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THE 1971-1972 DEEP OCEAN PROPAGATION EXPERIMENT: PRELIMINARY RESULTS

Part 1: Long-Term Power Measurements

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ABSTRACT

Since 1962 the Signal Processing Group at the Cooley Electronics Laboratory of The University of Michigan and the Acoustics group (now the Institute for Acoustical Research) of the University of Miami have been engaged in a cooperative effort (project MIMI) involving the use of modern signal processing techniques in studying and modeling how acoustic energy propagates in the ocean. In July of 1971 the Miami group installed an acoustic source at the Eleuthera U.S. Naval Facility in the Bahamas. This source was used to conduct a long-term experiment involving deep ocean propagation. This report contains a description of the primary experiment and the data obtained from it.

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1. INTRODUCTION

Since 1962 the Signal Processing Group at the Cooley Electronics Laboratory of The University of Michigan and the Acoustics Group (now the Institute for Acoustical Research)[1] of the University of Miami have been engaged in a cooperative effort (Project MIMI) involving the use of modern signal-processing techniques in studying and modeling how acoustic energy propagates in the ocean. Until the summer of 1971 these studies had principally been confined to the Straits of Florida, a shallow water channel through which the Gulf Stream flows. In July of 1971 the Miami group installed a 5 KW acoustic source at the Eleuthera U. S. Naval Facility in the Bahamas. This source was intended for use in conducting a long-term experiment involving propagation in the deep ocean between Eleuthera and Bermuda and an intermediate position. The Michigan group provided the digital field package and designed the signal-processing programs used in this experiment.

This report contains a description of the primary experiment and the data obtained from it. Later reports on reverberation and multipath will describe the results of short-term "snap shot" experiments conducted from the Eleuthera site.

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[1]Miami Division of Palisades Geophysical Institute

The success of these experiments is due to the effort of many people, including the staff at NAVFAC Eleuthera. This work was funded by ONR Code 468.

2. THE POWER MEASUREMENT EXPERIMENT (CMP8:15)

The power measurement algorithm (CMP) used in the experiment described herein was a variation on the DUAL algorithm designed by T. G. Birdsall. CMP experiment extracts from a reception a few key features that serve to characterize the reception. The experiment described involved the transmission of a broadband signal through the ocean between a fixed-site source and fixed-site receiver (bistatic propagation). At the receiving site, the energy in various frequency bands and the relative phase of the carrier line were used to characterize the reception.

The broadband transmission used in the CMP experiment consisted of a CW carrier modulated by a binary linear maximal sequence. The spectrum of the transmission was similar to that shown in Fig. 1. The clock signal used to generate the carrier and to clock the maximal sequence generator was derived from a rubidium time standard. The modulated carrier was amplified and then coupled into the ocean as an acoustic pressure wave. At the receiving site, the received signal was amplified, filtered, and then digitized using a PDP-8/L computer. The sampling clock used to digitize the reception was the same precision as the clock used in generating the original transmission. The use of ultrastable clocks for both the generation of the transmitted

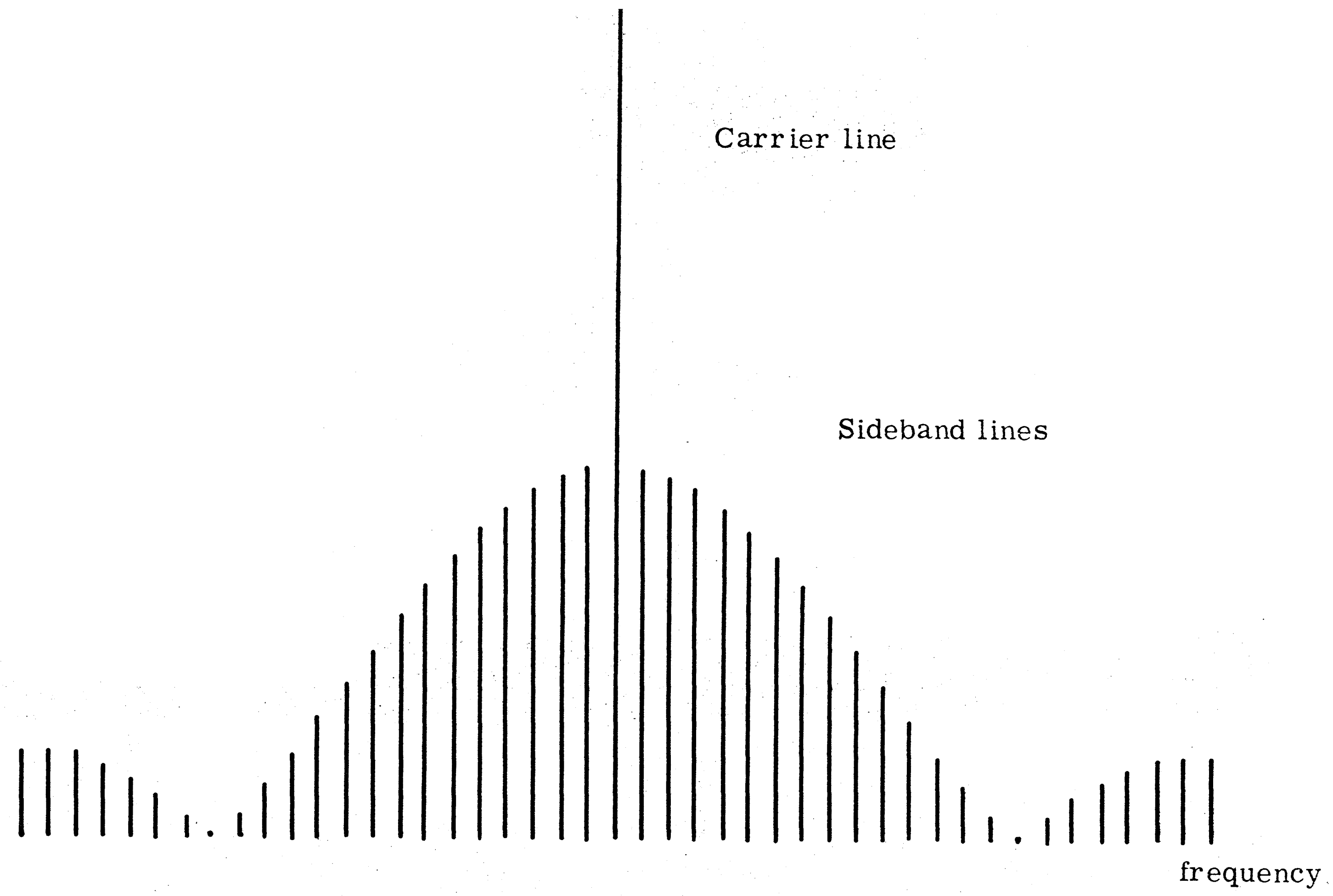


Fig. 1. Broadband signal amplitude spectrum

signal and the time base for processing the resulting reception insured that any observed fluctuations were due solely to changes in propagation. A digital computer was programmed to perform the desired filtering operations. The results of the computer computations were recorded on digital magnetic tape for later analysis and were also printed out on a chart recorder for on-line inspection. Figure 2 shows how the basic components involved in the CMP experiment were arranged.

The CMP program in use measured five parameters associated with the reception. These measurements were made every twelve minutes and were based on the last five minutes of data.

The five reception parameters measured were:

1. The power in the carrier line (C-PWR).

2. The phase of the carrier line relative to the transmitted signal.

3. The power in a narrowband of frequencies around the carrier line. This was to serve as a measure of the amount of reverberation present (R-PWR).

4. The power in a set of frequencies corresponding to the lines in the spectrum of the transmitted signal, not including the carrier line (W-PWR).

5. The power in the frequencies not associated with the signal. This is a measure of the background noise (N-PWR).

Figure 3 schematically illustrates the placement of the filters used in making these measurements.

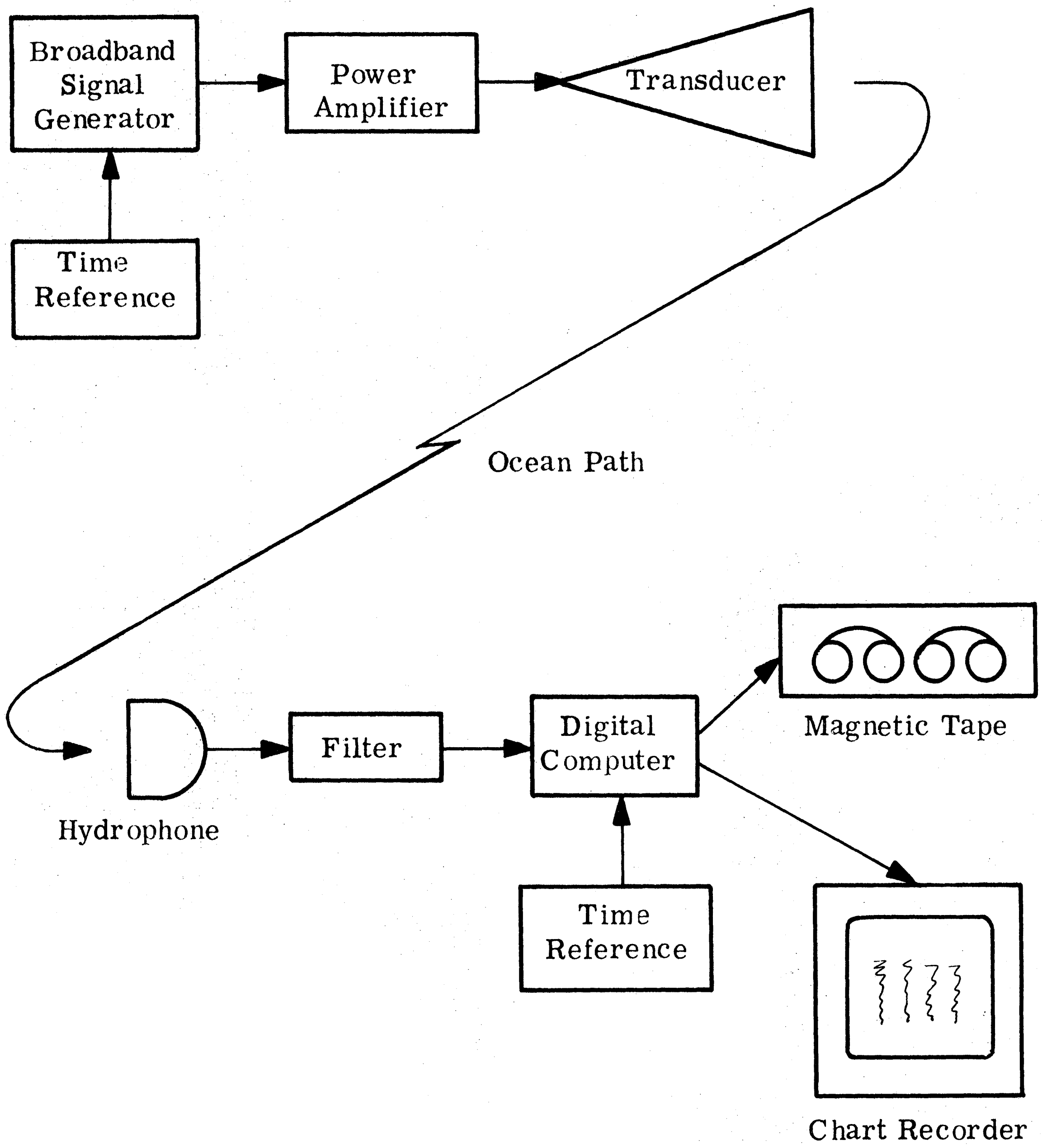


Fig. 2. Equipment arrangement for the CMP experiment

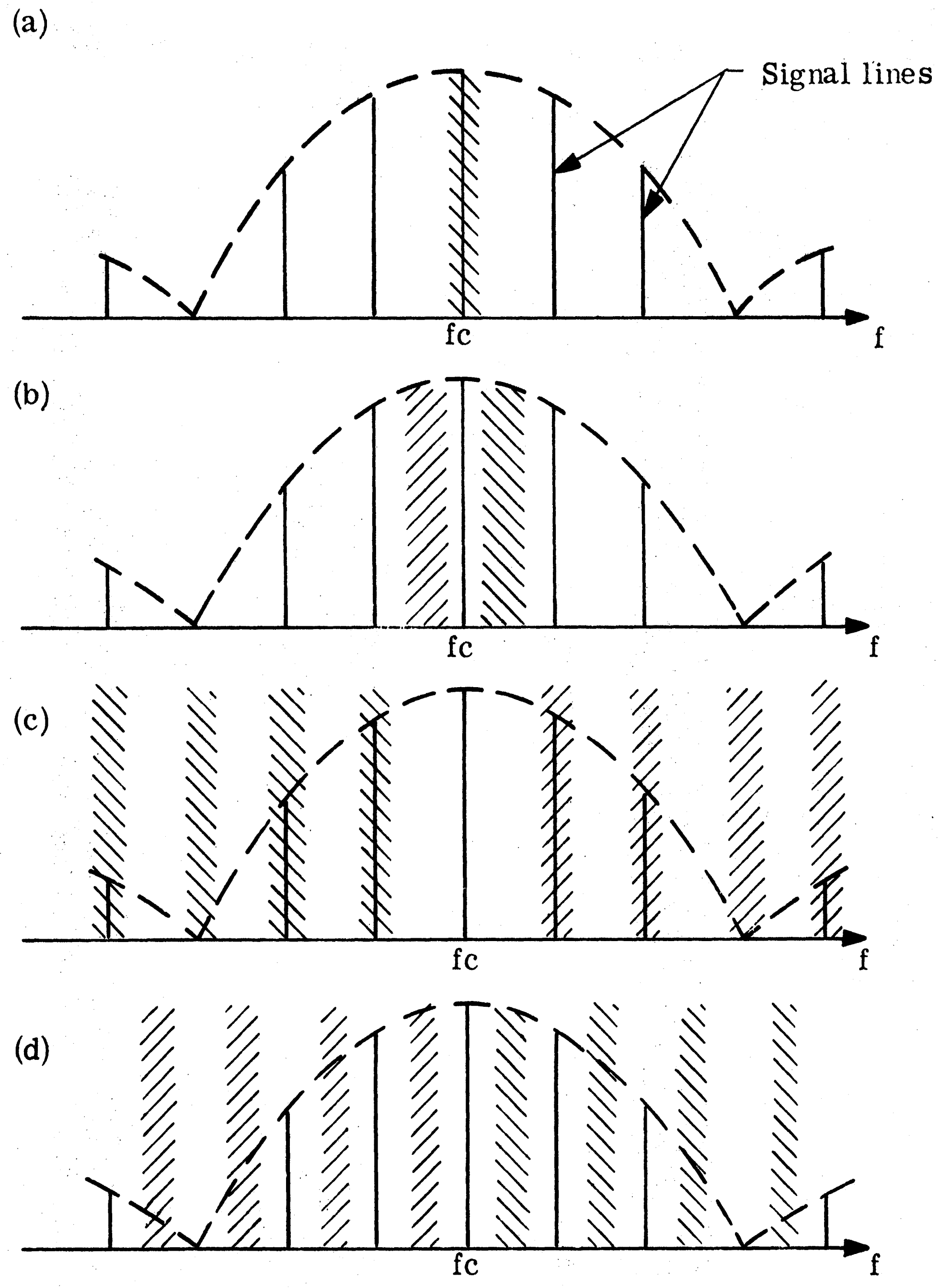


Fig. 3. Transmitted line spectra showing CMP filter positioning (a) carrier, (b) reverberation, (c) sideband and (d) noise

The basic concepts involved in implementing a CMP or DUAL-like experiment are explained and analyzed in detail in a report currently in preparation and are thus omitted here.

3. CHARACTERISTICS OF THE TRANSMITTED SIGNAL

The signal used in the CMP experiment consisted of a constant carrier phase-modulated by a periodic digital sequence. The modulating sequence was a linear maximal sequence with a period of 255 digits (Refs. 1, 2, 3). Each digit was exactly 15 carrier cycles in duration. The carrier frequency was 406 Hz. The modulation technique was phase shift keying. The power level to the transducer was approximately 450 W electrical (corresponding to about 225 W acoustic into the water). The Q of the transducer was approximately 8. The ratio of carrier power to side-band power is 1.00003. Table I summarizes some of the key features of the test signal.

Table I. Properties of the transmitted signal

Carrier frequency	406	Hz
Digit duration	0.0369^{+}	sec
Sequence period	9.42^{+}	sec
Line separation	0.106^{+}	Hz
Distance to first spectral zero	27.07	Hz
Nominal bandwidth	27.07	Hz
Sequence law	(8, 6, 5, 1, 0)	
Modulation	± 45 degrees, phase	

The form of phase modulation used has been referred to as complementary phase modulation (CM) by project personnel. Since the sequence used for this transmission was generated by an 8-stage shift register generator and the digit duration was 15 carrier cycles, it has become customary to refer to the transmission as CM8:15.

4. HANDLING OF THE RECEPTION

The reception was processed using the Field-8/L digital signal processing system shown in Fig. 4. The hydrophone was observed for a 5-minute period every 12 minutes.

The phone was followed by an analog filter, which was constructed by CEL and is termed an M/W-2. It has a nominal center frequency of 406 Hz and a nominal bandwidth of 35 Hz. A 6-pole Butterworth design was used.

The filter output fed a computer controlled gain/attenuation unit. This unit was controlled by the computer and was used to maintain the signal level at the A/D converter input at approximately 60 to 80 millivolts rms. Level changes could be made in 6 dB steps. The processing program took into account the setting of this unit when computing power levels.

The A/D converter on the Field-8/L is a 10-bit converter set to operate over a ± 1 volt range. Samples were taken on command from an external clock input. When a sample had been converted, the computer was notified by means of an interrupt. This procedure eliminated any jitter in the sample timing. The sample clock was at 1624 Hz, 4 x 406.

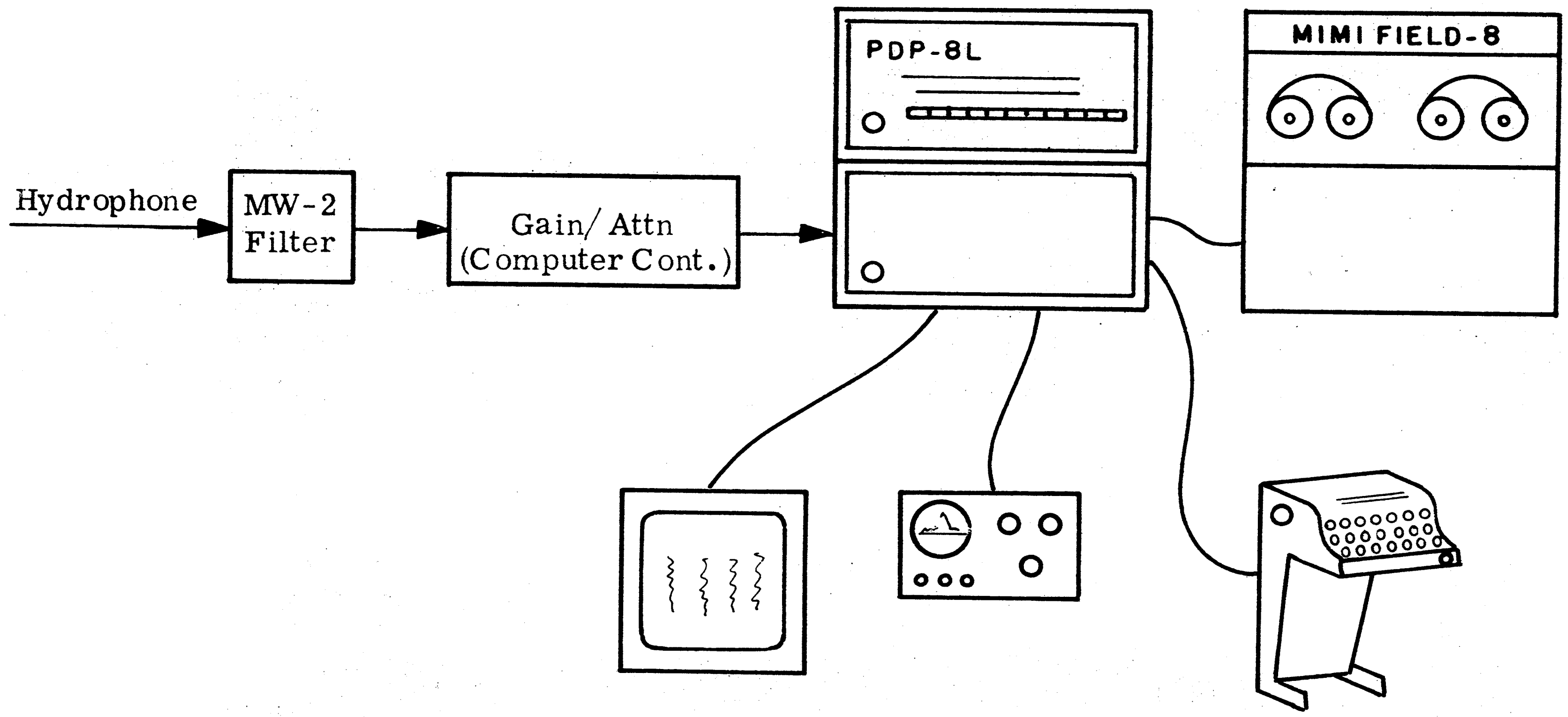


Fig. 4. Field-8/L digital signal processing system

In the computer, the reception was quadrature demodulated down to baseband and digitally filtered. Approximately five minutes of data were used to form the five numbers, which were the primary data of interest.

The computer program used to process the data was named CMP8:15. In addition to being able to extract the desired five parameters, this program could also generate a display showing the current digit response path structure of the channel. The results obtained using this feature are to be reported in a companion report.

The basic program operation was as follows:

1. Data over a 5-minute interval were accumulated and digitally filtered. (32 sequence period, 301.478^{-} sec)
2. At the end of 5 minutes the data-taking was suspended and the desired parameters and channel digit response were computed. This required on the order of 45 to 50 seconds.
3. The hydrophone gain/attenuator setting (based on the results of the last data set) was made.
4. At the end of the processing interval (exactly 44 sequence periods in duration, 414.532^{+} sec) data acquisition for the next data set was started.
5. Every 16 data sets a single tape block was written containing the results of the parameter measurements.

6. While the data were being accumulated for the next data set, the channel digit response computed from the last data set was displayed and the multipoint output plotted.

The CMP8:15 program operated in a foreground, midground, background mode with the background being multiprogrammed. Extensive on-line operator interaction was possible. Under normal use each data tape could hold about three months' worth of data. Two tapes were left mounted on the computer at all times. A Teletype log was maintained by the program and an on-site observer. Although operation was essentially unmanned, the machine was monitored once a day so that any abnormalities or problems could be reported.

Table II summarizes the key features of the processing used on the reception. The carrier power measurement was made using a digital filter with a bandwidth of 3.3 millihertz. The wide band power measurement used a comb filter whose teeth were also 3.3 millihertz wide. Approximately 35 to 40 teeth contributed to this measurement. The filter used to measure the reverberation power was about 0.1 Hz in bandwidth and was centered at 406 Hz. The carrier line was notched out of both the W-PWR and R-PWR measurements. The noise power measurement used a 35 Hz bandwidth and was made using the residual variance approach (to be described in a companion report). In essence this approach involved computing the total power contained in the reception and subracting off those contributions contained in the C, R and W-PWR measurements.

The digital filters used in obtaining these measurements were designed so that their gain-bandwidth products were equal. This permits the reading of the signal-to-noise ratios at the filter outputs directly. If it is necessary to relate a given measurement to any measurement other than noise power, a correction factor is necessary. The unity gain correction factors given in Table II can be used for this purpose. For example, to compare C-PWR and W-PWR subtract 28.8 dB from the C-PWR measurement, C-43.9-(W-15.1) at transmitter.

Table II. Summary of processing parameters

CMP 8:15 SUMMARY 7/71 - 7/72	
Carrier	406 Hz
Digit duration	15 carrier cycles
Modulation	phase, $\pm 45^{o}$
Sequence polynomial	(8, 6, 5, 1, 0)
Sequence length	255 digits
Sequence period	9.421^{+} seconds
Number of periods per data set	32
Number of periods per block average	1
Number of demodulates per digit	3
Tooth width	3.32 millihertz
Signal tooth spacing	0.106^{+} Hz
Unity gain correction factors	C-pwr -43.9 dB W-pwr -15.1 dB R-pwr -28.8 dB N-pwr 0.0 dB
Sequence periods per processing gap	44
Total data set duration (inc. gap)	11.9335^{+} minutes

APPENDIX

This appendix contains plots for the far phone of the carrier power (C-PWR), wideband signal power (W-PWR), noise power (N-PWR) and carrier angle for the 48-week period, 19 August 1971 through 21 July 1972. The reverberation (R-PWR) has been omitted. These plots are unedited and show the effects of unplanned gain changes, transducer outages, calibration signals and a few currently unexplained happenings. These plots were made from the summary records produced by the CMP program. These records were reformatted, converted from LINC tape to 9-track IBM tape and then plotted using The University of Michigan's CALCOMP facility.

The processing gains and filter bandwidths have been adjusted so that the signal-to-noise ratio on a given measurement can be read directly, as the difference between the desired signal power and the noise power (power in dB). For example, on Day 231 the signal-to-noise ratio on the C-PWR measurement is approximately 45 dB and on the W-PWR measurement it is about 18 dB.

The transmitted signal contained approximately equal power in the carrier and the side bands. The difference in processing gain between the C and W power measurements is 29 dB. If this amount is subtracted from the C-PWR measurement, it is seen that, on the average, the C and W-PWR measurements track each other.

The time axis on each plot spans seven days and is marked with the day number. Points are plotted at the basic phone data rate of five per hour. Powers are plotted in dB, to an accuracy of 0.125 dB. The power axis spans 60 dB, and is marked every 10 dB. The base level (0 dB) was chosen for plotting convenience. The phase angle is measured and shown in cycles (1 cycle is 2π radians or 360 degrees), accurate to 1/64 cycle (5.625 degrees), spanning 32 cycles.

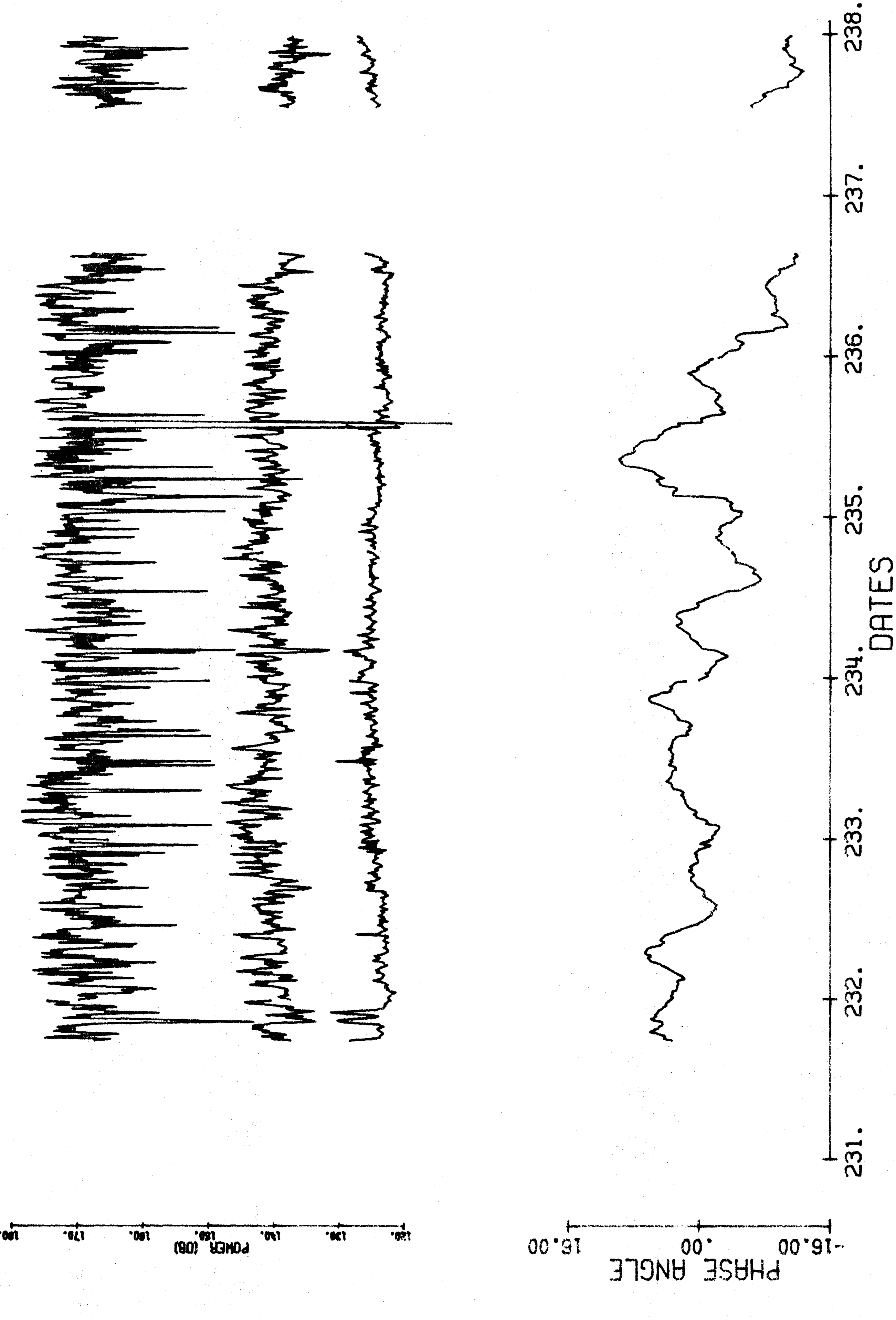
The C-, W-, and N-PWR are not identified on these plots, but they have unique identifiable behavior. C-PWR is highest, and spans about 10 dB exclusive of the 5 to 10 deep fades per day; W-PWR is the middle power with a 5 to 10 dB hourly spread and no deep fades; N-PWR is the lowest power, with its own variable behavior.

Plotting gaps mean that the receiver or processor was off, simultaneous changes in all three plotted powers indicate gain changes prior to the processor; when W-PWR drops and tracks N-PWR, it indicates that the transmission was changed to CW (carrier only), and when both signal powers drop and track N-PWR, this event indicates that the transmitter was off.

Dates are in Julian form using GMT.

During the period 1145 7 October 1971 (Day 280) through 1230 25 October 1971 (Day 298), the normal CM8:15 transmission was replaced by a special transmission consisting of carrier only, cycled on for 4 minutes every 60 minutes. No conclusions should be drawn from this period. A special editing may yield valuable N-PWR results.

Starting on Day 319, a program of system calibrations was started. These calibrations were made once a day or less frequently. The primary effect of these calibrations was to cause downward spikes in the noise-power measurements and to complicate the post processing of the data.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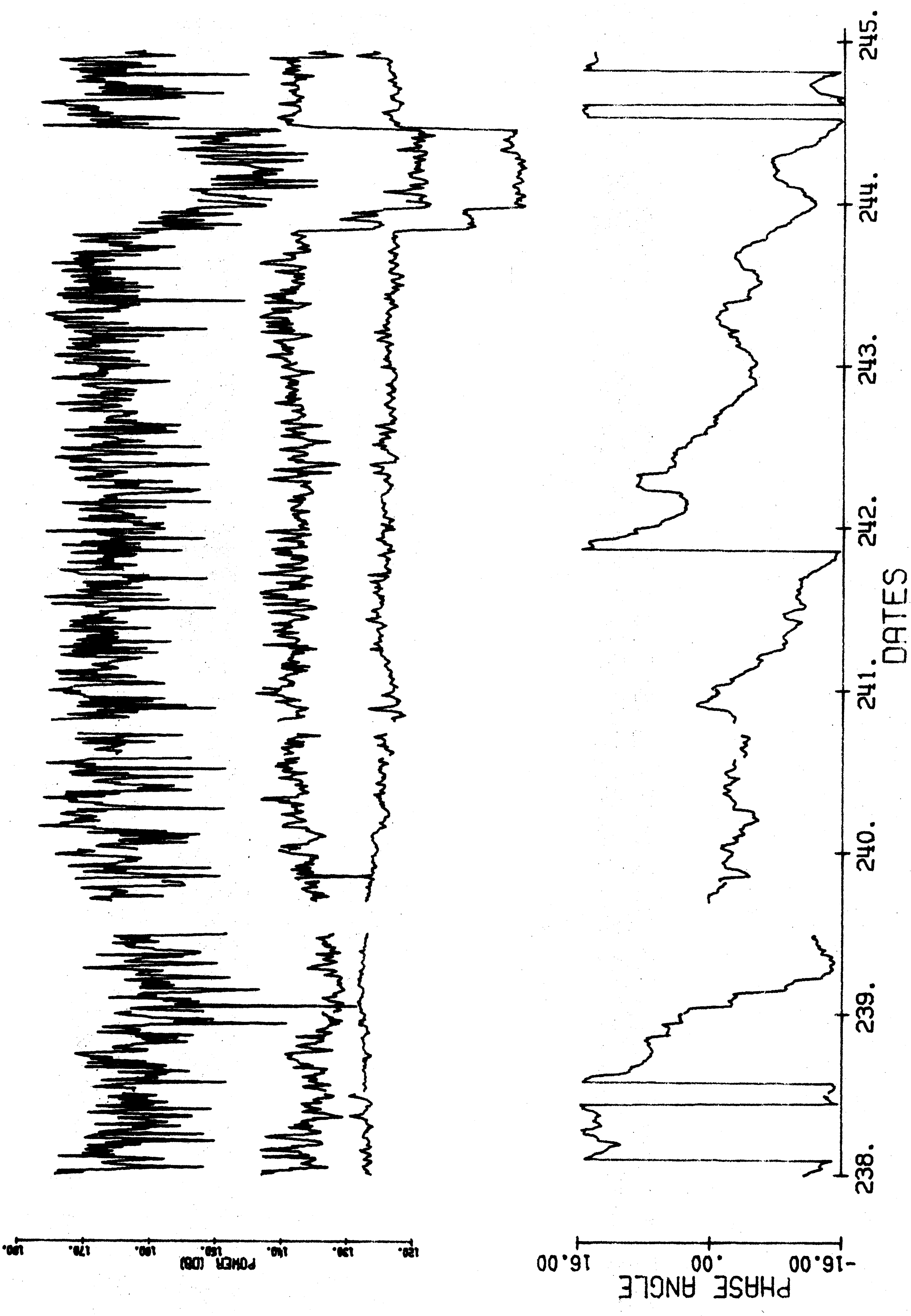
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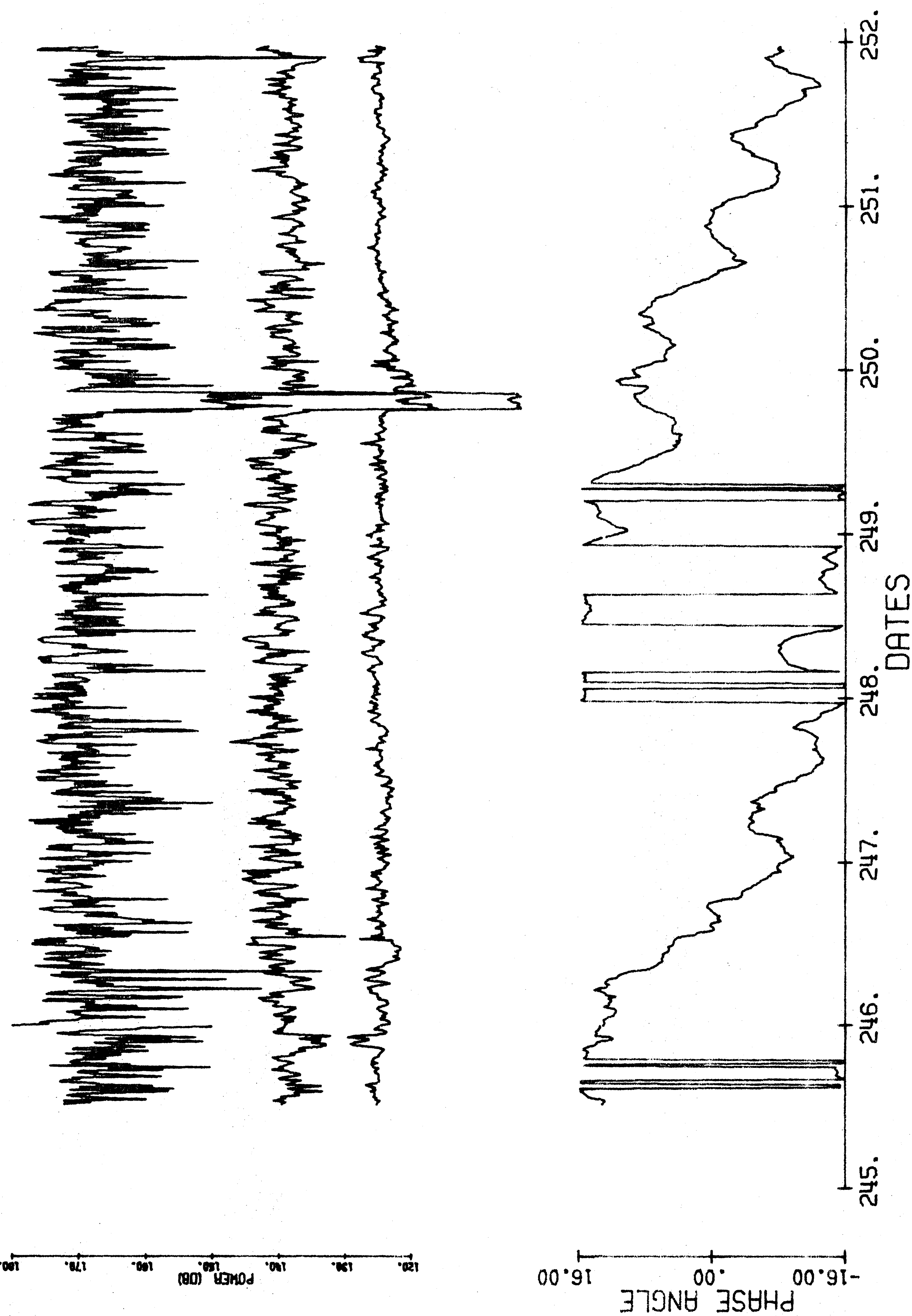

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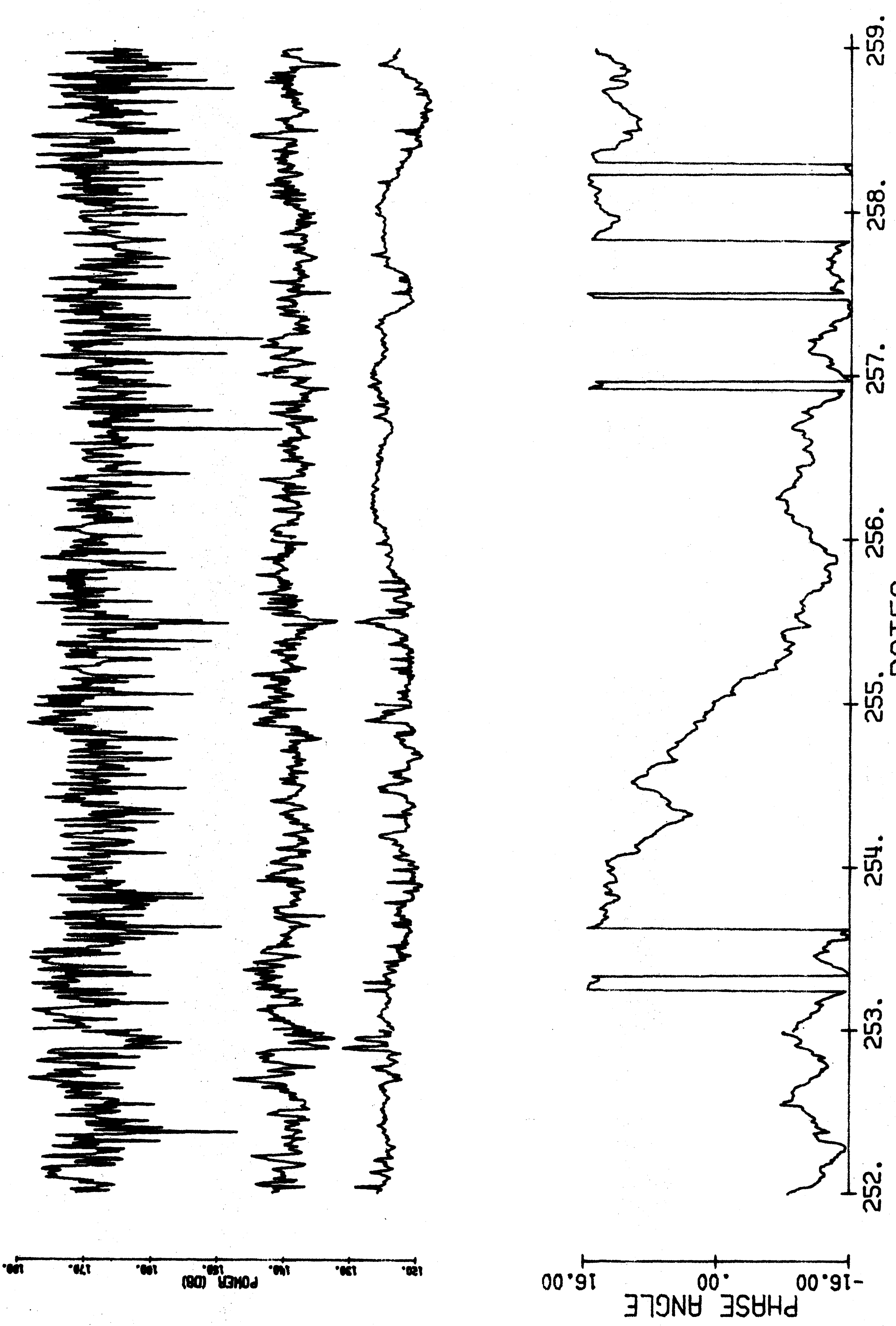

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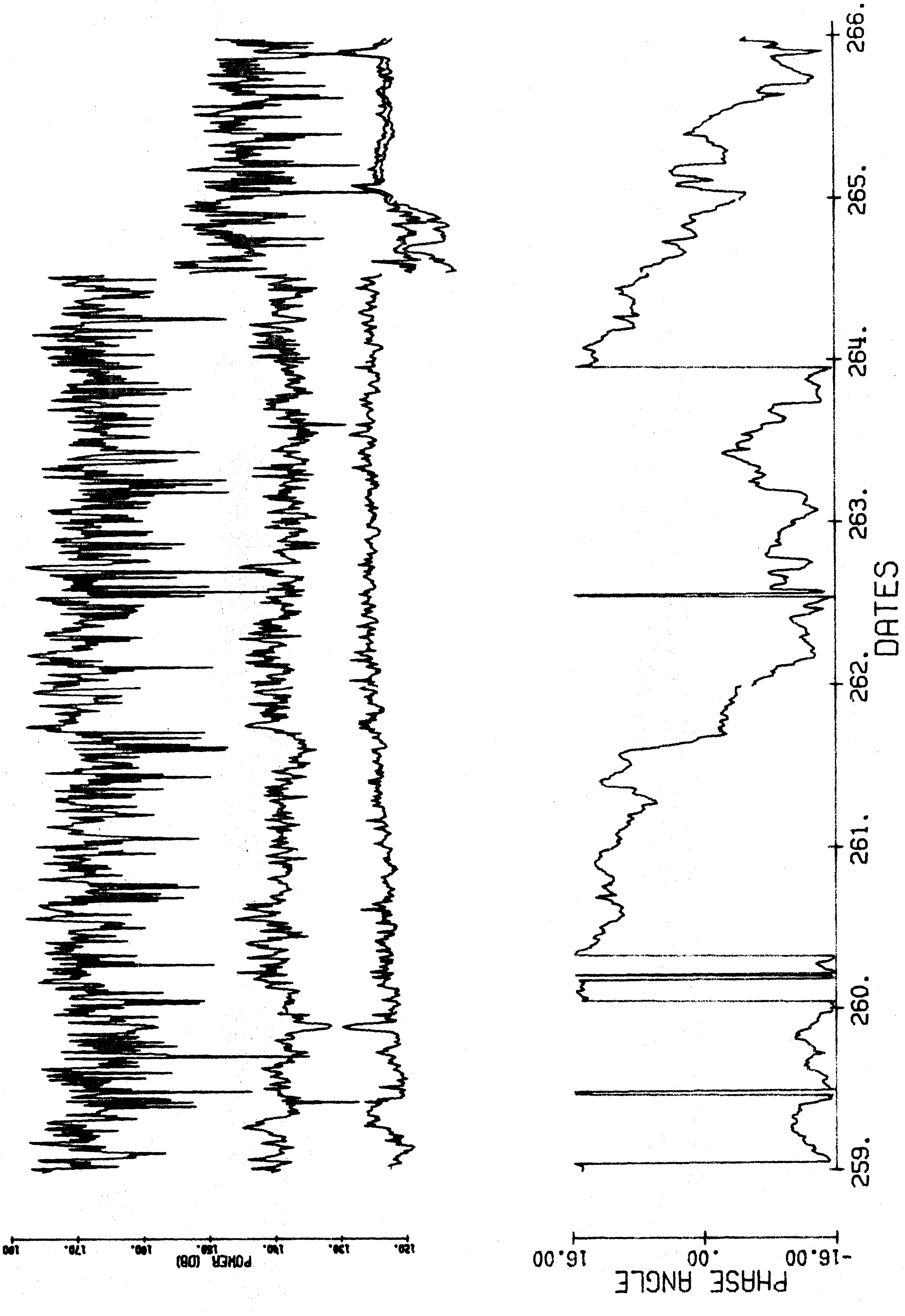
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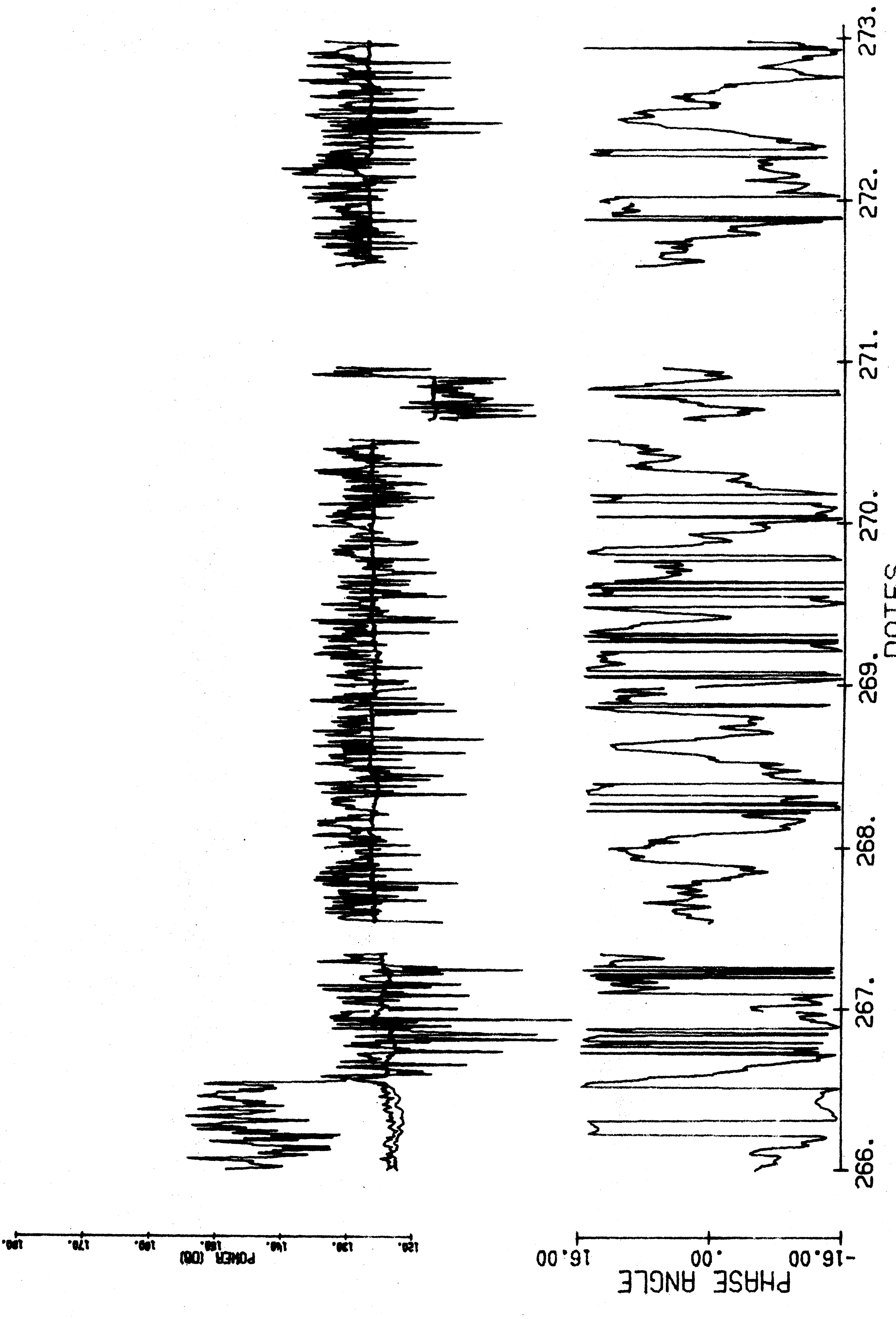
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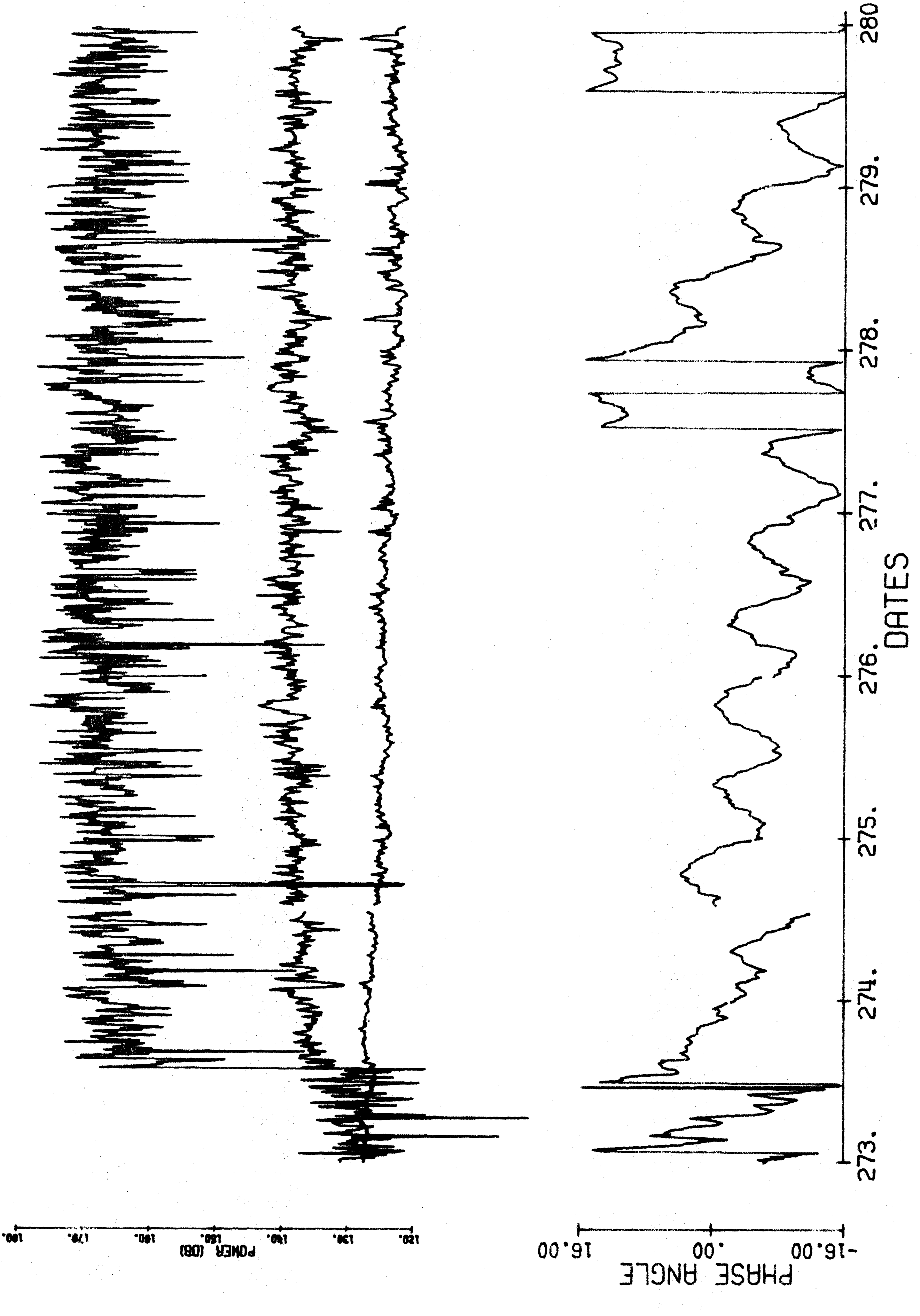
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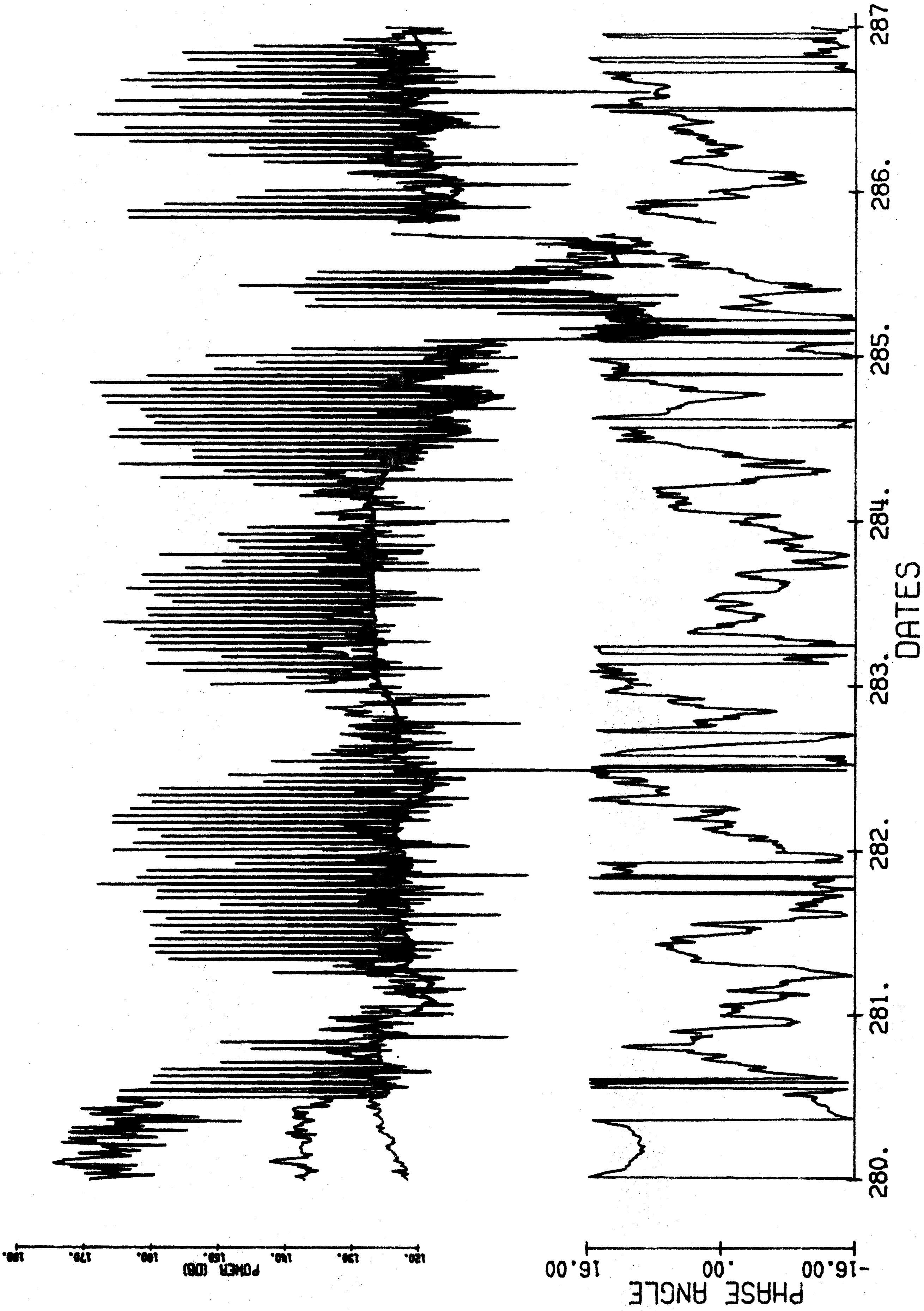

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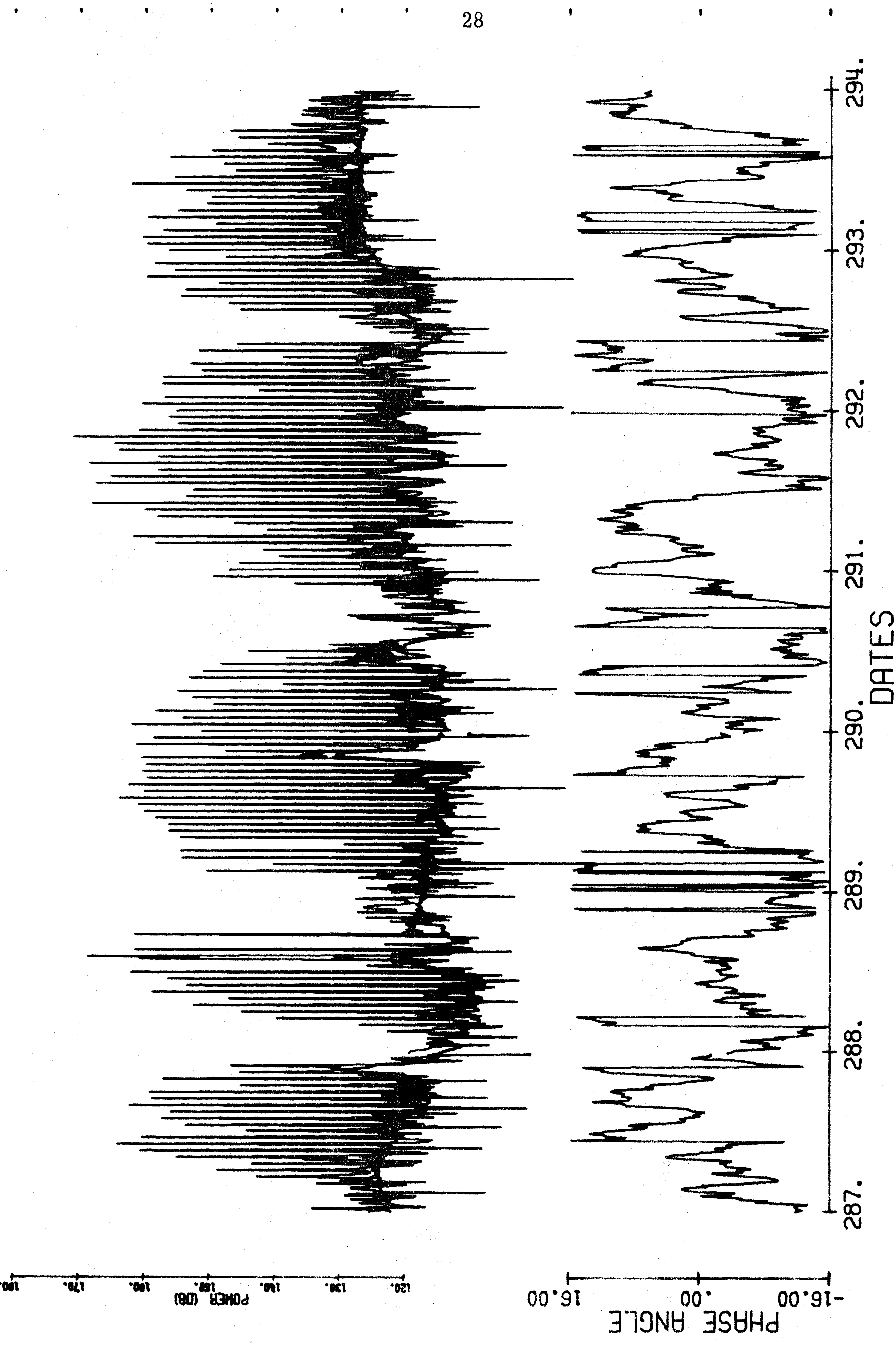
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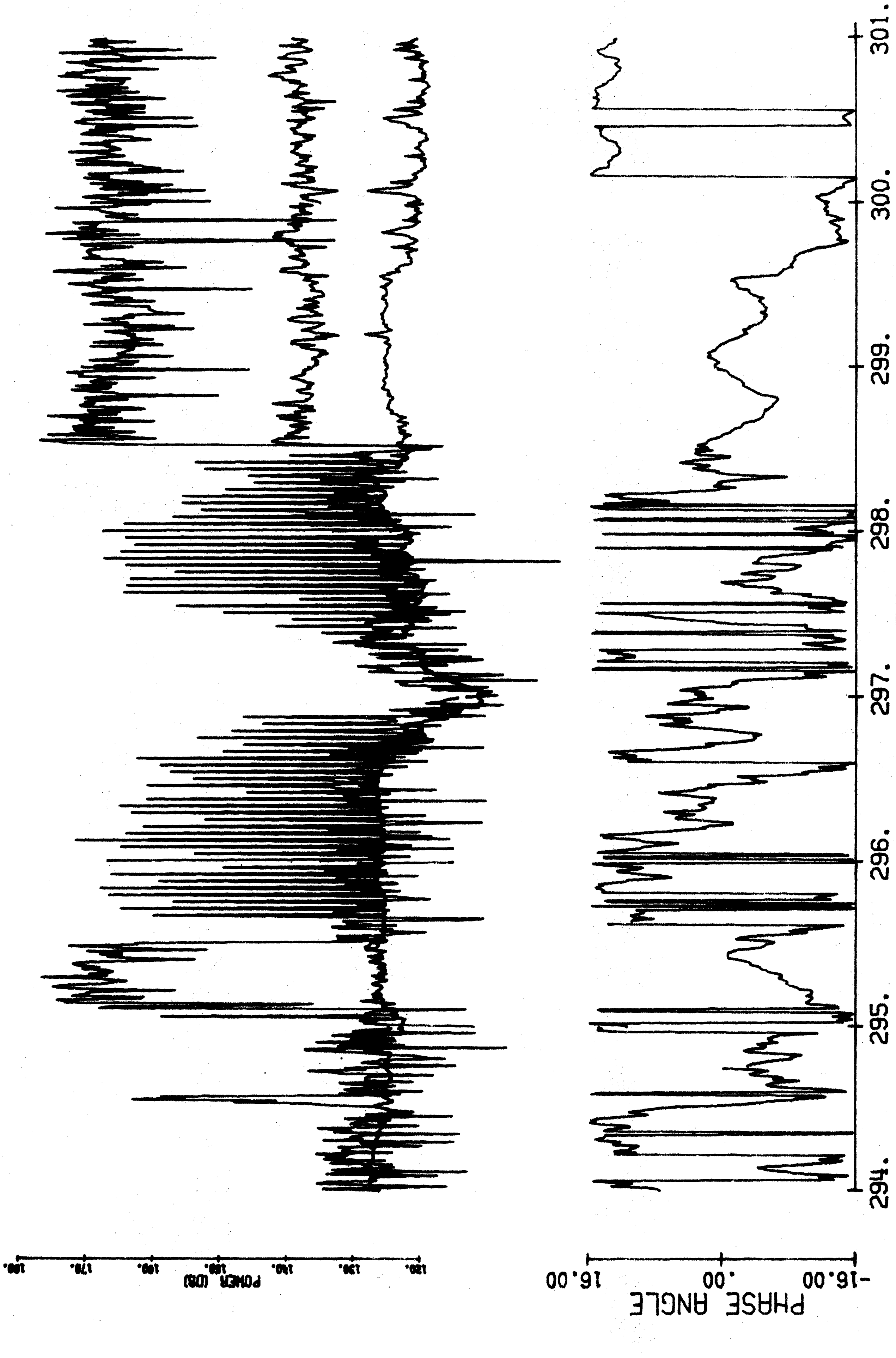
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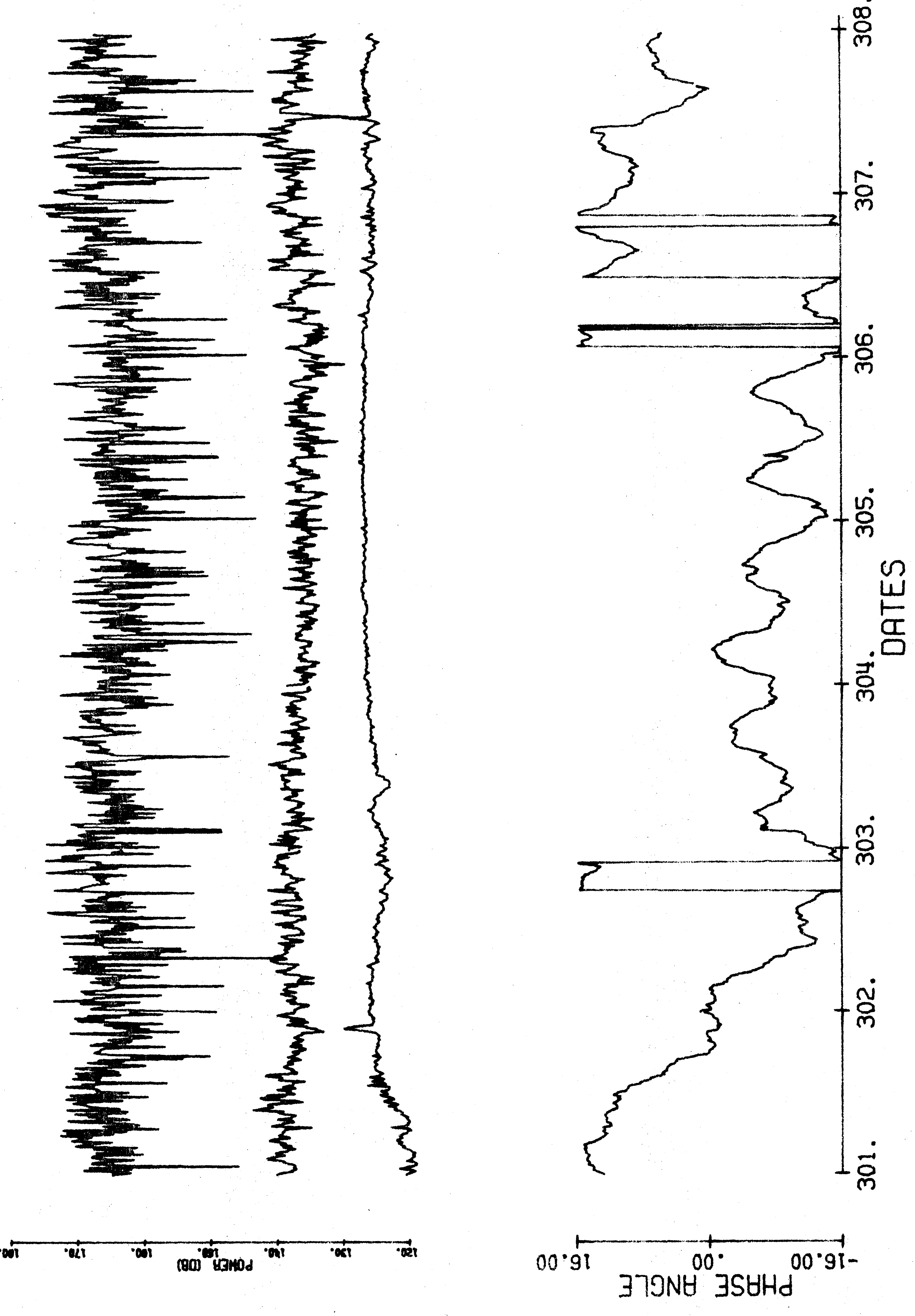

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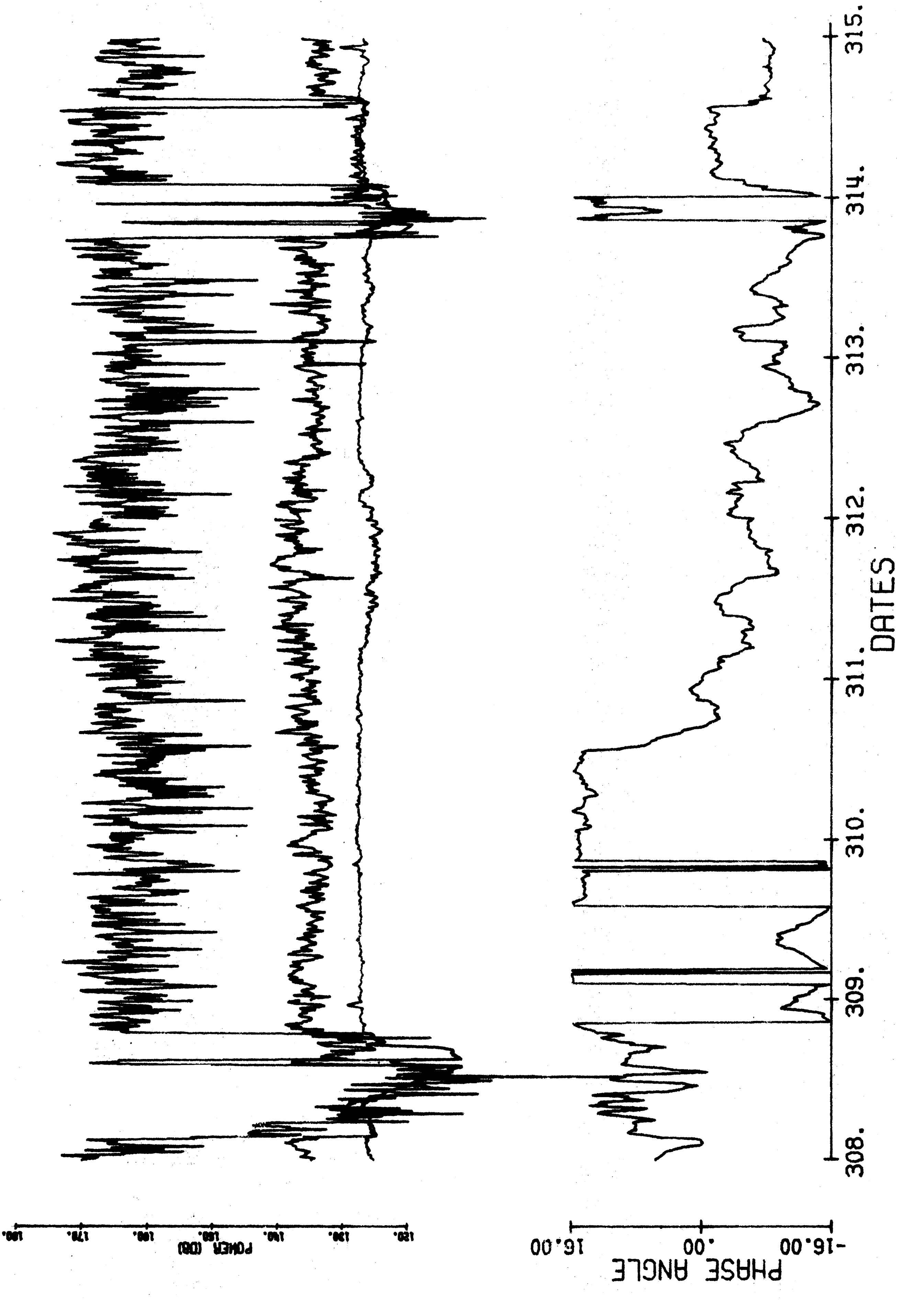
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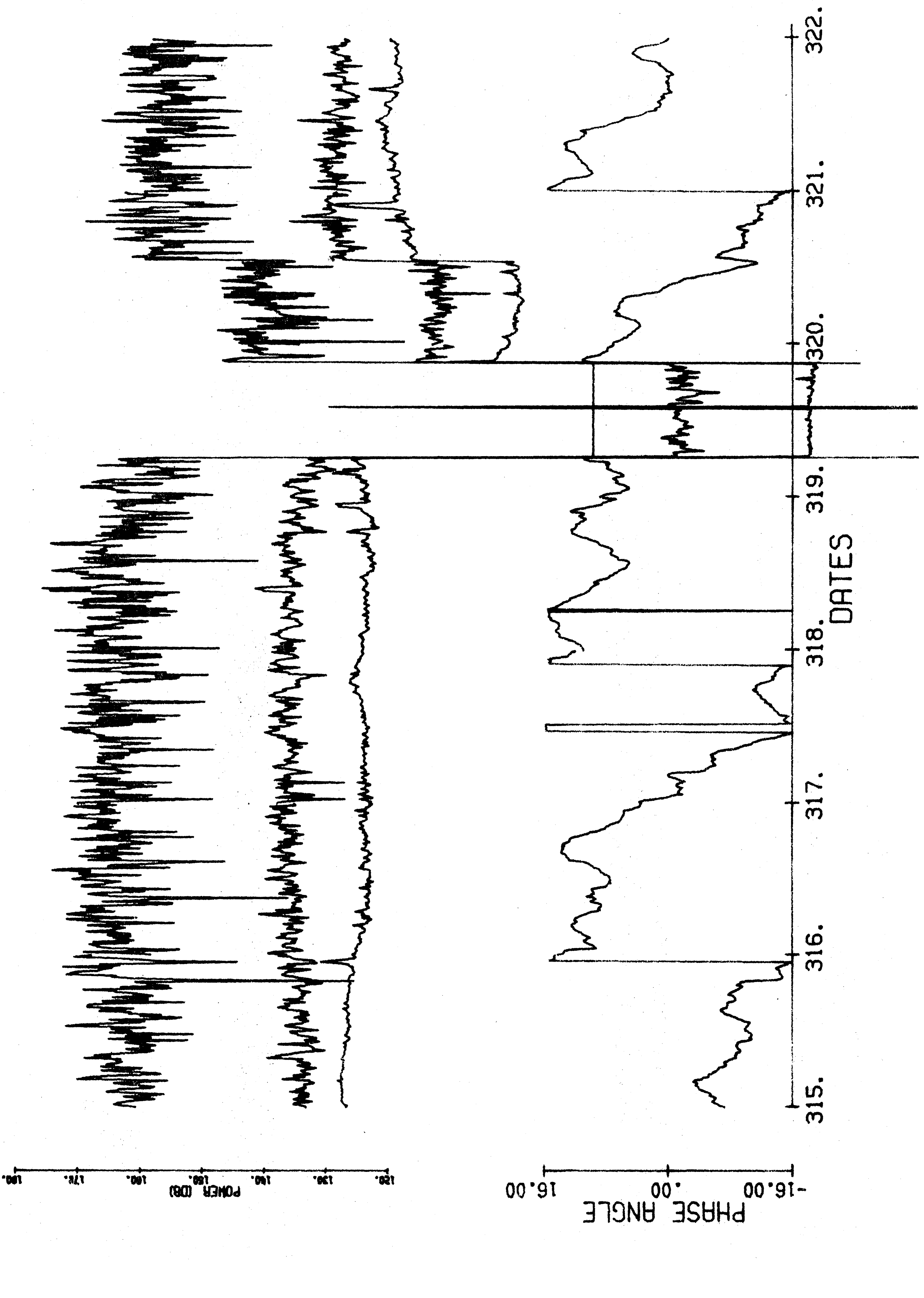
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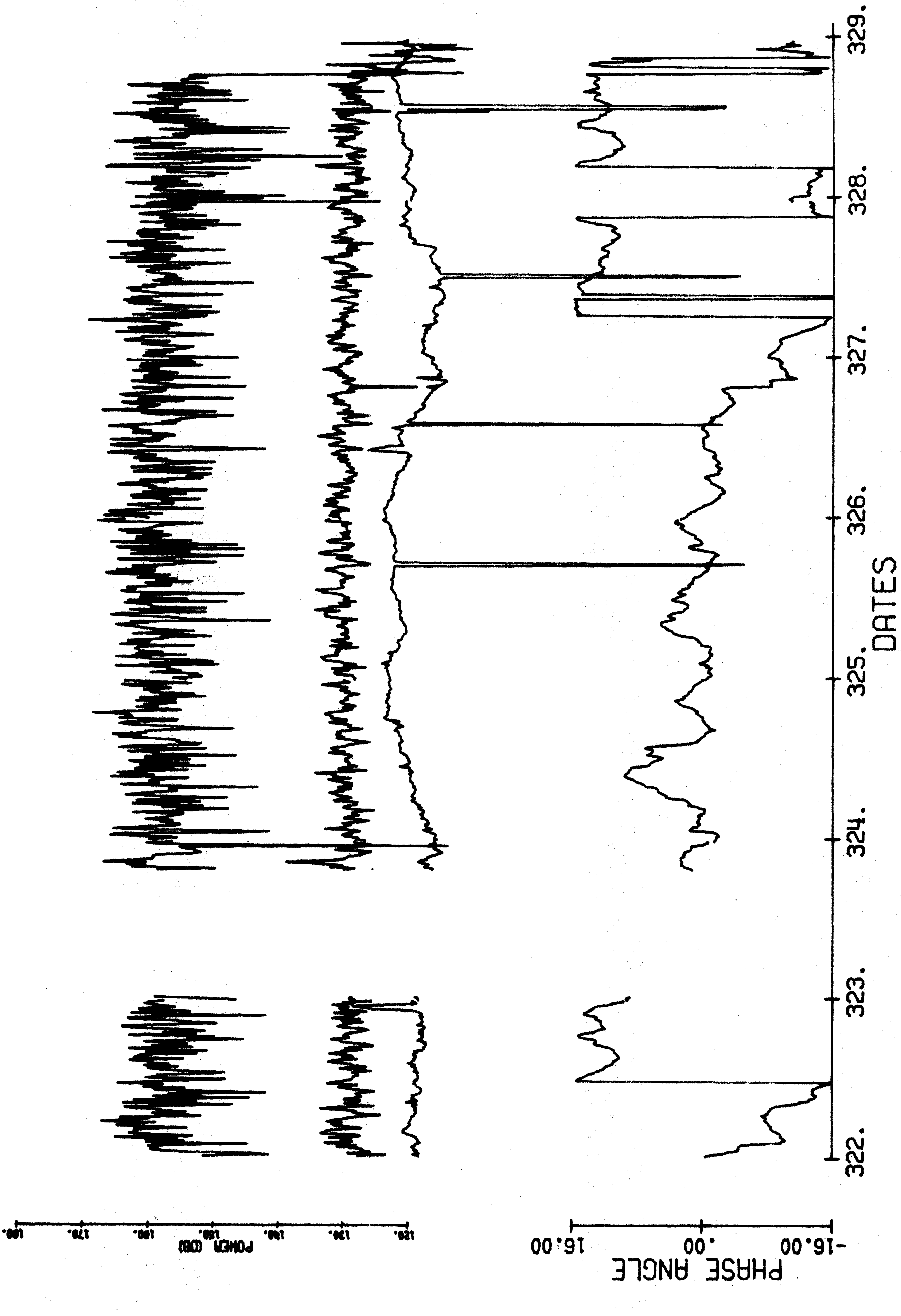
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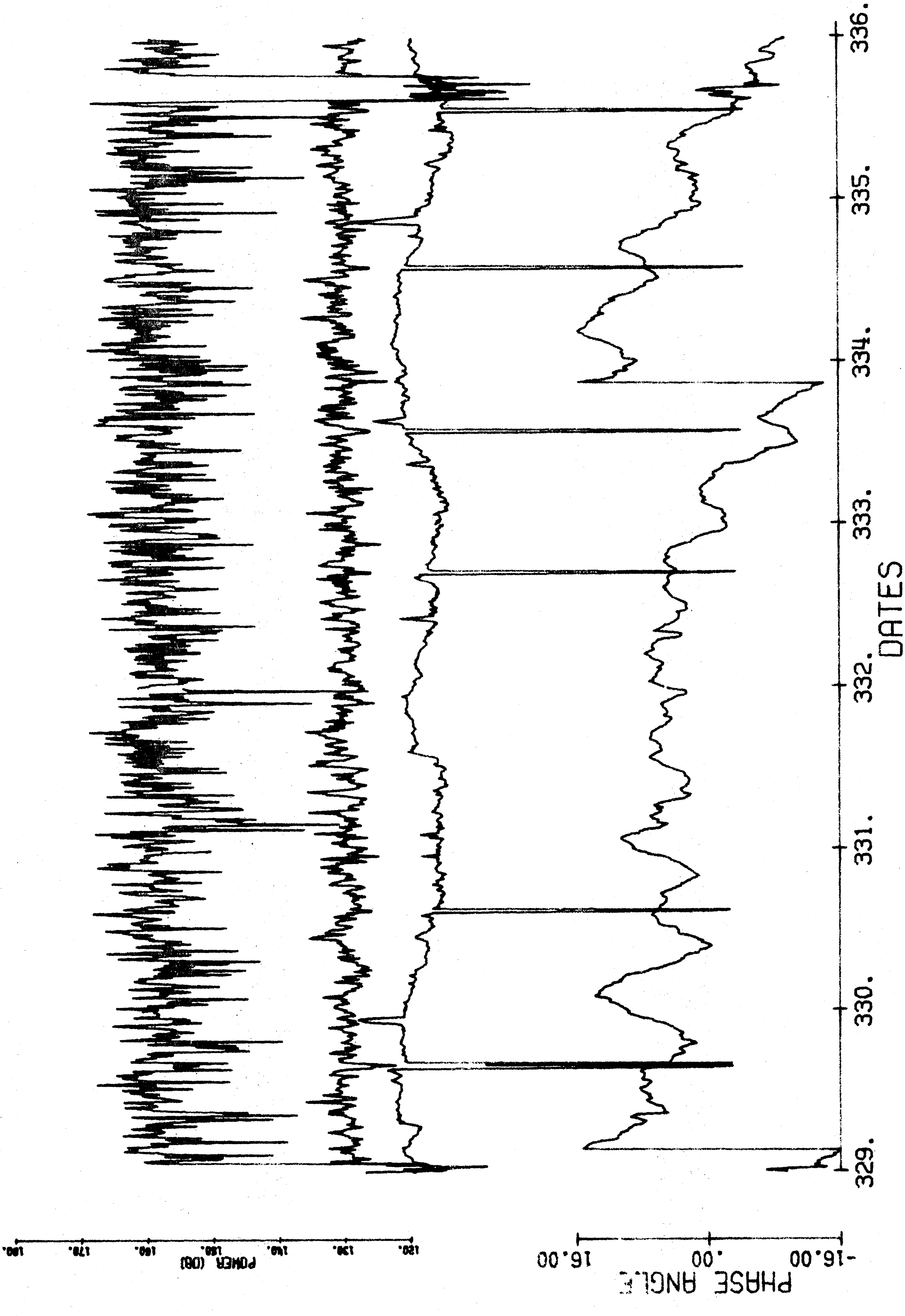

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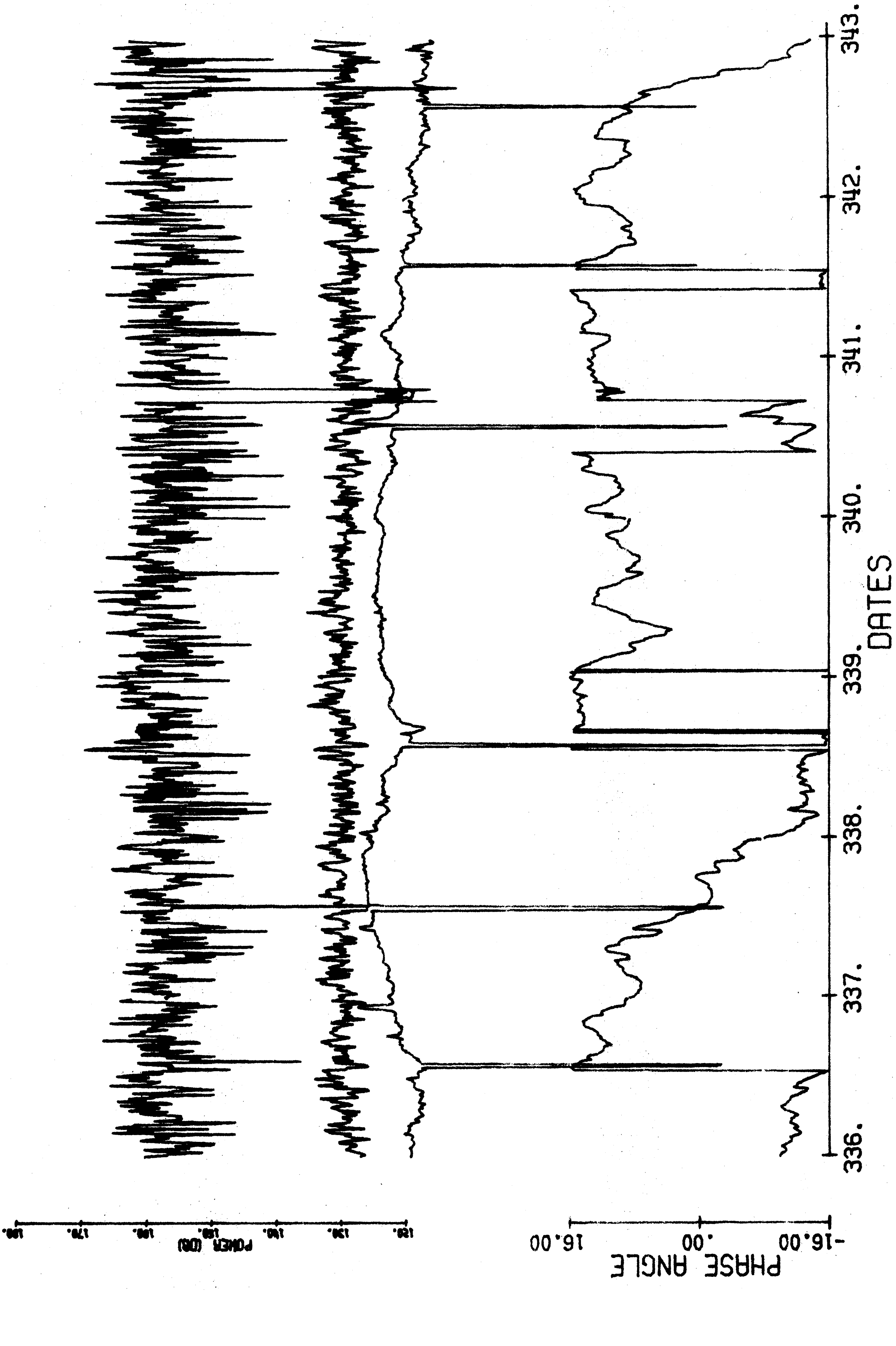

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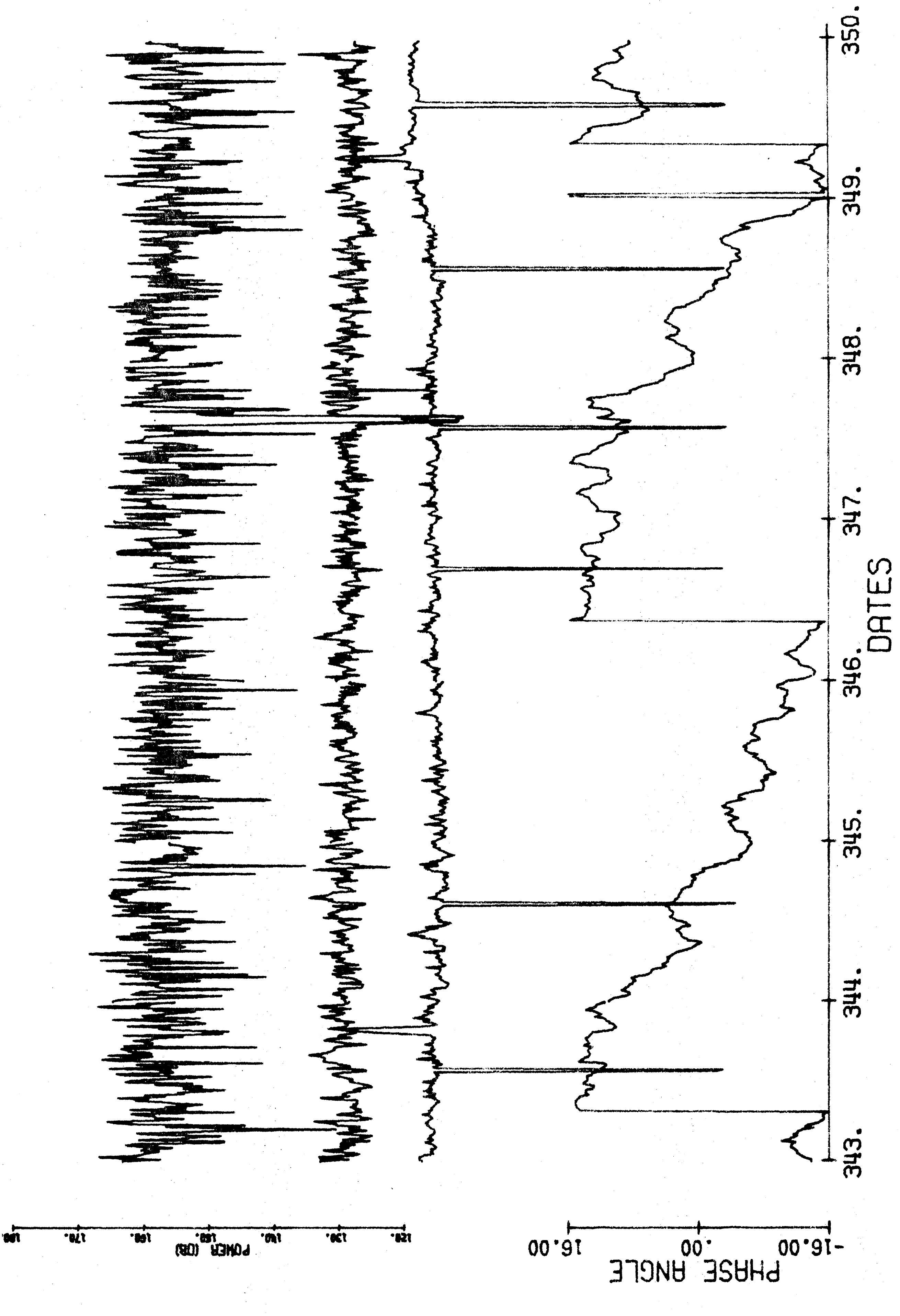

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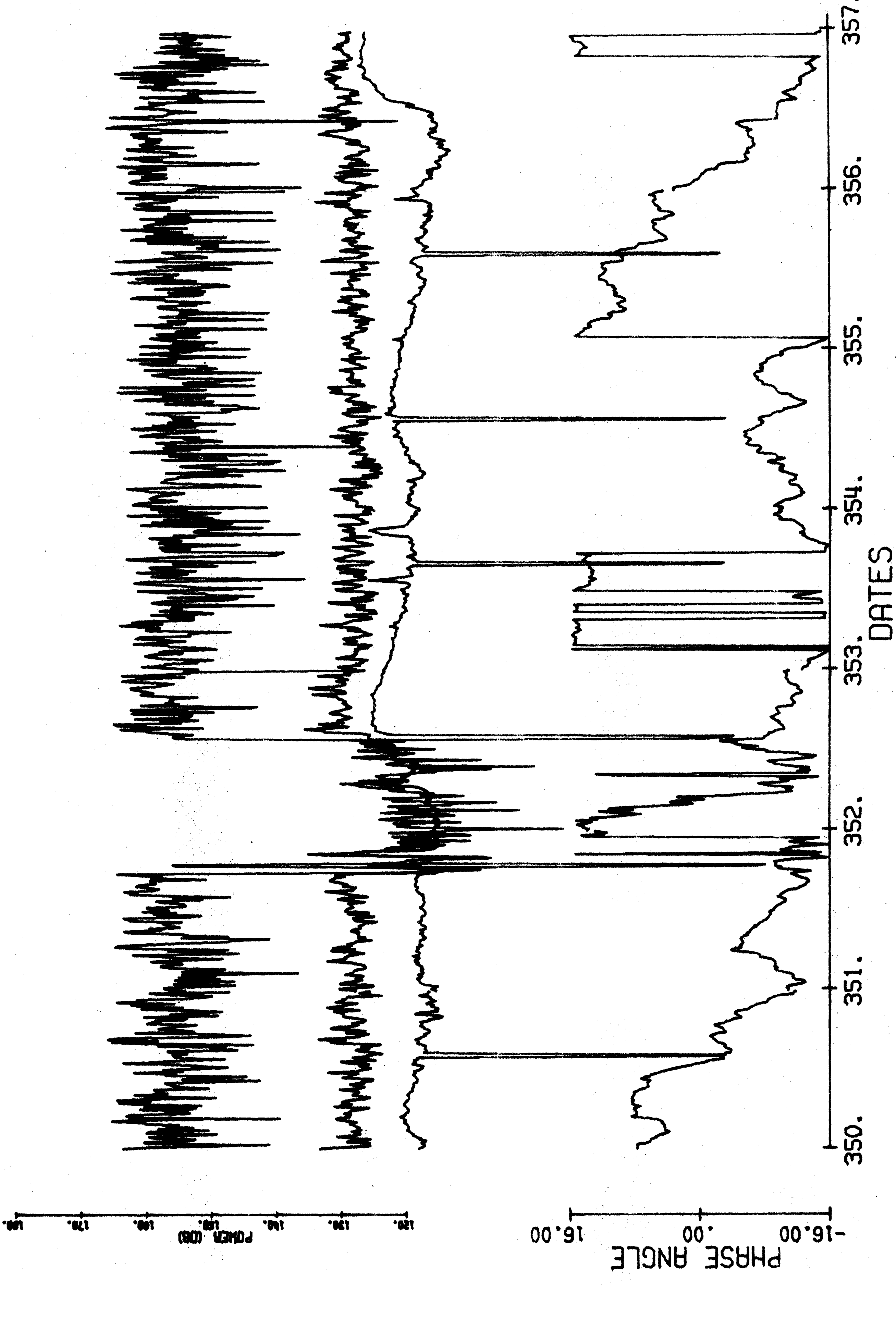
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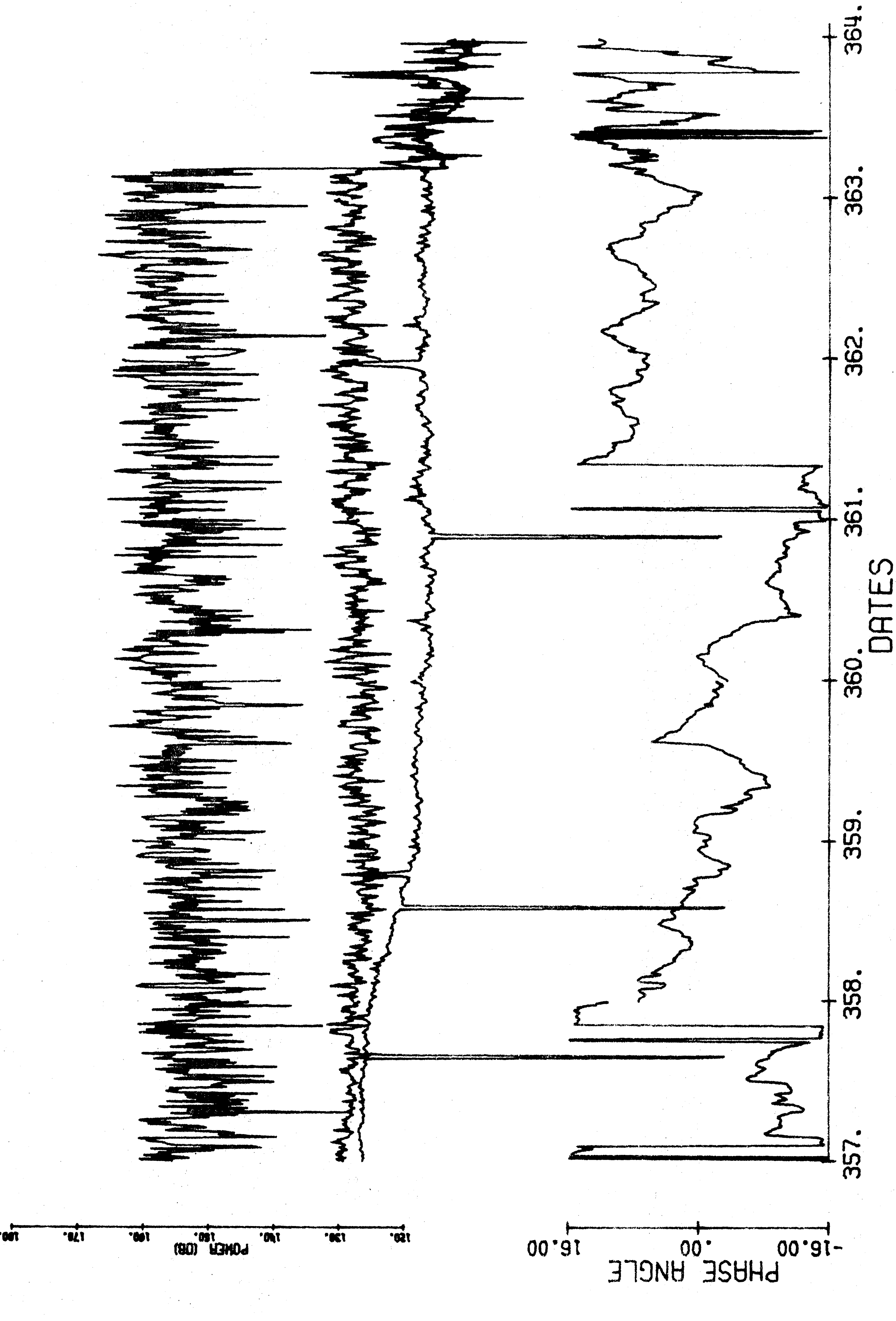
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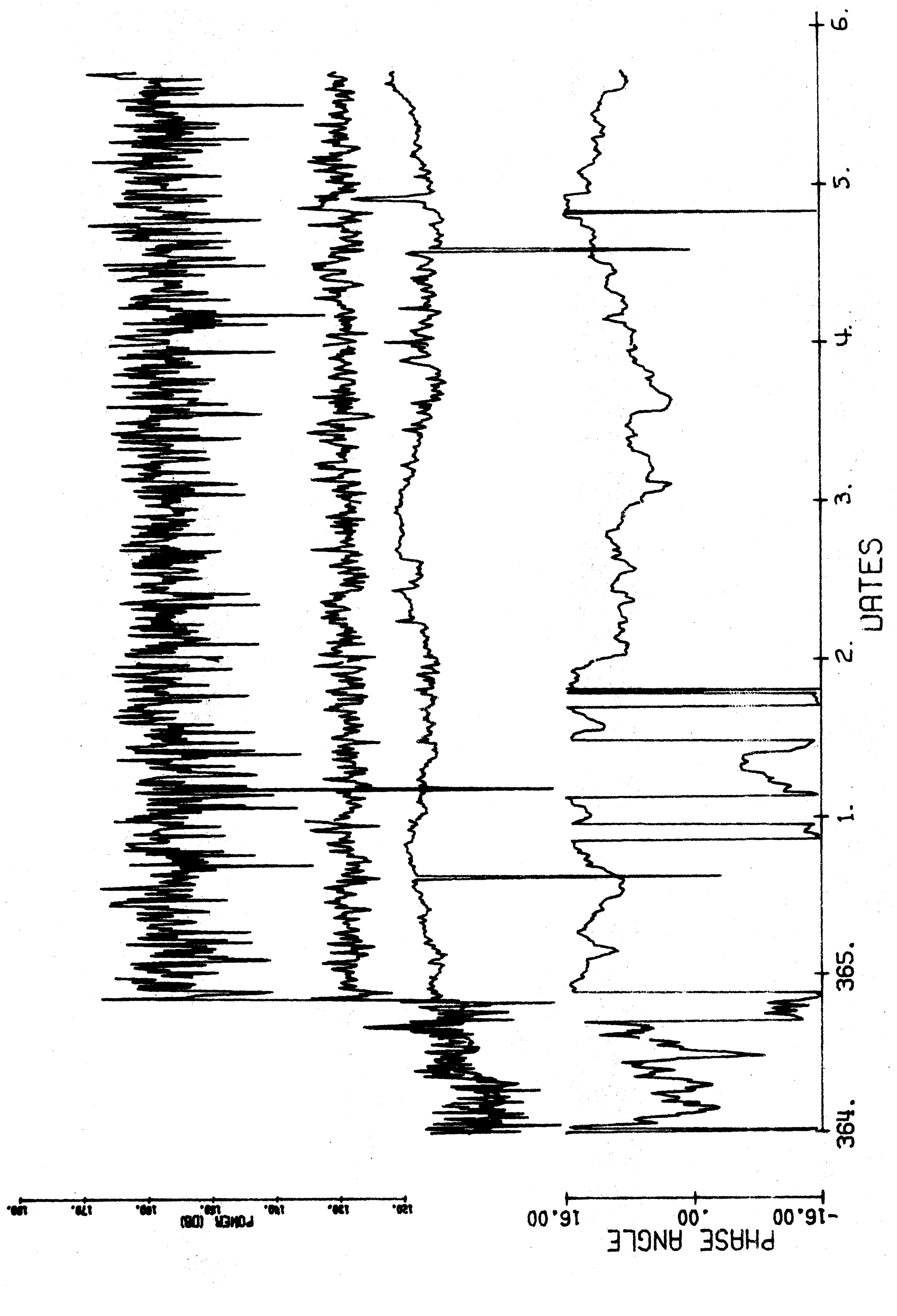
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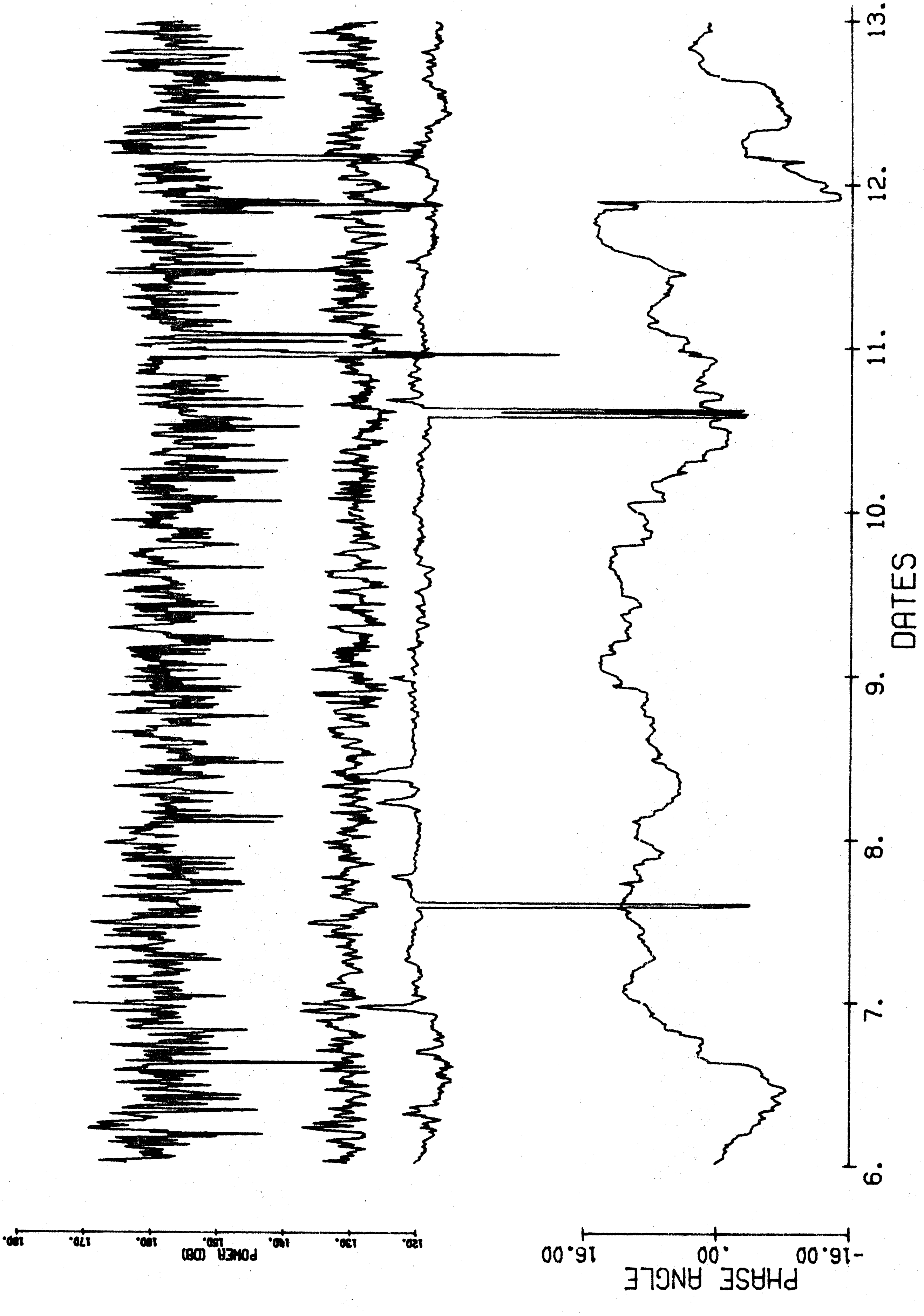

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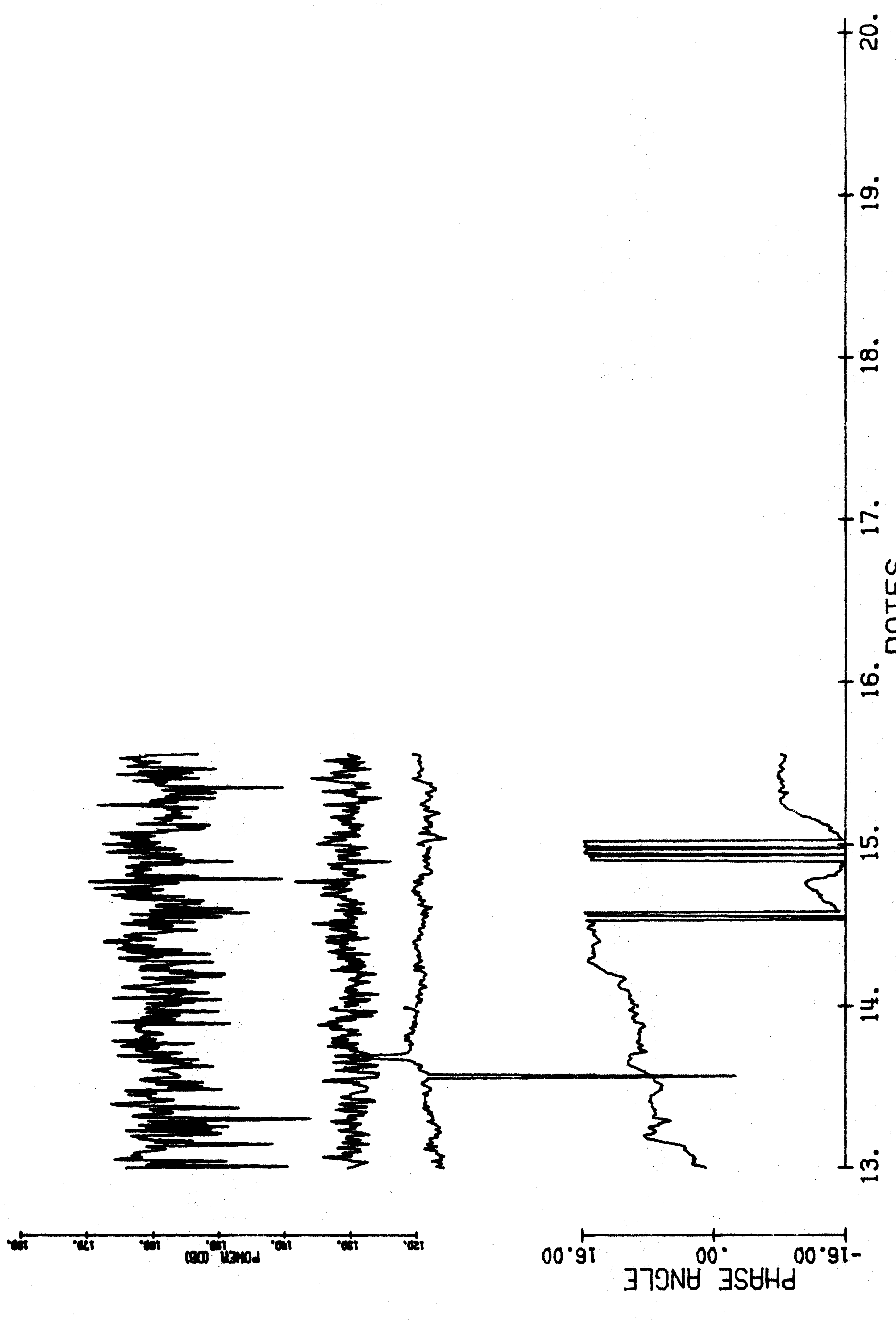
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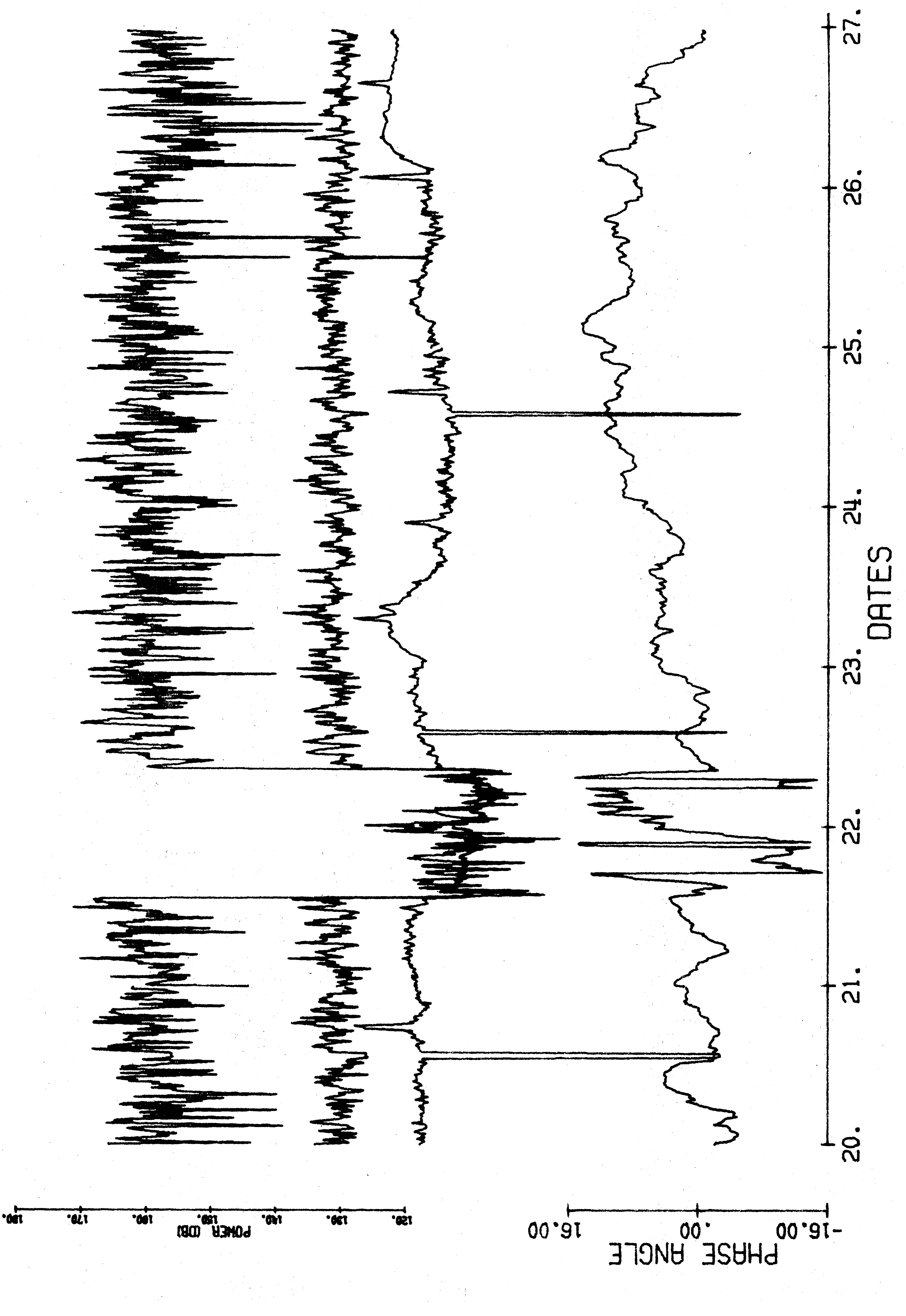
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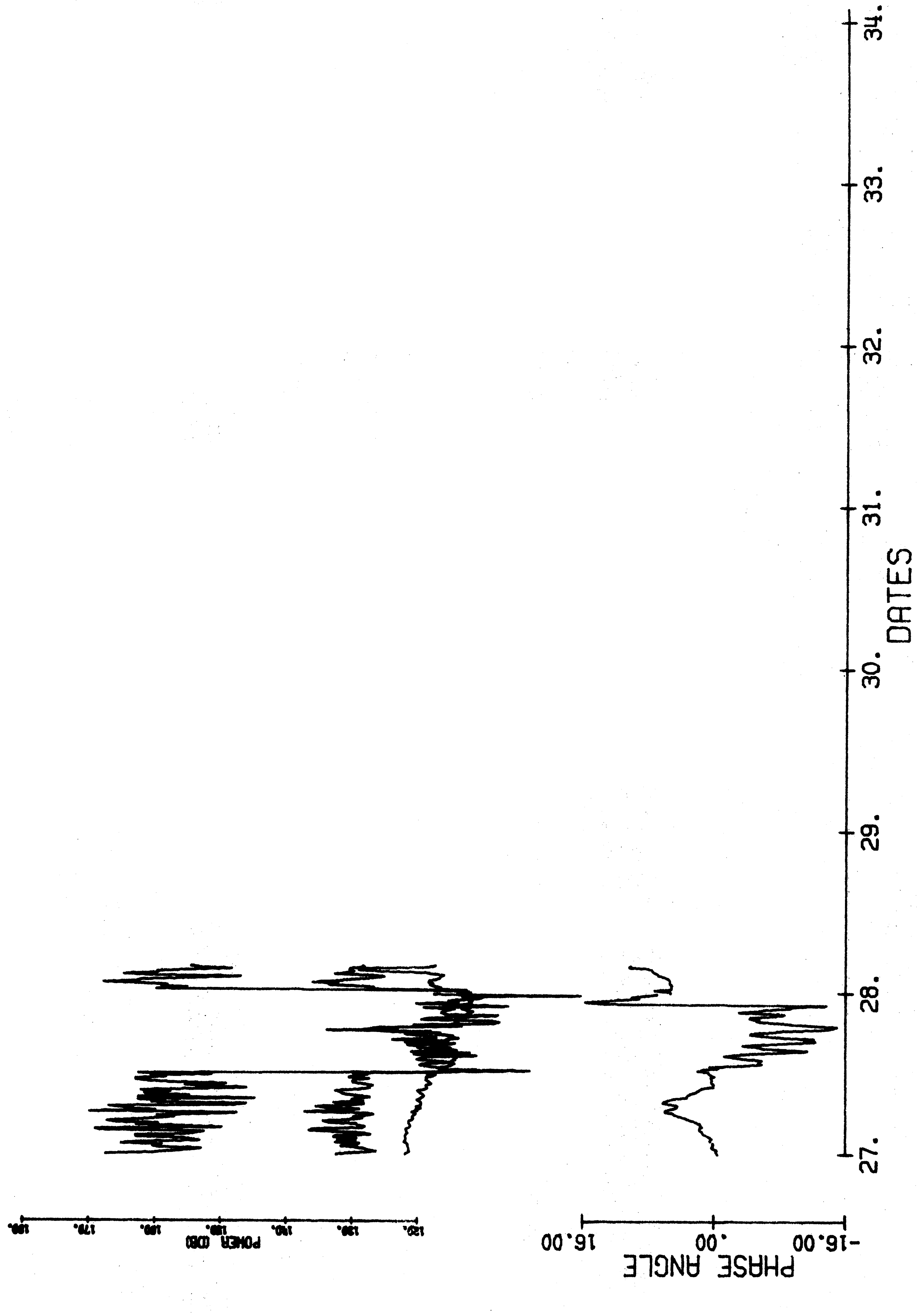
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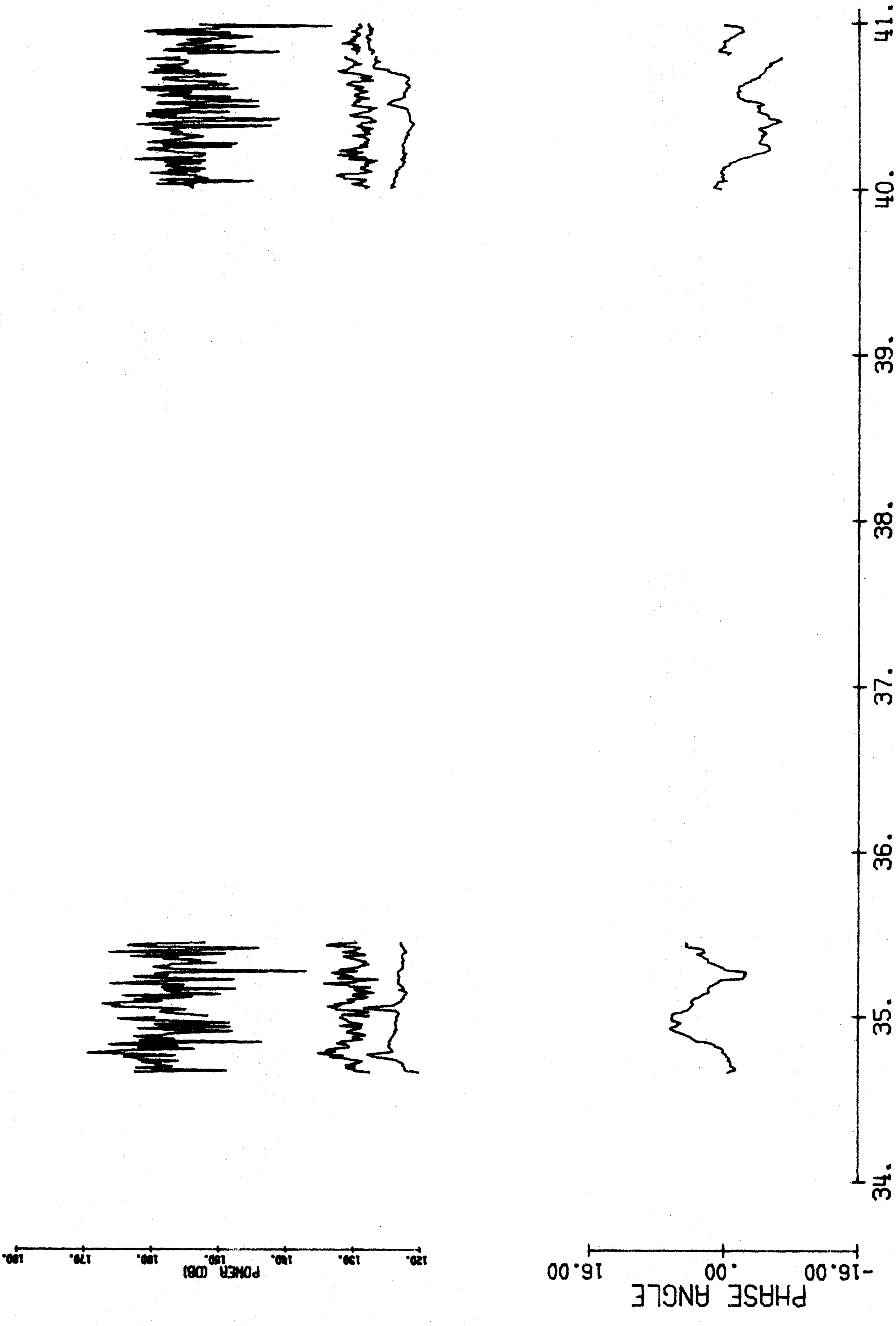
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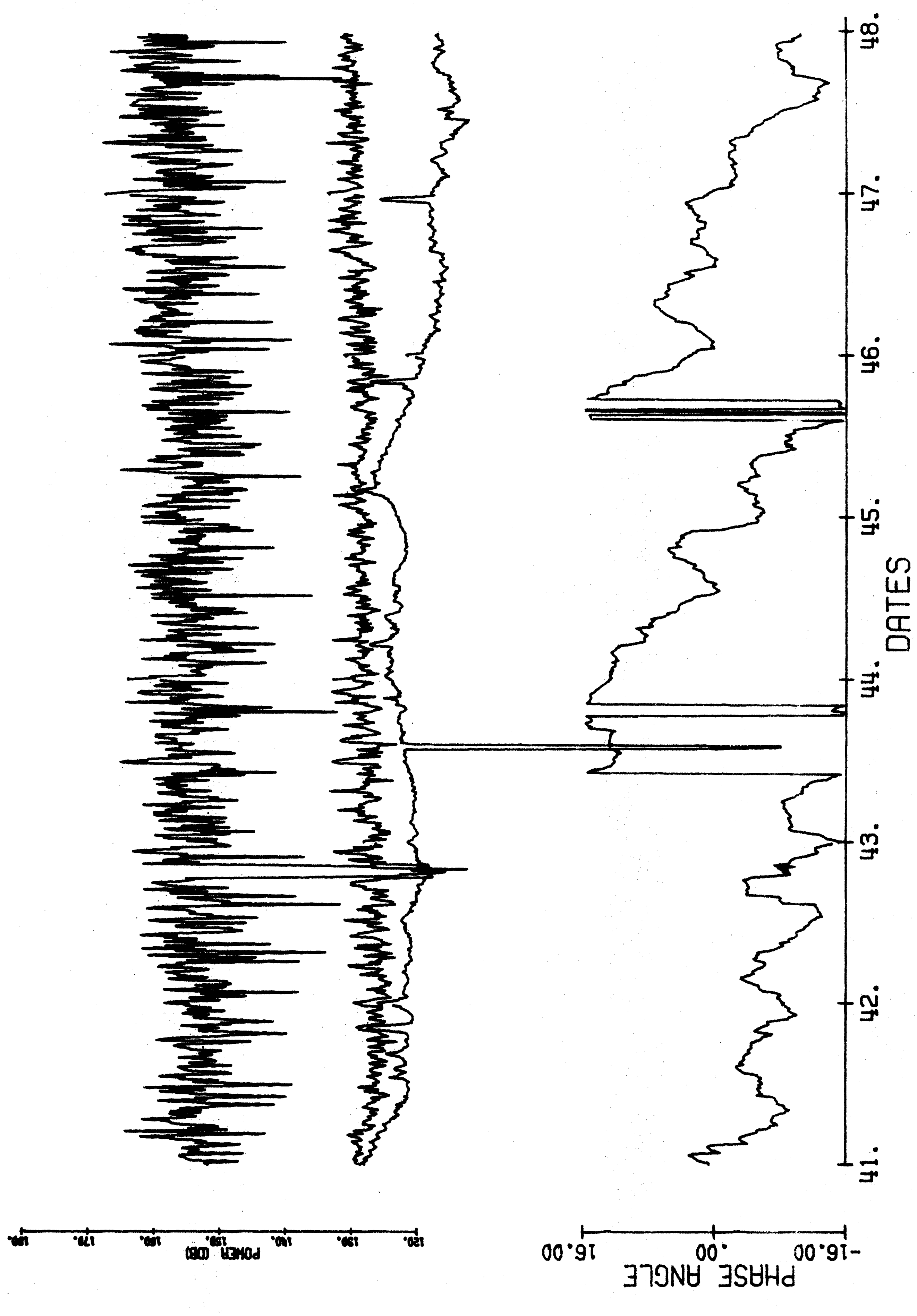
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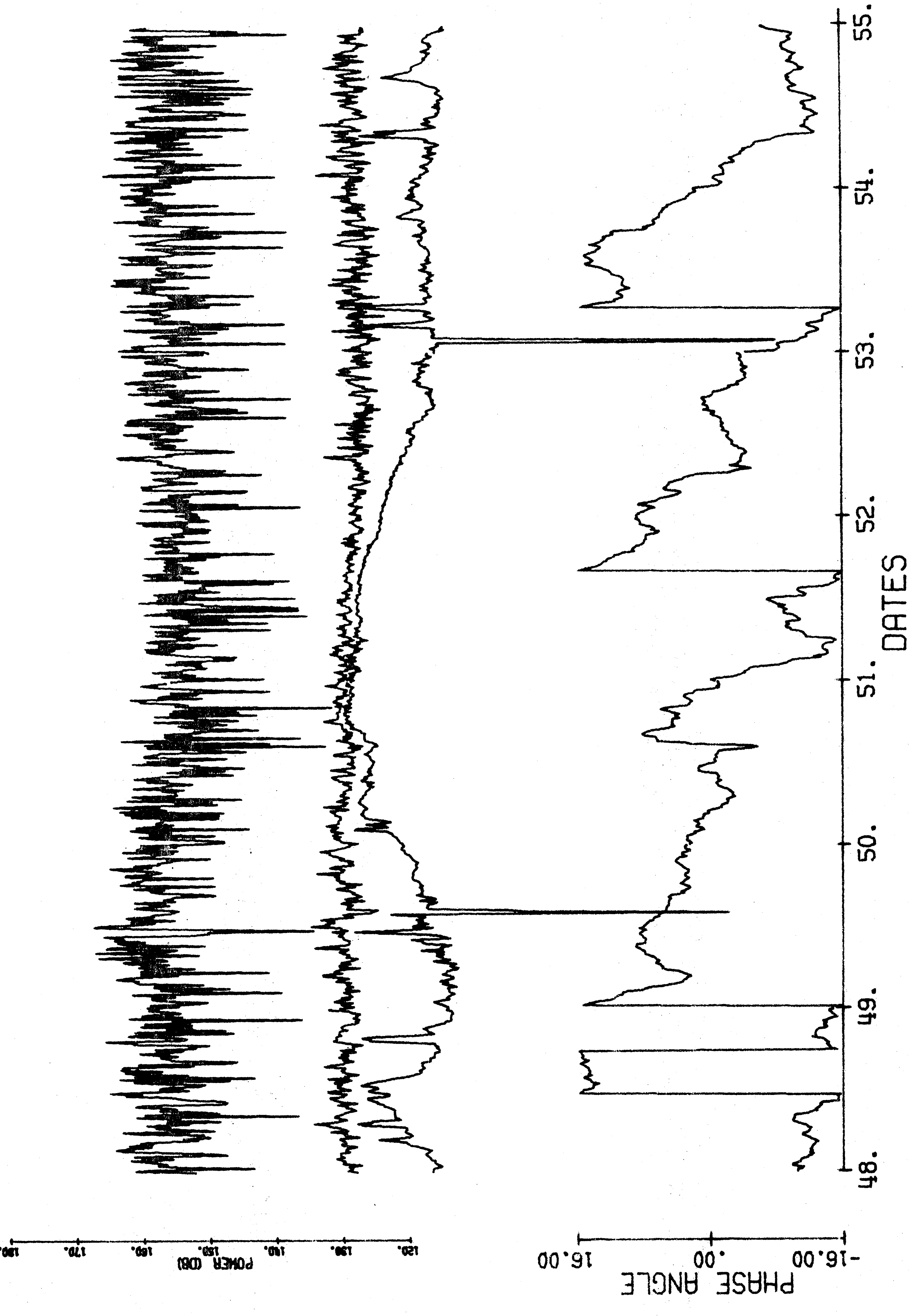
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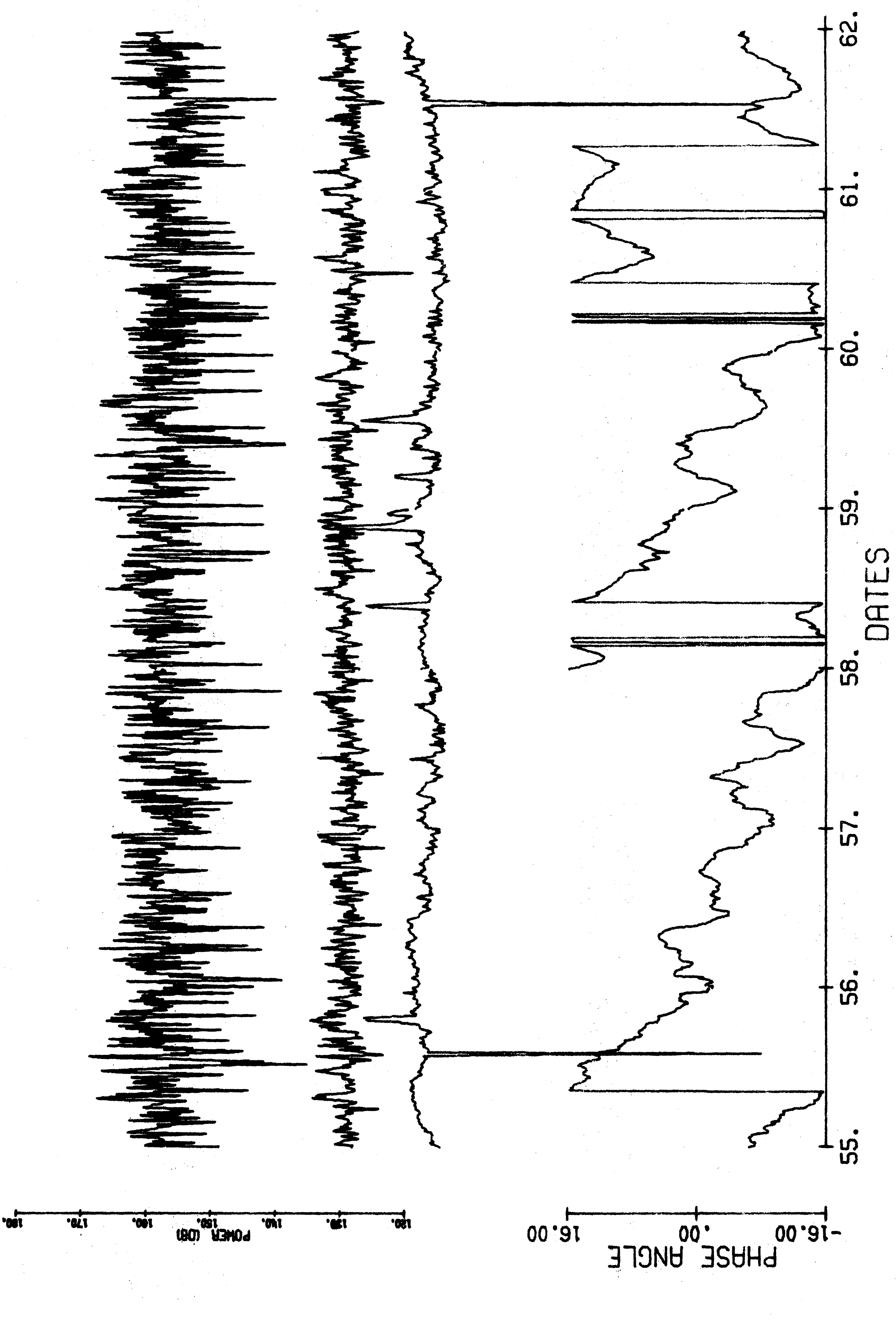

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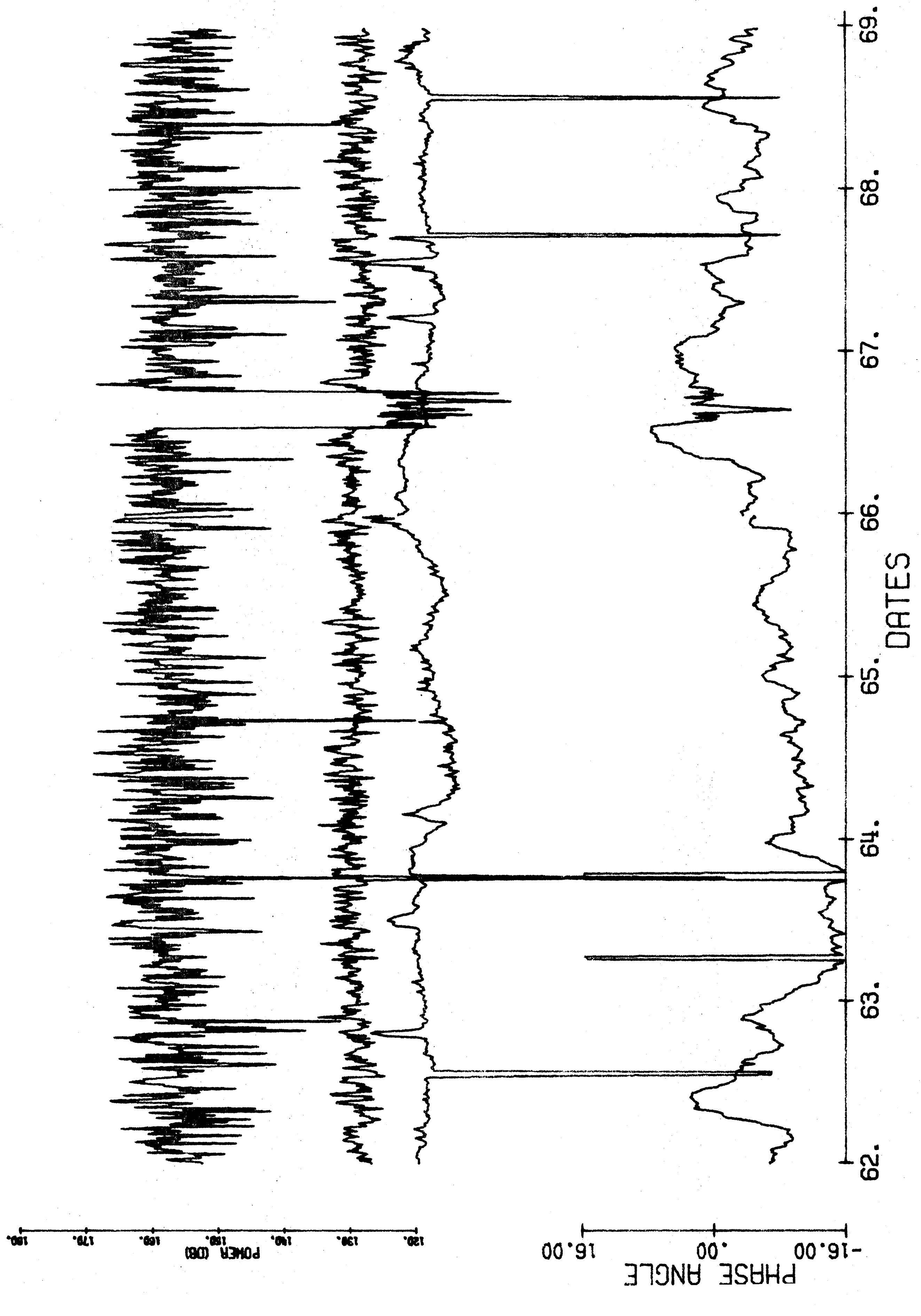

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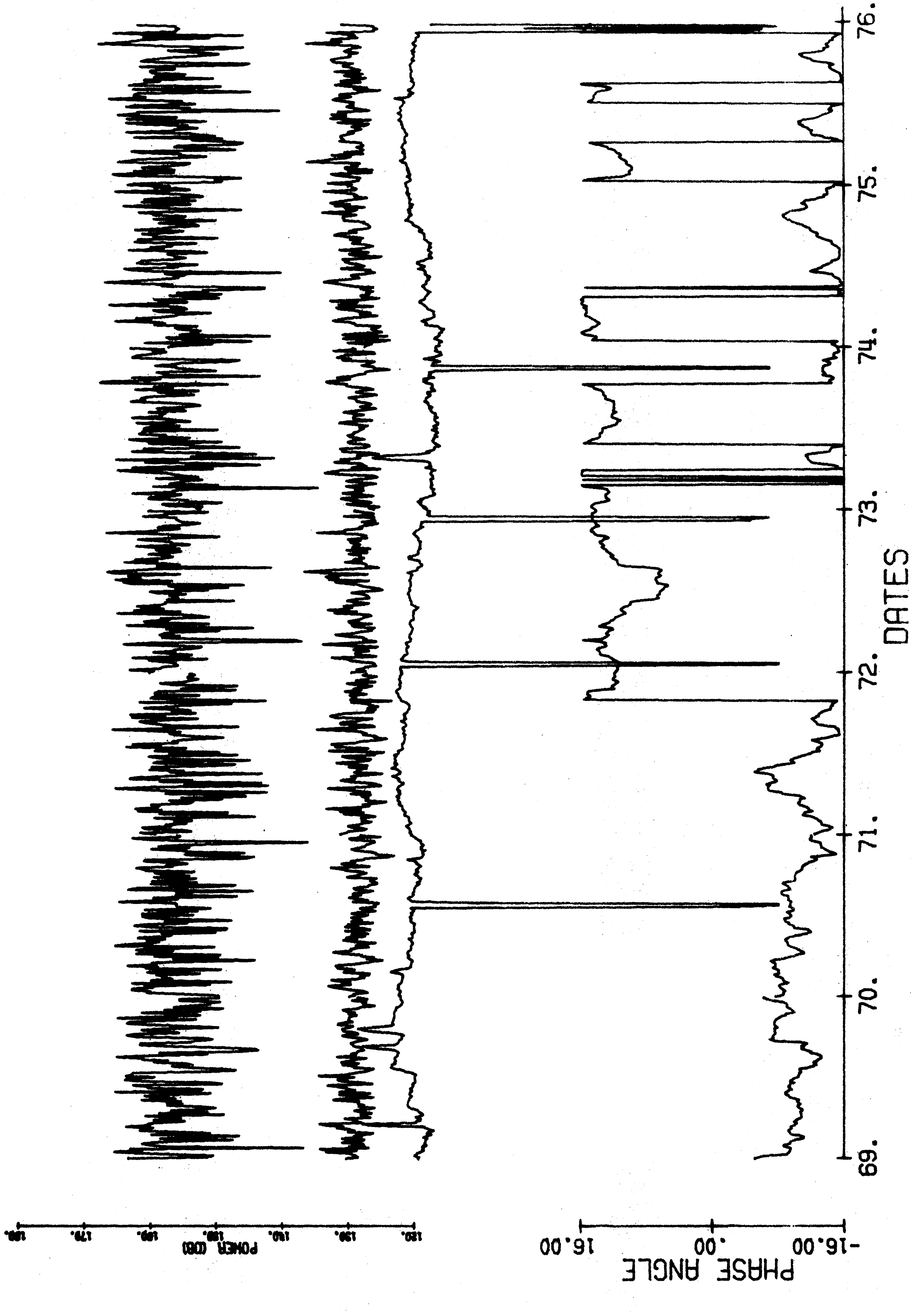
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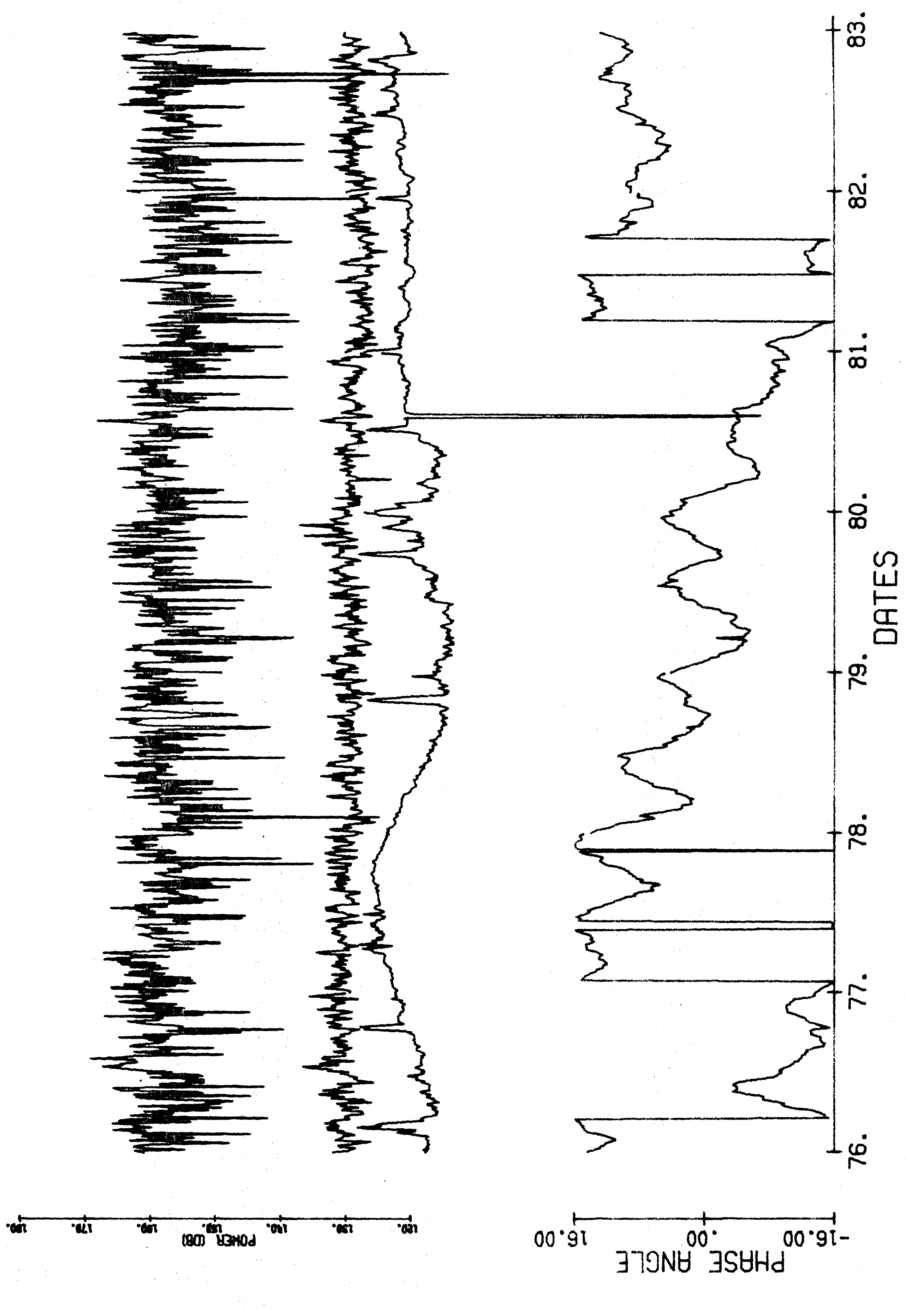
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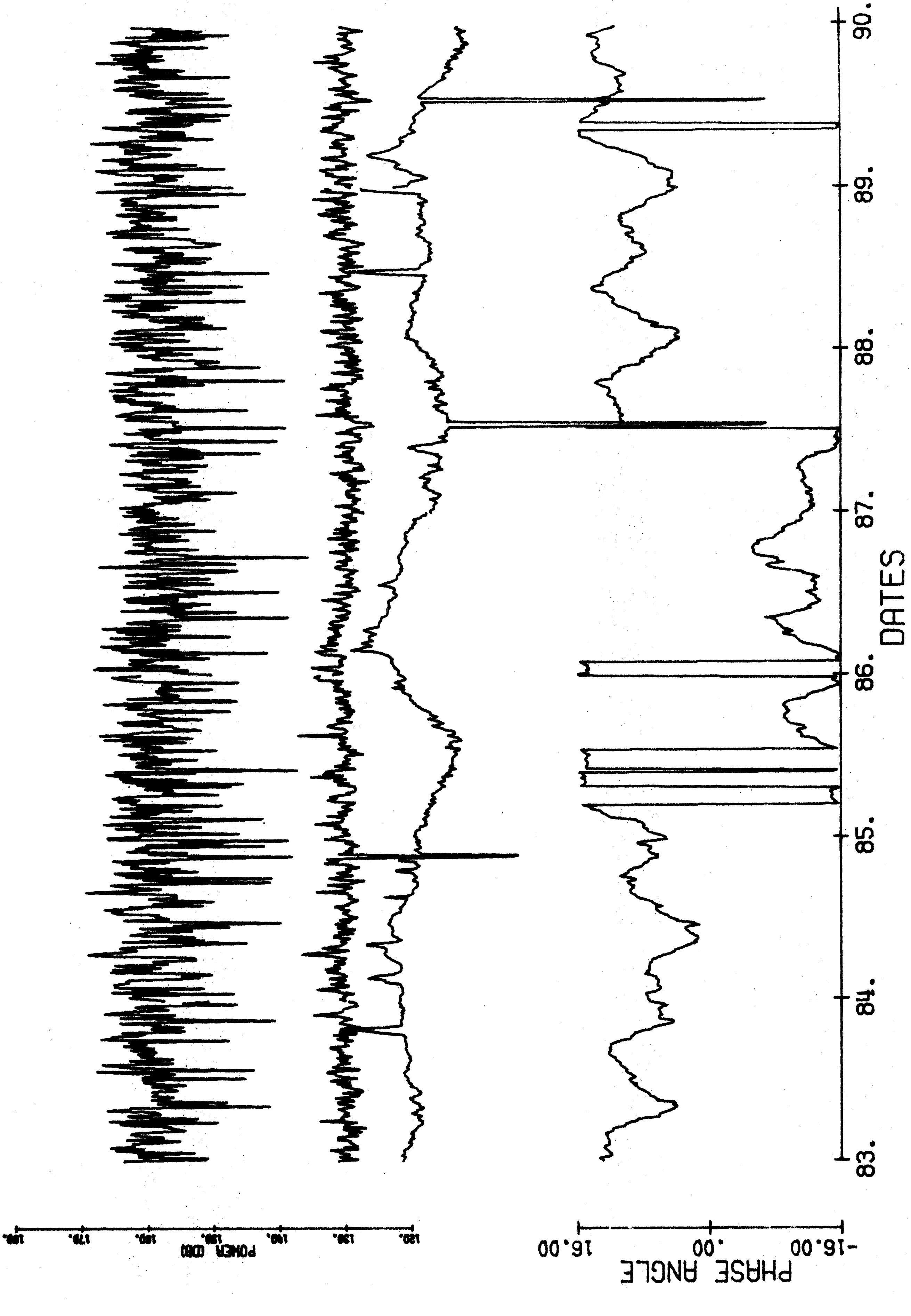

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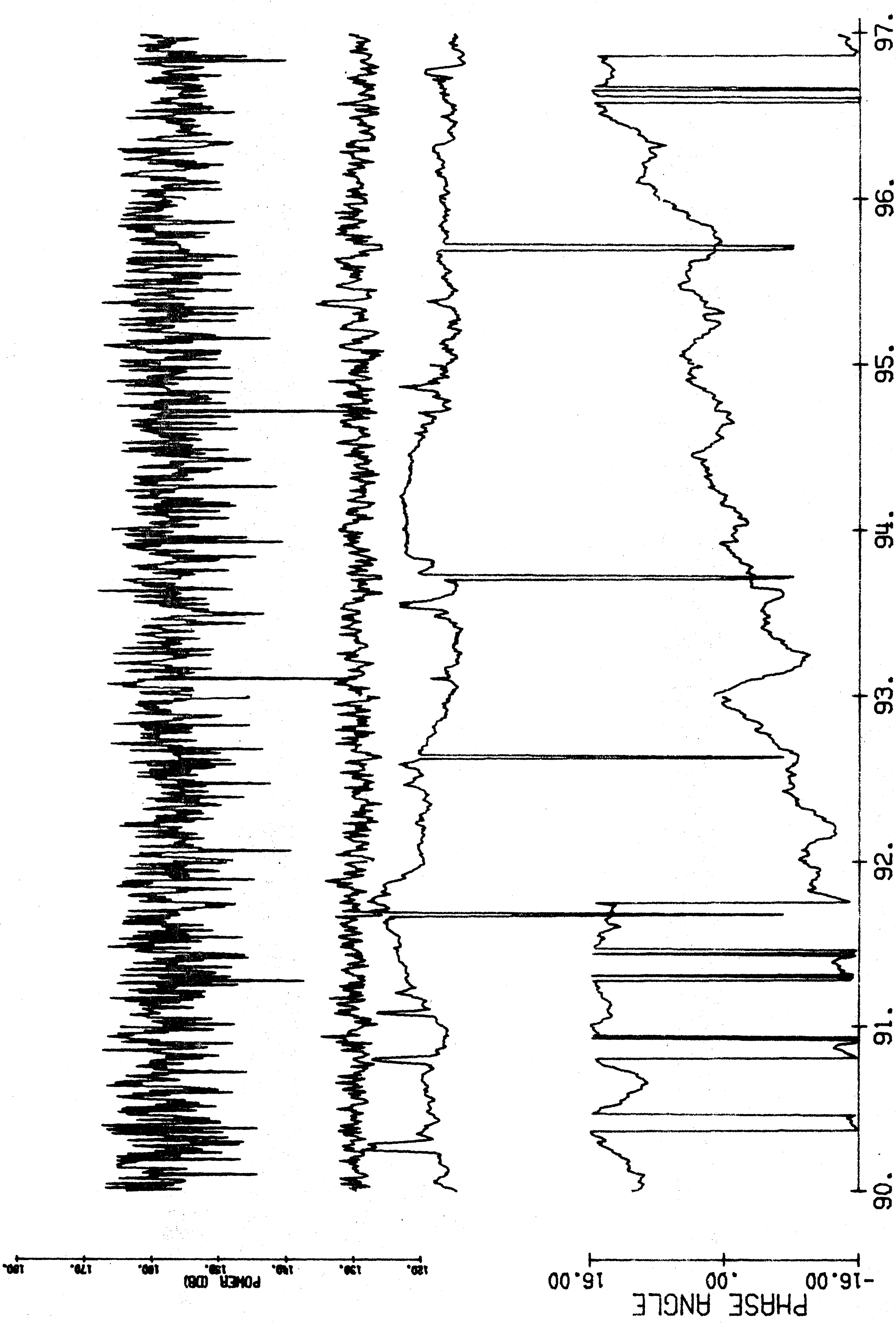
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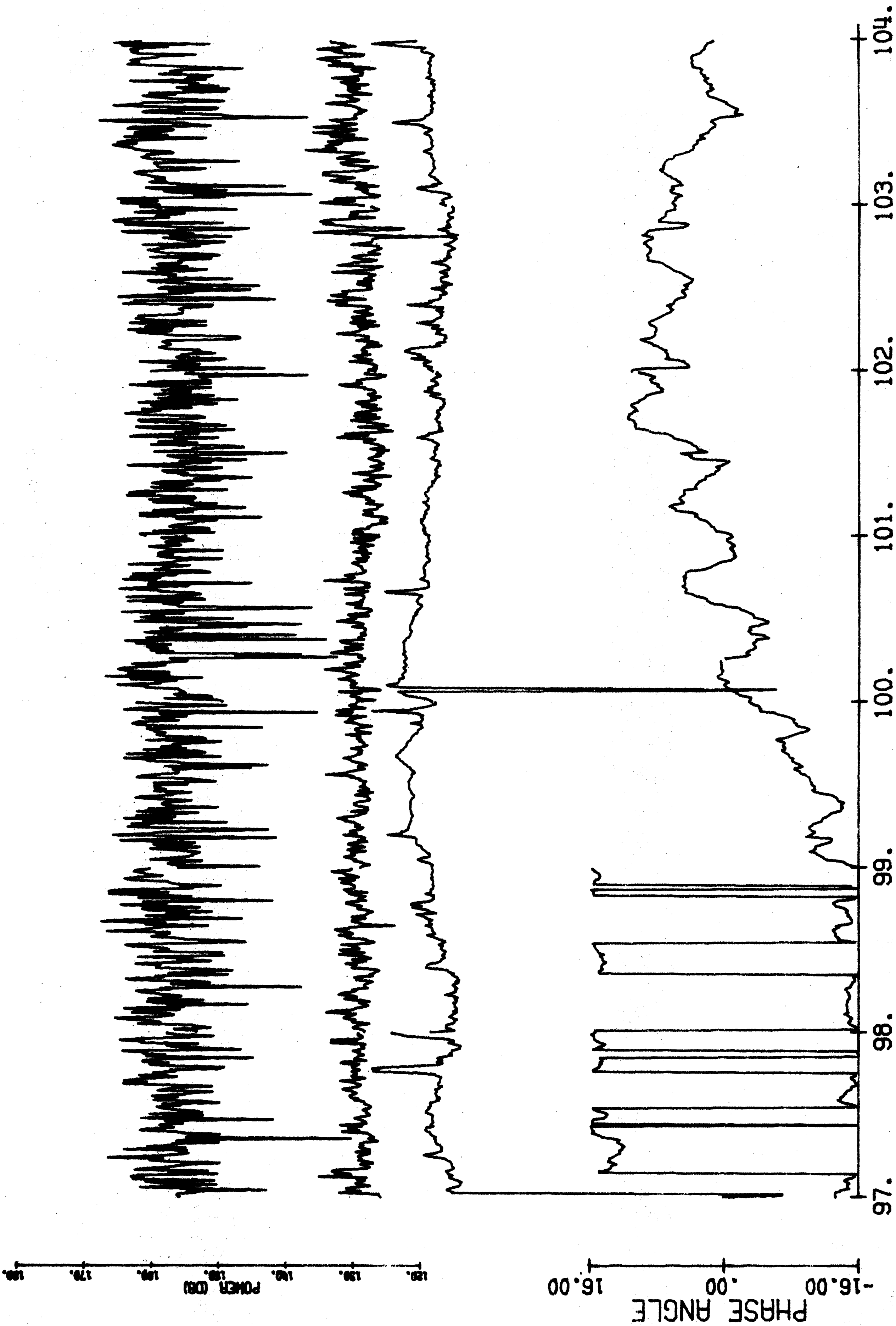

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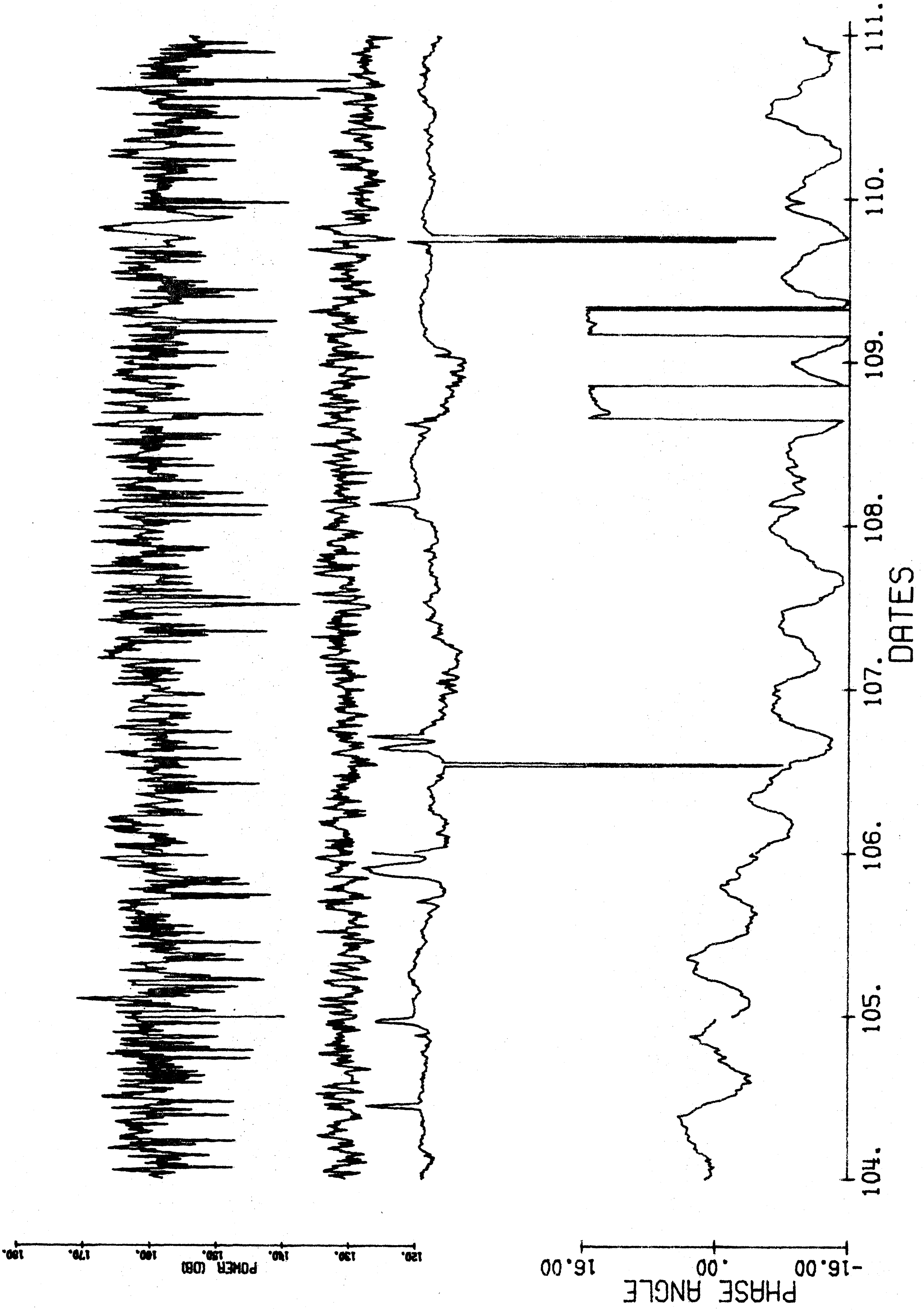
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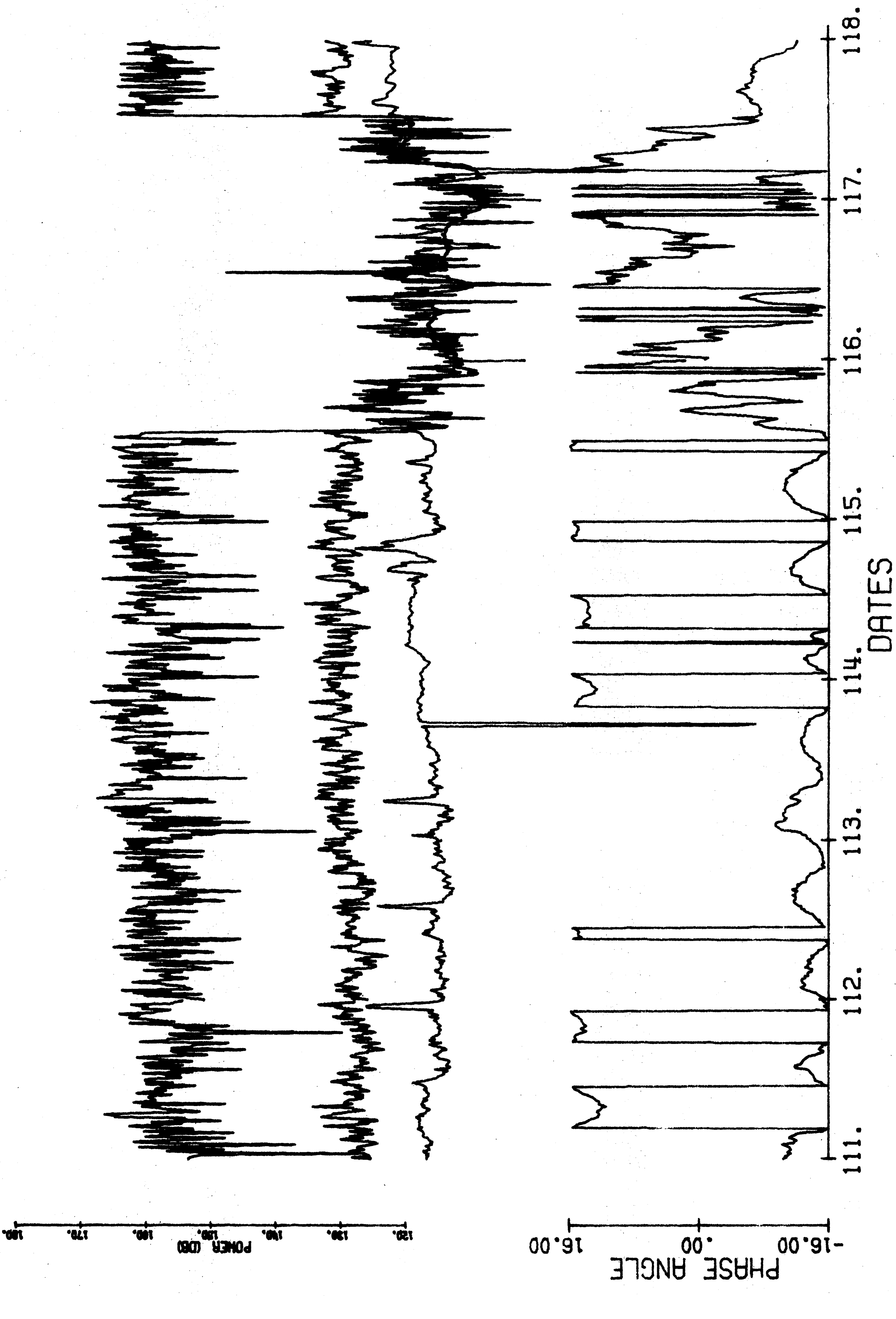
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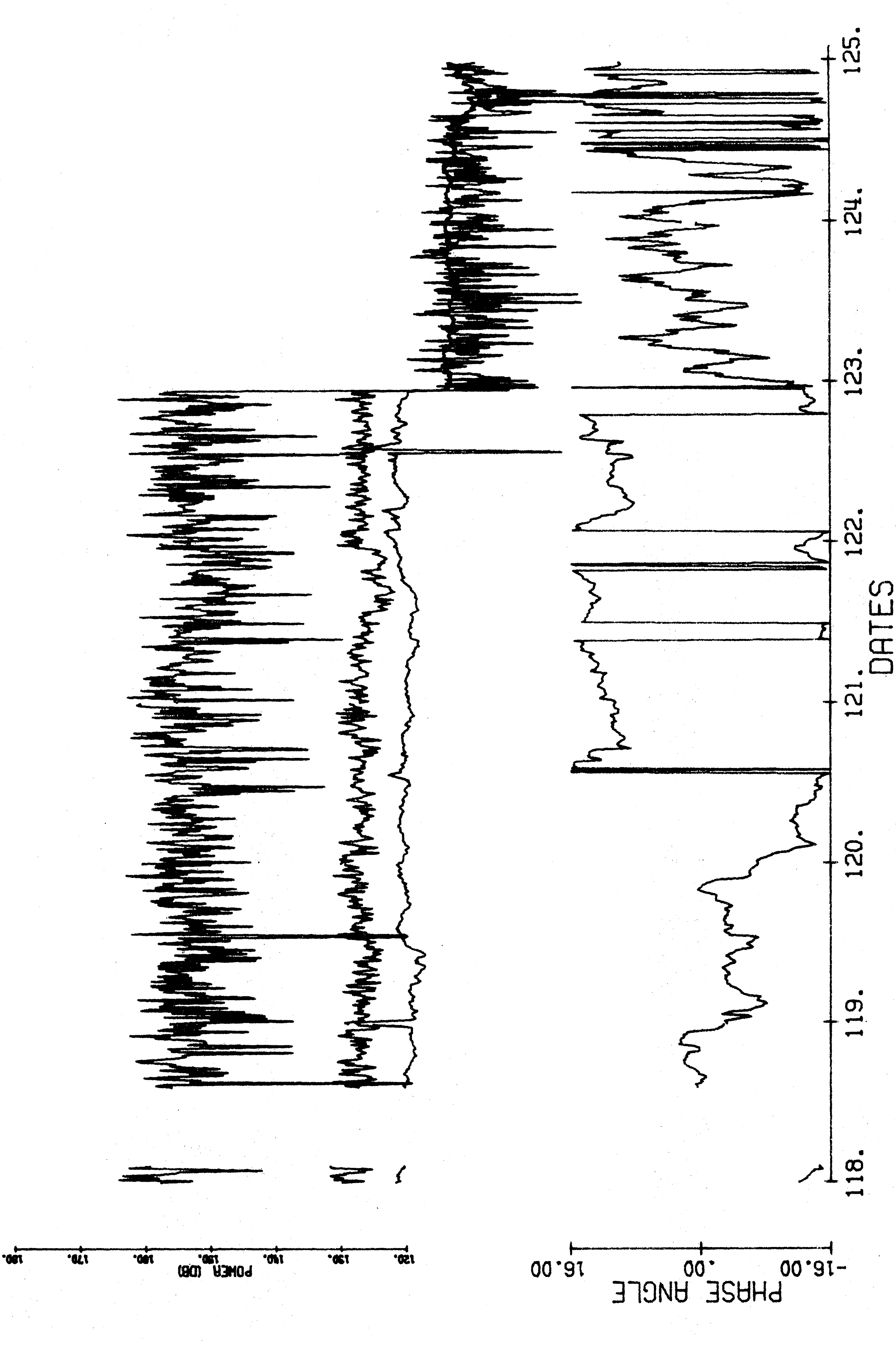
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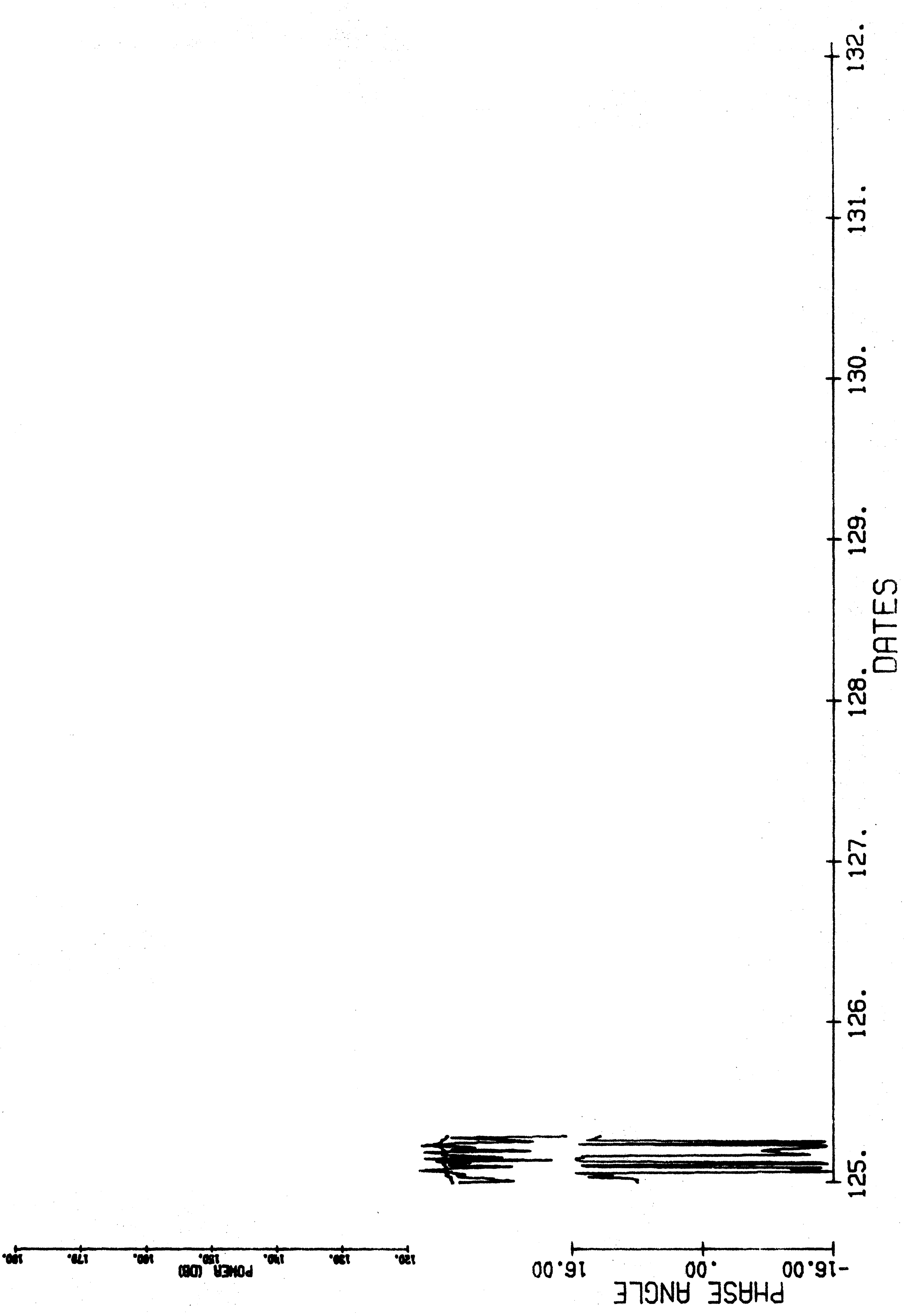
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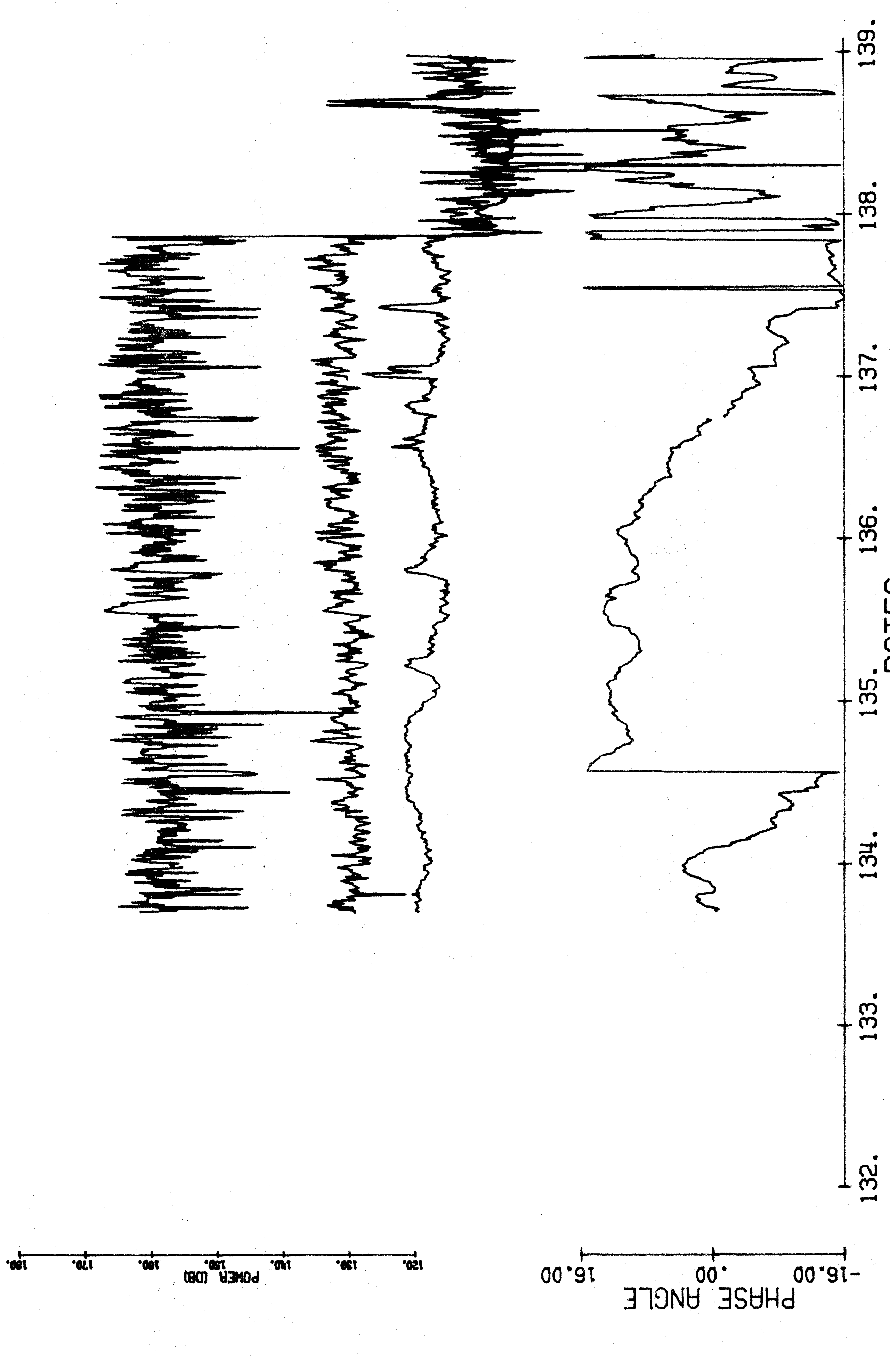
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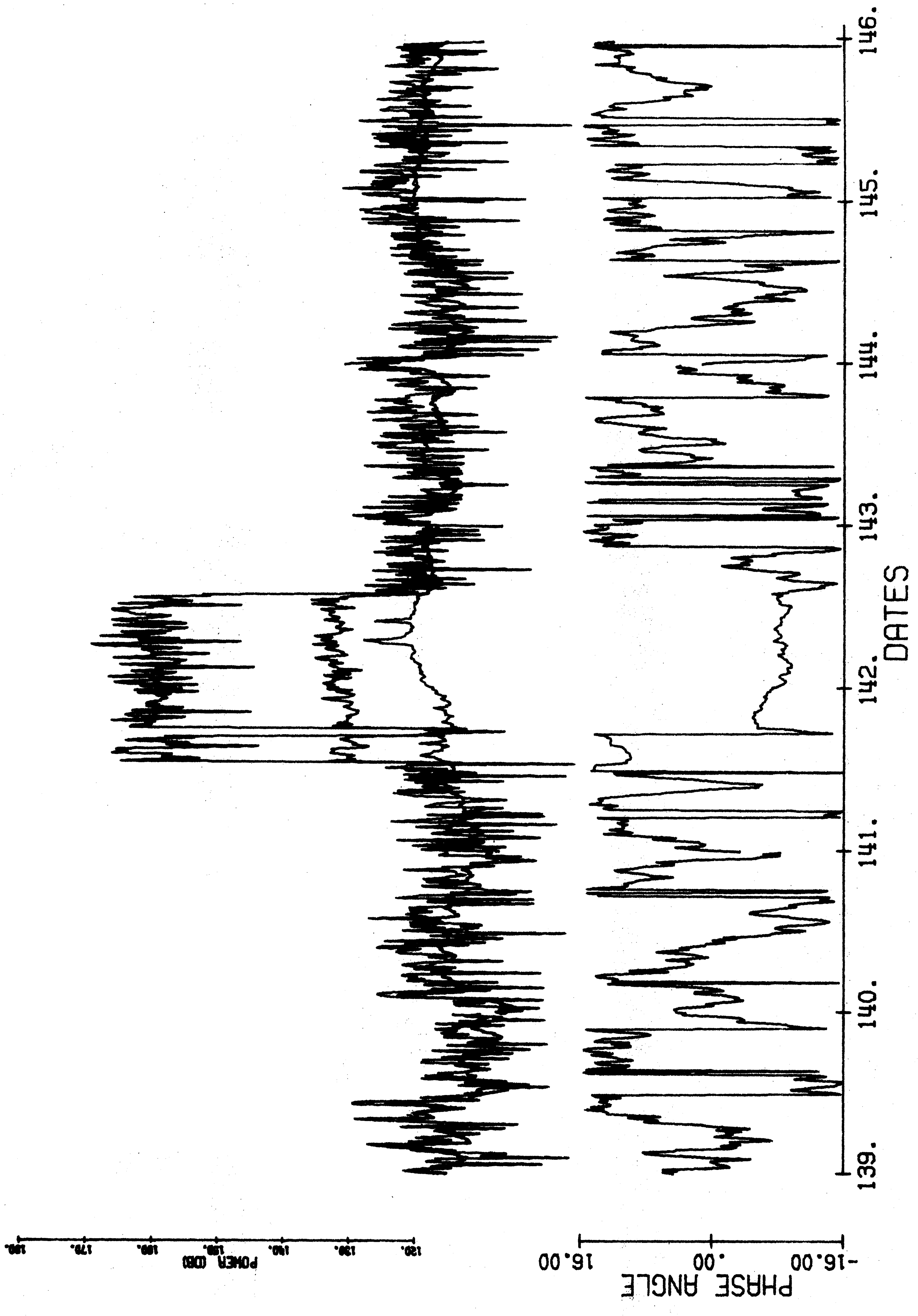

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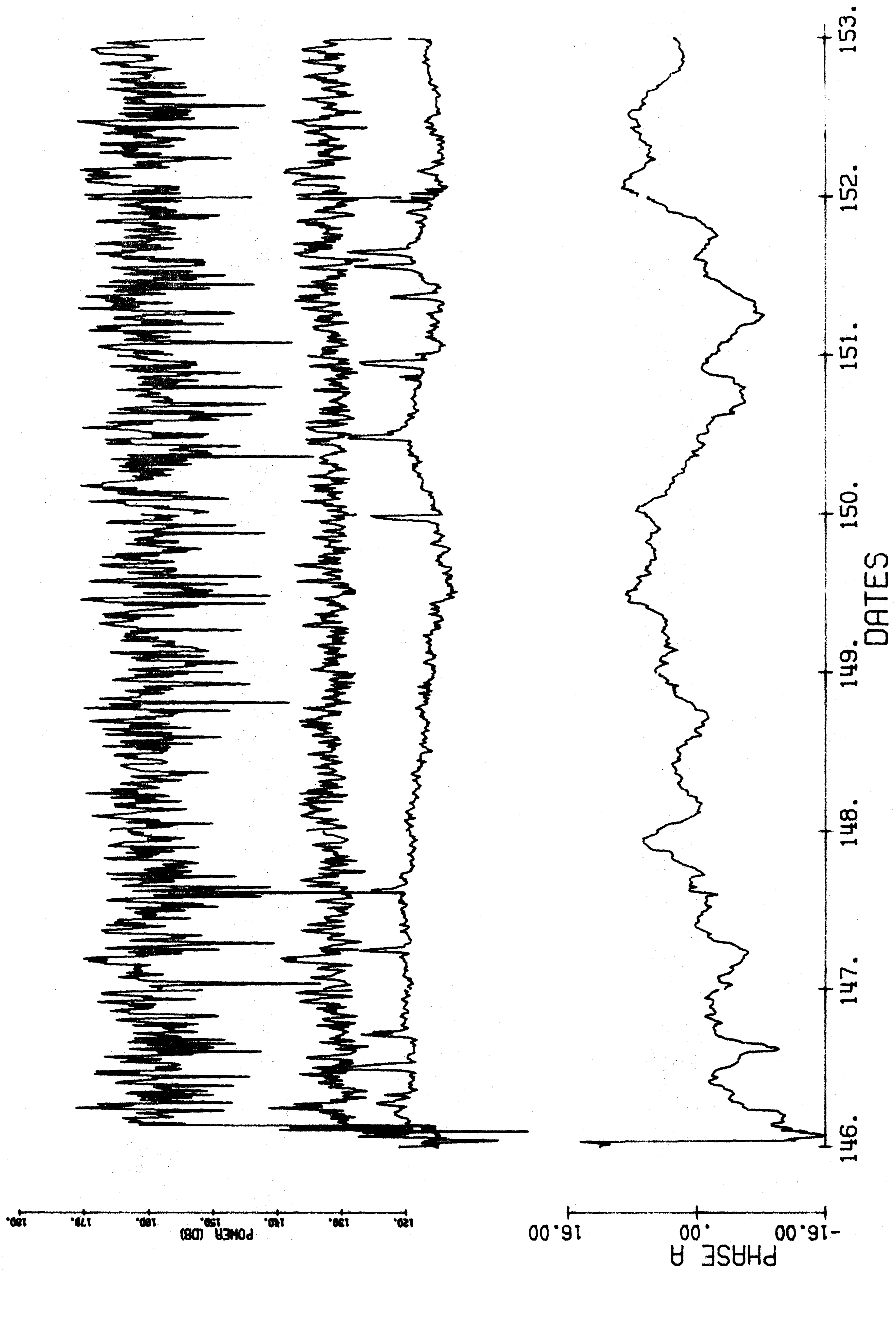

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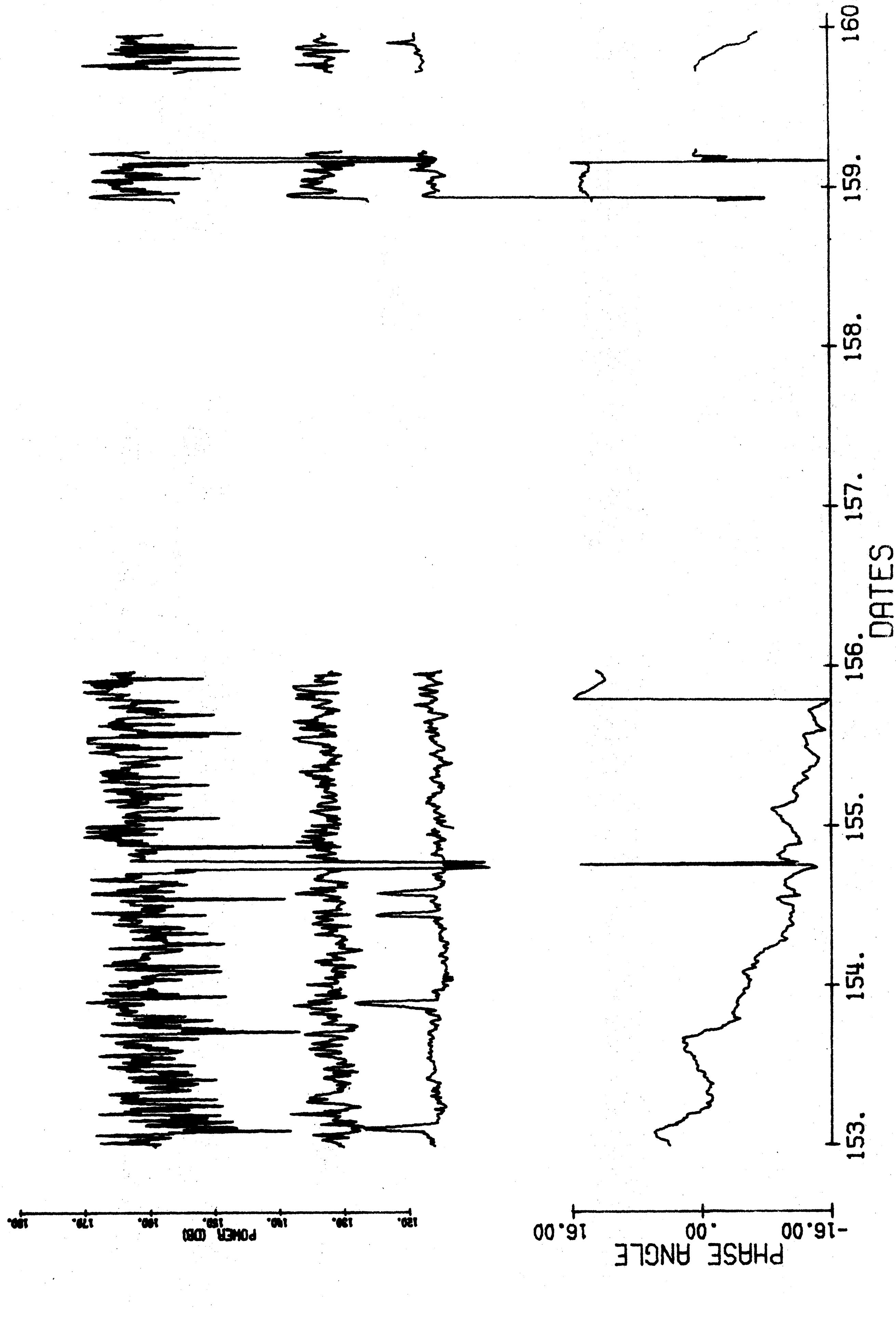
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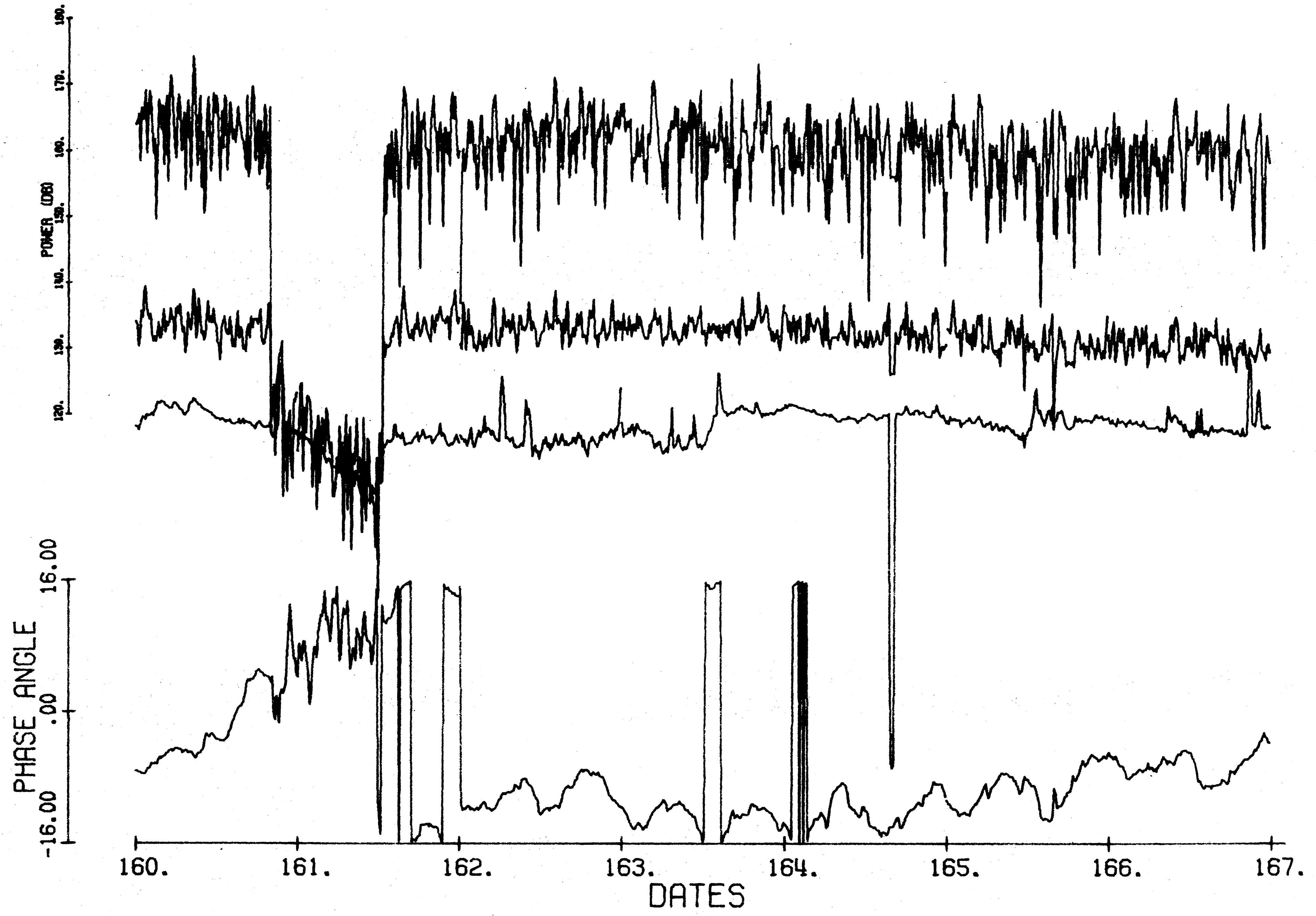
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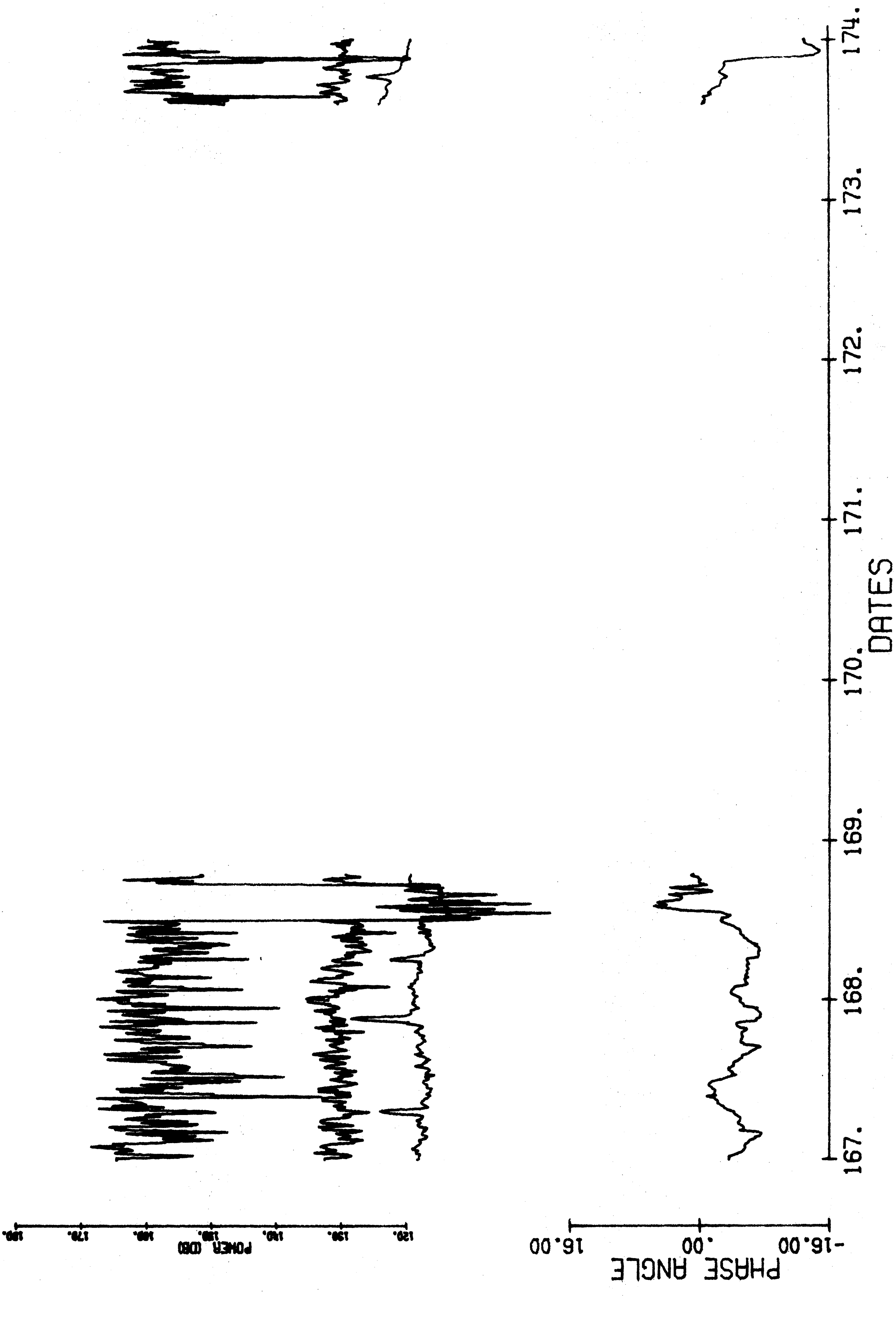
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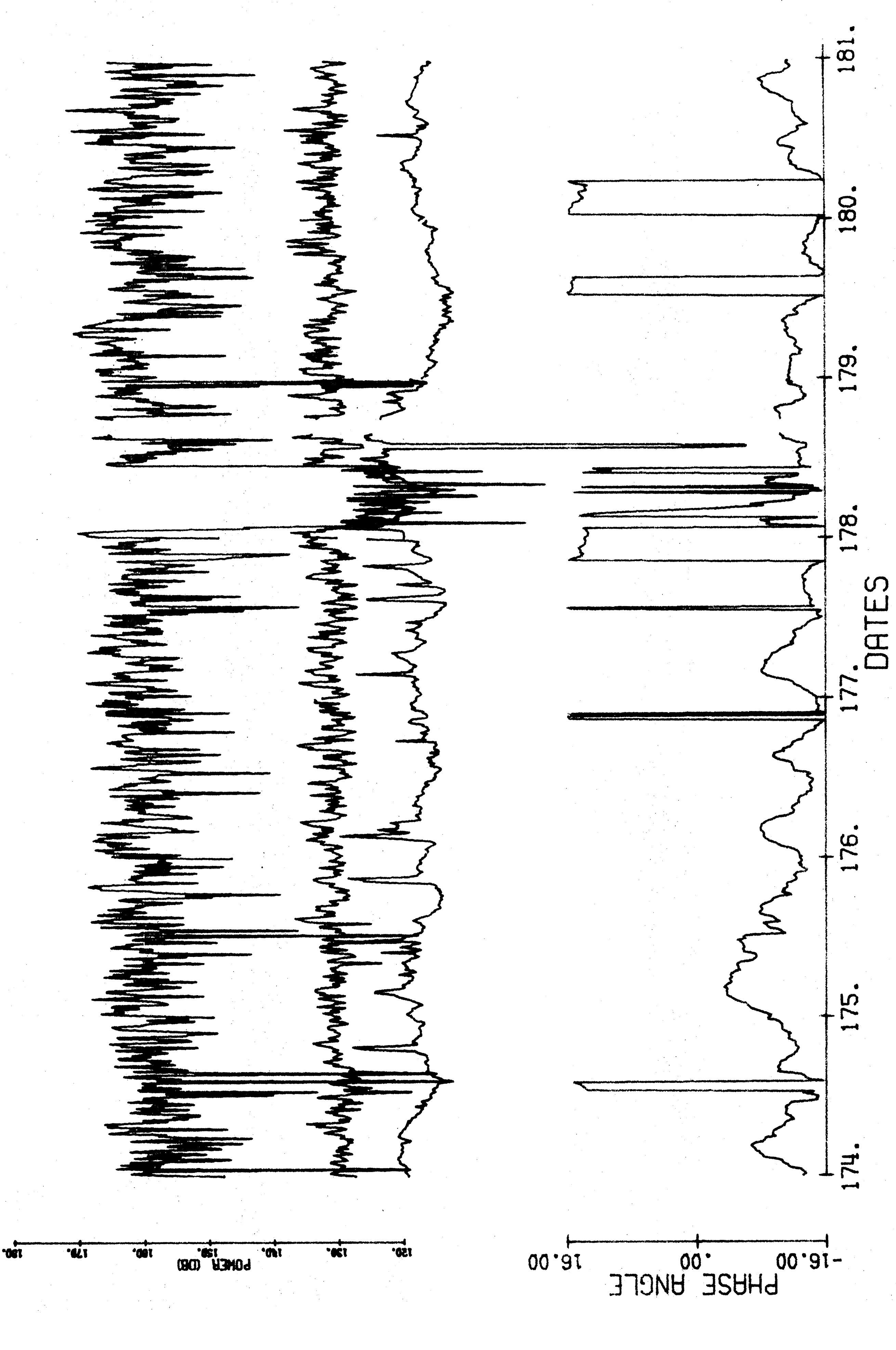

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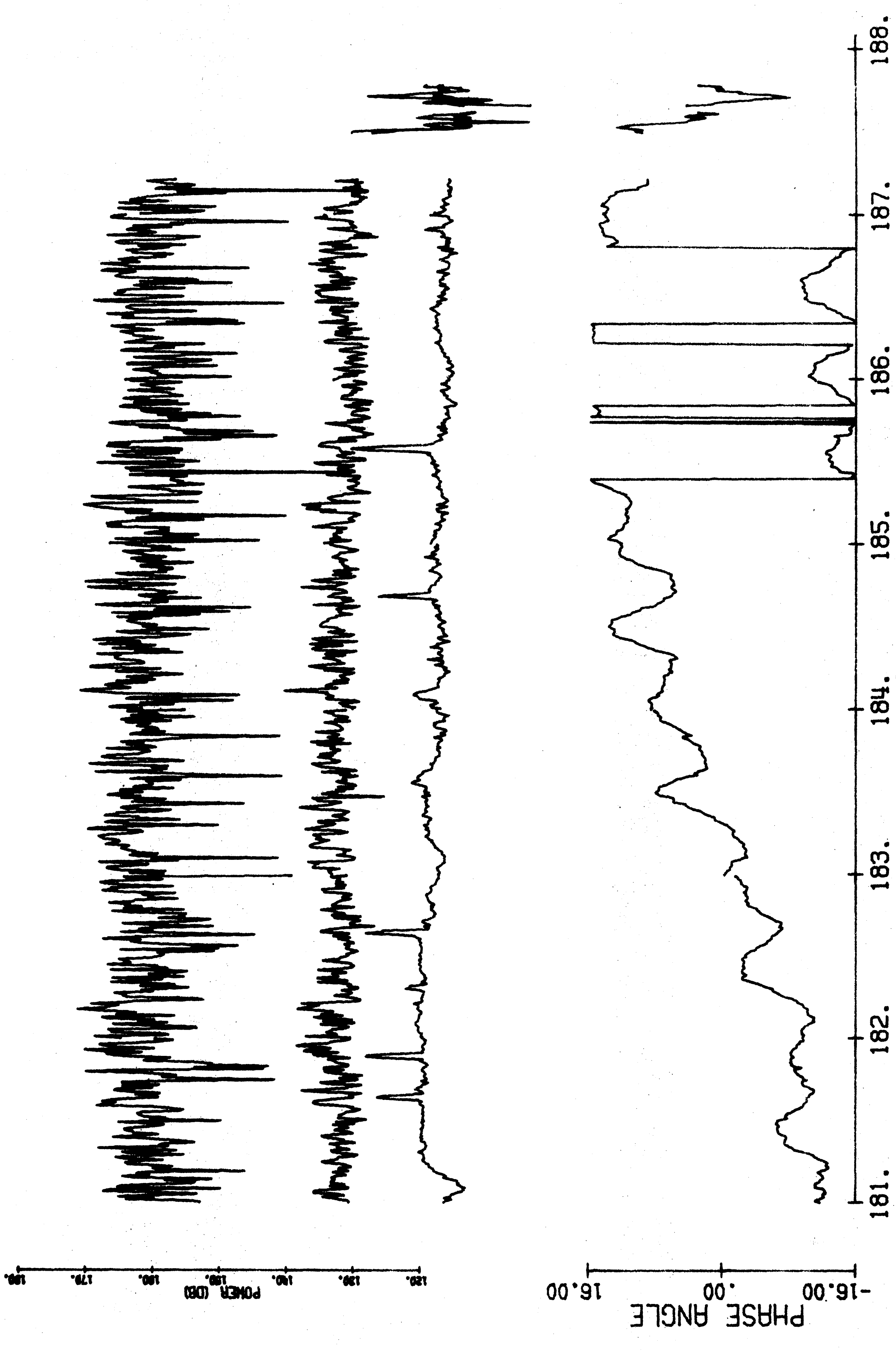
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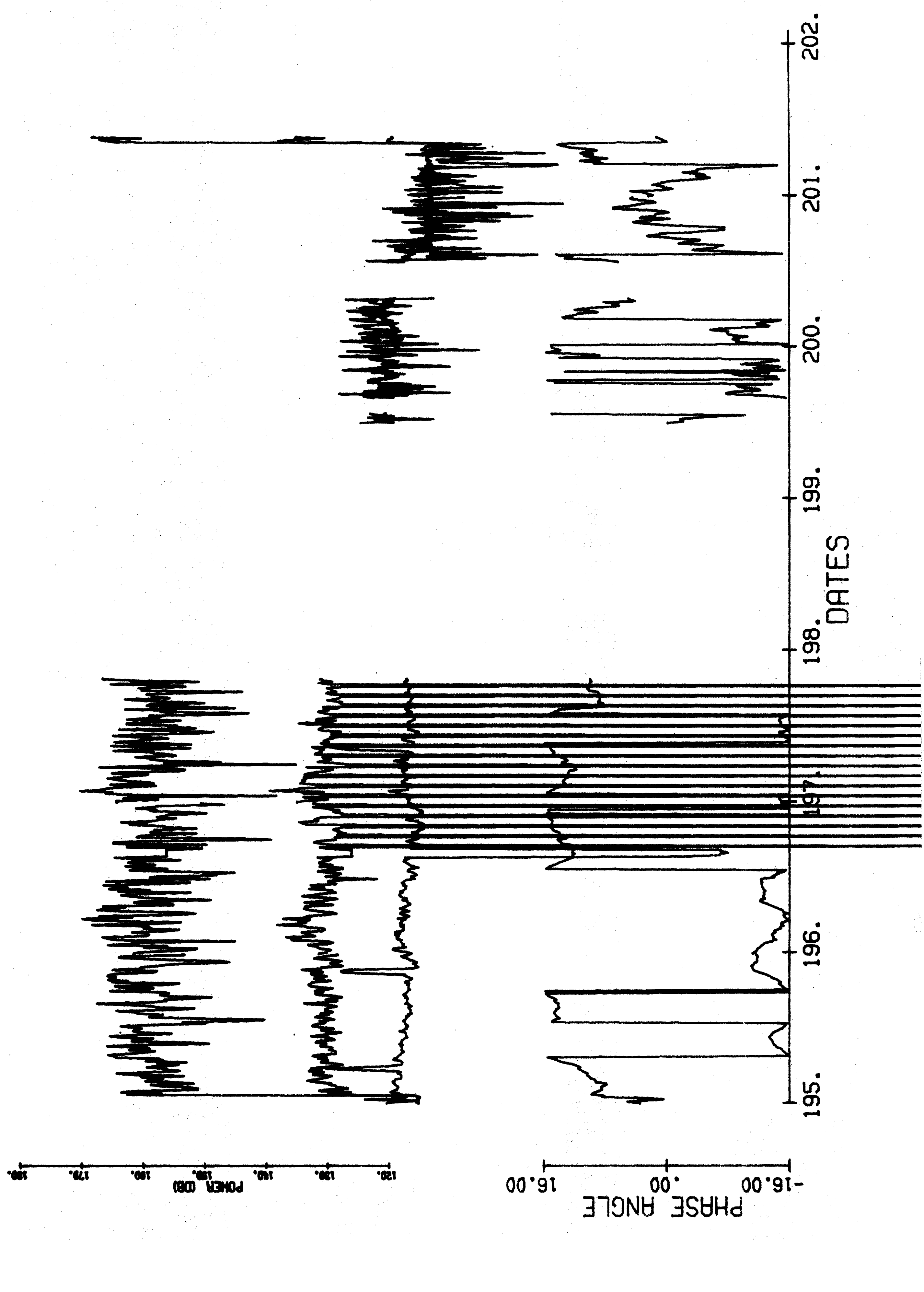
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13. ABSTRACT

Since 1962 the Signal Processing Group at the Cooley Electronics Laboratory of The University of Michigan and the Acoustics group (now the Institute for Acoustical Research) of the University of Miami have been engaged in a cooperative effort (project MIMI) involving the use of modern signal processing techniques in studying and modeling how acoustic energy propagates in the ocean. In July of 1971 the Miami group installed an acoustic source at the Eleuthera U.S. Naval Facility in the Bahamas. This source was used to conduct a long-term experiment involving deep ocean propagation. This report contains a description of the primary experiment and the data obtained from it.

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