or month), time of day, frequency, and area of the world. This type of simulator would be a great advantage to modem and receiver design engineers. Present simulators can only be adjusted for noise level and impulsiveness.

# METRIC SYSTEM

## BASE UNITS:

| Quantity                  | Unit     | SI Symbol | Formula |
|---------------------------|----------|-----------|---------|
| length                    | metre    | m         | ...     |
| mass                      | kilogram | kg        | ...     |
| time                      | second   | s         | ...     |
| electric current          | ampere   | A         | ...     |
| thermodynamic temperature | kelvin   | K         | ...     |
| amount of substance       | mole     | mol       | ...     |
| luminous intensity        | candela  | cd        | ...     |

## SUPPLEMENTARY UNITS:

|             |           |     |     |
|-------------|-----------|-----|-----|
| plane angle | radian    | rad | ... |
| solid angle | steradian | sr  | ... |

## DERIVED UNITS:

|                                    |                           |     |                    |
|------------------------------------|---------------------------|-----|--------------------|
| Acceleration                       | metre per second squared  | ... | m/s                |
| activity (of a radioactive source) | disintegration per second | ... | (disintegration)/s |
| angular acceleration               | radian per second squared | ... | rad/s              |
| angular velocity                   | radian per second         | ... | rad/s              |
| area                               | square metre              | ... | m                  |
| density                            | kilogram per cubic metre  | ... | kg/m               |
| electric capacitance               | farad                     | F   | A·s/V              |
| electrical conductance             | siemens                   | S   | A/V                |
| electric field strength            | volt per metre            | ... | V/m                |
| electric inductance                | henry                     | H   | V·s/A              |
| electric potential difference      | volt                      | V   | W/A                |
| electric resistance                | ohm                       | ... | V/A                |
| electromotive force                | volt                      | V   | W/A                |
| energy                             | joule                     | J   | N·m                |
| entropy                            | joule per kelvin          | ... | J/K                |
| force                              | newton                    | N   | kg·m/s             |
| frequency                          | hertz                     | Hz  | (cycle)/s          |
| illuminance                        | lux                       | lx  | lm/m               |
| luminance                          | candela per square metre  | ... | cd/m               |
| luminous flux                      | lumen                     | lm  | cd·sr              |
| magnetic field strength            | ampere per metre          | ... | A/m                |
| magnetic flux                      | weber                     | Wb  | V·s                |
| magnetic flux density              | tesla                     | T   | Wb/m               |
| magnetomotive force                | ampere                    | A   | ...                |
| power                              | watt                      | W   | J/s                |
| pressure                           | pascal                    | Pa  | N/m                |
| quantity of electricity            | coulomb                   | C   | A·s                |
| quantity of heat                   | joule                     | J   | N·m                |
| radiant intensity                  | watt per steradian        | ... | W/sr               |
| specific heat                      | joule per kilogram-kelvin | ... | J/kg·K             |
| stress                             | pascal                    | Pa  | N/m                |
| thermal conductivity               | watt per metre-kelvin     | ... | W/m·K              |
| velocity                           | metre per second          | ... | m/s                |
| viscosity, dynamic                 | pascal-second             | ... | Pa·s               |
| viscosity, kinematic               | square metre per second   | ... | m/s                |
| voltage                            | volt                      | V   | W/A                |
| volume                             | cubic metre               | ... | m                  |
| wavenumber                         | reciprocal metre          | ... | (wave)/m           |
| work                               | joule                     | J   | N·m                |

## SI PREFIXES:

| Multiplication Factors                        | Prefix | SI Symbol |
|-----------------------------------------------|--------|-----------|
| 1 000 000 000 000 = 10 <sup>12</sup>          | tera   | T         |
| 1 000 000 000 = 10 <sup>9</sup>               | giga   | G         |
| 1 000 000 = 10 <sup>6</sup>                   | mega   | M         |
| 1 000 = 10 <sup>3</sup>                       | kilo   | k         |
| 100 = 10 <sup>2</sup>                         | hecto* | h         |
| 10 = 10 <sup>1</sup>                          | deka*  | da        |
| 0.1 = 10 <sup>-1</sup>                        | deci*  | d         |
| 0.01 = 10 <sup>-2</sup>                       | centi* | c         |
| 0.001 = 10 <sup>-3</sup>                      | milli  | m         |
| 0.000 001 = 10 <sup>-6</sup>                  | micro  | μ         |
| 0.000 000 001 = 10 <sup>-9</sup>              | nano   | n         |
| 0.000 000 000 001 = 10 <sup>-12</sup>         | pico   | p         |
| 0.000 000 000 000 001 = 10 <sup>-15</sup>     | femto  | f         |
| 0.000 000 000 000 000 001 = 10 <sup>-18</sup> | atto   | a         |

\* To be avoided where possible

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RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C<sup>3</sup>) activities, and in the C<sup>3</sup> areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

