UNIVERSITY OF MIAMI

ROSENSTIEL SCHOOL OF MARINE AND ATMOSPHERIC SCIENCES

RADAR SEA STATE ANALYZER

FINAL REPORT
DECEMBER 1969

by
G. F. Andrews and H. W. Hiser

Prepared under Contract N00019-68-C-0393 for the
Naval Air Systems Command, Department of the Navy

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UNCLASSIFIED

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ABSTRACT

The theory and description of a Radar Sea State Analyzer are presented. Installation, operation, adjustments, and readout interpretation instructions are also included. The instrument is the product of three years of research to obtain sea state information by using an existing radar as the remote sensor. This device is an attachment to the radar and examines the "sea return" signals at a selected range within the limits of the radar horizon. The outputs are available in digital and analog form. It is small in size and uses modern semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy and reliability.

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1.0 INTRODUCTION

This report gives the theory and description of a Radar Sea State Analyzer and provides installation, operation, adjustments, and readout interpretation instructions for it. This prototype instrument is an attachment for existing radar systems. It has been developed and tested during the latter part of a three-year research project devoted to the study of techniques for extracting sea state data from radar echoes from a rough sea surface. These echoes are known as "sea clutter" or "sea return". The objective was to remotely sense the state of the sea some distance from the radar out to the limits of the radar horizon.

During the first year of research, an extensive literature survey was made to supplement our knowledge of radar sea return that had been gained from several years of observations and photography. Concurrently, a recording and spectrum analysis system was developed to store and analyze both radar video and wave sensor data. During the second year, analysis of the data was performed, using both manual and automatic digital techniques. As results were achieved, new cases were stored and studied.

The instrument designed to perform this remote sensing function is small in size, and uses semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy, and reliability. It can significantly increase the potential utility of an existing radar at a nominal cost by providing information about the ocean. The outputs of the device are available in digital and analog form. Future possibilities include computer processing of these cutputs in real-time to derive additional information such as long-period ground swells and trends in the state of the sea for operational applications.

2.0 SYSTEM CONCEPTS: RADAR REMOTE SENSING

2.1 THEORETICAL CONCEPTS

This instrument is the product of three years of research and development. During and since World War II, many investigators have studied radar sea return echoes usually with the objective of removing them from viewing scopes or to develop means for identifying other targets in their presence. The hypothesis of this project was that sea state conditions probably could be remotely sensed by radar observations of sea return.

The power returned from the sea surface is primarily a function of the average radar cross section of sea echo per unit area of the sea surface $(\sigma)^o$, radar characteristics, and the angle of incidence of the radar beam on the sea surface. Goldstein in a book by Kerr [21] indicates that the target responsible for sea echo can always be resolved into a number of individual scatterers that can be treated as independent of each other. These scatterers may range in size from small spray droplets to large-scale surface waves or even a train of waves. Goldstein also states that the important quantity σ^o is independent of many of the characteristics of the radar set but is a function of at least five parameters:

1. The angle that the incident ray makes with the horizontal.
2. Radar wavelength.
3. Direction of polarization of the radar energy.
4. State of the sea.
5. Azimuth relative to the wave pattern on the sea surface (that is, upwind or downwind, etc.)

Experiments have shown that σ^o changes with the direction of the wind. If σ^o_u denotes the upwind value of σ^o, σ^o_d the downwind value, and σ^o_c the crosswind value, then: $\sigma^o_u > \sigma^o_d > \sigma^o_c$ for vertical polarization and $\sigma^o_u > \sigma^o_c > \sigma^o_d$ for horizontal polarization. The differences between σ^o_u, σ^o_c and σ^o_d are of the order of 0 to 5 db, Beckmann and Spizzichino [36].

For small grazing angles, with which we are concerned, Davies and Macfarlane [39] observed a rapid increase of σ^o as the ocean wave height increased, until a sort of "saturation" set in. At X-band, the saturation height has been observed to be about 2 or 3 feet, Skolnik [40], and as the radar wavelength increases, the saturation height increases. Other investigators, Boring, et.al. [18], have observed sudden increases in σ^o (as much as 10 db in a one-minute interval) for a sea with a 2-foot average wave height at the time of an abrupt increase in wind speed. Empirical formulas fitted to their data by Long, et.al. [12], indicate that for small grazing angles (less than 4°) σ^o varies about as the cube of the wind speed for horizontal polarization of the radar energy and as the square of the wind speed for vertical polarization. The dependence on wave height was much weaker. Other observers, Schooley [56], have reported for horizontal polarization that "σ^o is very approximately proportional to the local wind velocity squared". Long, et.al. [12] conclude that there may be a saturation effect with wind speed similar to the saturation effect with wave height. For example, σ^o is less sensitive to a 5-knot change in wind speed at 25 knots than at 10 knots.

Our observations, Hiser and Andrews [54], [57], also show the non-linear increase of σ^o with increasing wave height. A freshening sea shows a rapid increase in σ^o up to a certain roughness or wave height. Beyond this, there is a less rapid increase of σ^o with wave height. This complicates the problem of remotely measuring the wave height with radar.

2.2 SYSTEM DEVELOPMENT

For several years, we had made qualitative observations of radar sea return east of Miami in the Gulf Stream during periods of strong north and northeast winds. Winds from these directions are opposing the Gulf Stream current and have a long fetch region in which to produce high seas. Fortunately, the Underwater Acoustics Group in the Division of Ocean Engineering of this School had previously installed wind, wave height and other sensors at Fowey Rocks lighthouse 13 nautical miles southeast of our radar facility. Use of information from these assisted us greatly as we began quantitative sea-return measurements. The wave-height sensor is in deep water east of the lighthouse on the west side of the Gulf Stream.

An Ampex model VR-1500 video magnetic tape recorder was modified to permit storage of analog wideband video output from the UM/10-cm radar system when sea clutter was observed. This permitted post analysis of the data using various spectrum analysis techniques. The wave-height sensor data were brought by submarine cable and telephone line from Fowey Rocks lighthouse to our Laboratory where they were recorded in analog form on an auxiliary channel of the Ampex video tape recorder. The axis of the radar beam was positioned at approximately +0.5° elevation above the horizontal and was held stationary on a particular azimuth, usually that of the lighthouse and sensors, while sea clutter video and wave-height sensor data were being tape recorded.

The radar is 10-cm wavelength, horizontally polarized, and provides a choice of a one or two microsecond pulse duration at a pulse repetition frequency of 300 pulses per second. The one-microsecond pulse duration was most often used for recording sea clutter video. This provided a sample depth in range of 150 meters. The antenna system in use during most of the project provided a 3-degree conical beam. At the range to the sensors this gave a beamwidth resolution of approximately 1300 meters on the sea surface. A new 12-ft diameter antenna was installed in 1968 and this provided a 2-degree conical beam for the 1968-69 data period. Results obtained with the new antenna agreed with those from the previous system.

Spectrum analysis was performed on the radar video data with equipment designed by Andrews [58] for all dates that were tape recorded. Usually, three range-gated samples of radar video were analyzed. The range gates were set to encompass 150 meters each and were usually positioned starting at 24.7, 25.0 and 25.3 kilometers respectively thus allowing 150 meters separation in range between each sampled area, Figure 2.1. The sample at 24.7 kilometers was approximately over the wave-height sensor. Illustrations of the analog chart readouts of spectrum analyzed video data from the gated sample areas are presented in Figures 2.2 and 2.3. The wave-height sensor data were read out from the tape onto these analog charts simultaneously with the radar data, insuring time synchronization of the data.

Mean wave periods were manually extracted from these charts of both radar and wave sensor data. In addition, automatic digital computations of period (P) and mean period ($\bar{P}$) were performed and printed on paper tape. The results of both the manual and automatic digital techniques showed that the radar indeed could provide average wave period to match the wave sensor readout with a high degree of confidence, Hiser and Andrews [57]. This was the basis for designing the computer to automatically read out wave period in units and tenths of seconds in the Radar Sea State Analyzer. From this period information, certain other interrelated wave parameters such as wave length and velocity can be determined. In addition, estimates of wave heights (within the constraints mentioned in Section 2.1) or, more precisely, trends of wave heights, can be made.

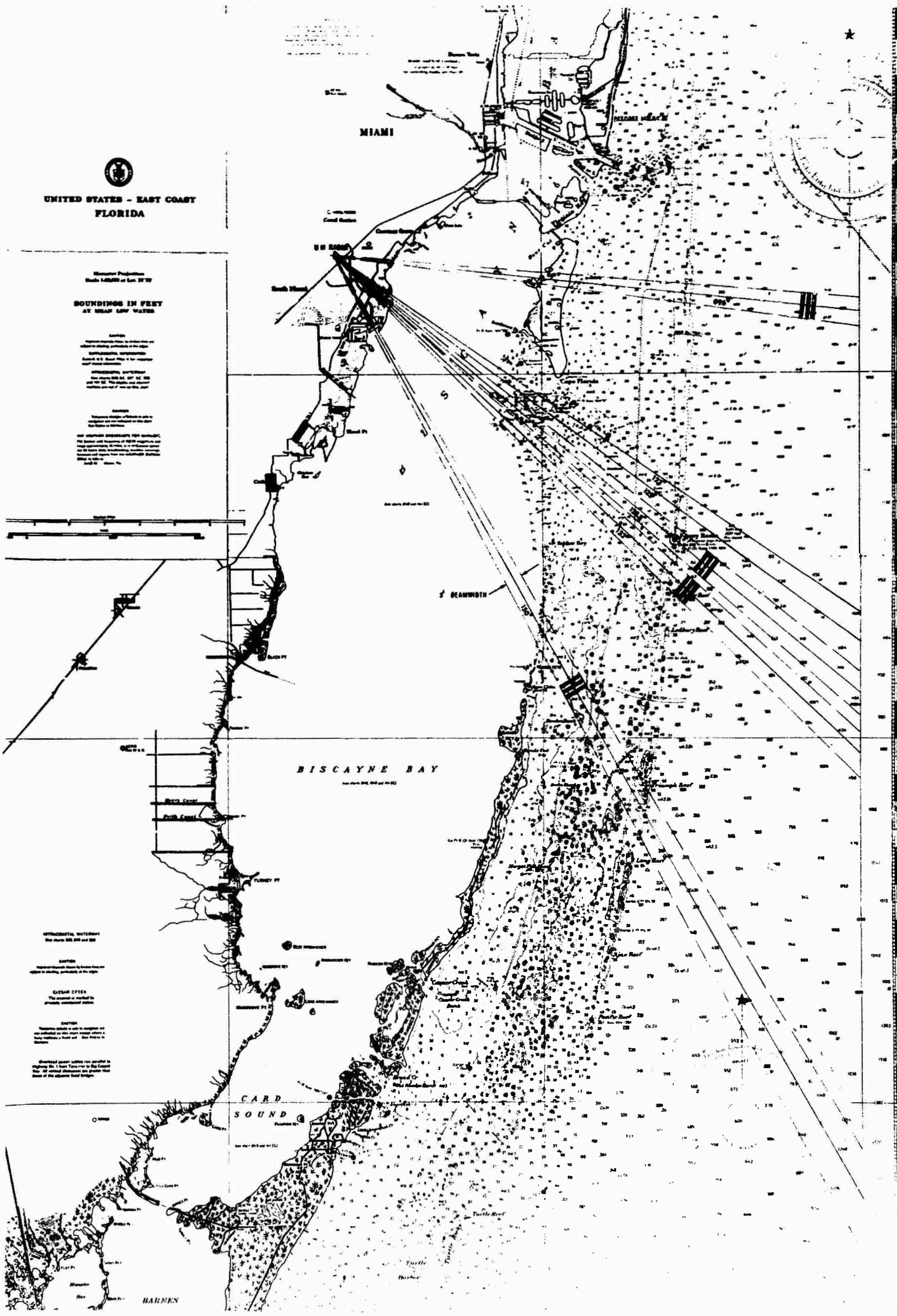


FIG. 2.1 - MAP SHOWING ALL OF THE AZIMUTHS AND SOME OF THE GATED SAMPLE AREAS INVESTIGATED

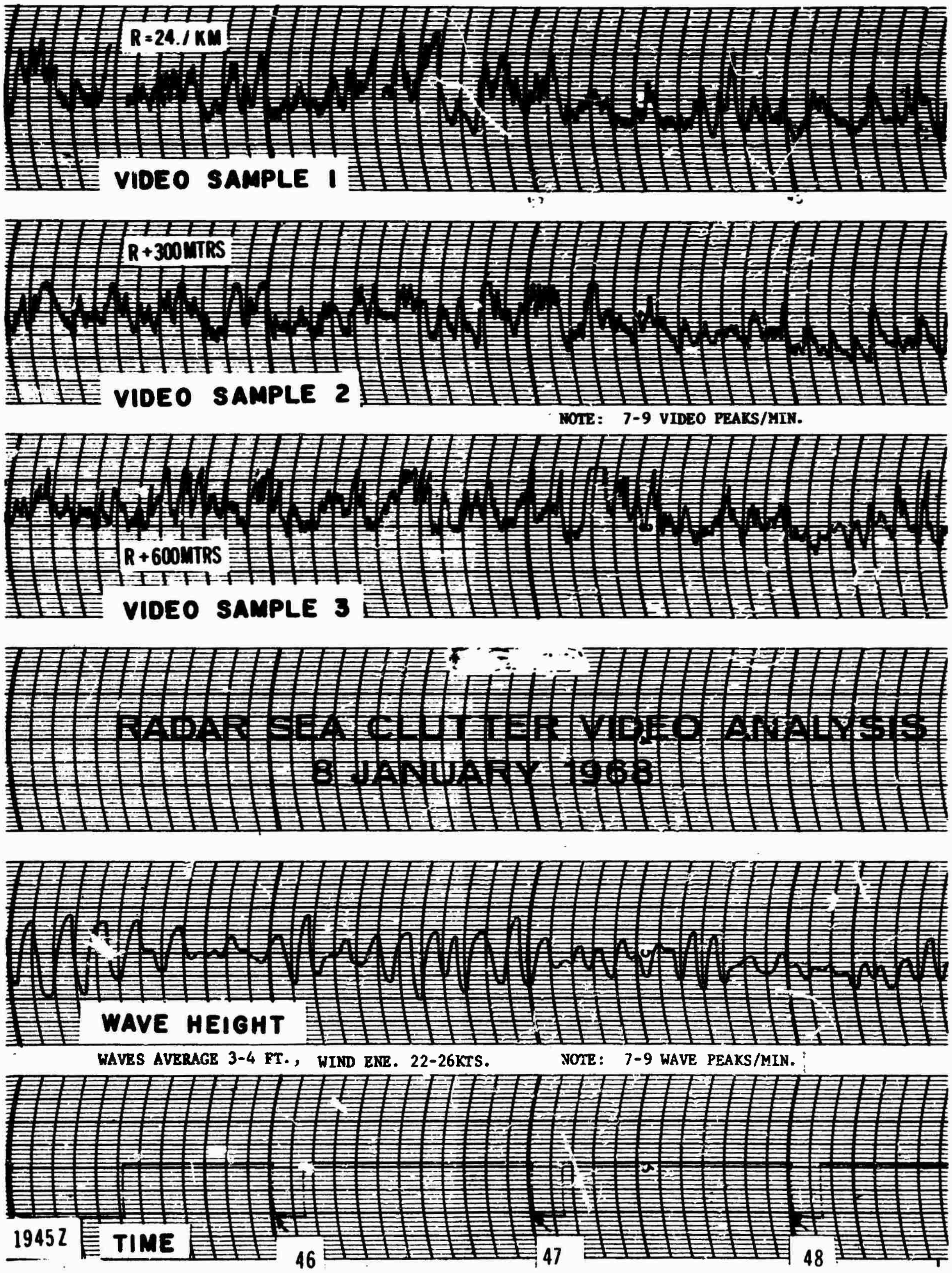


FIG. 2.2 - DATA SAMPLE USING RADAR ANTENNA WITH 3-DEGREE BREAMWIDTH

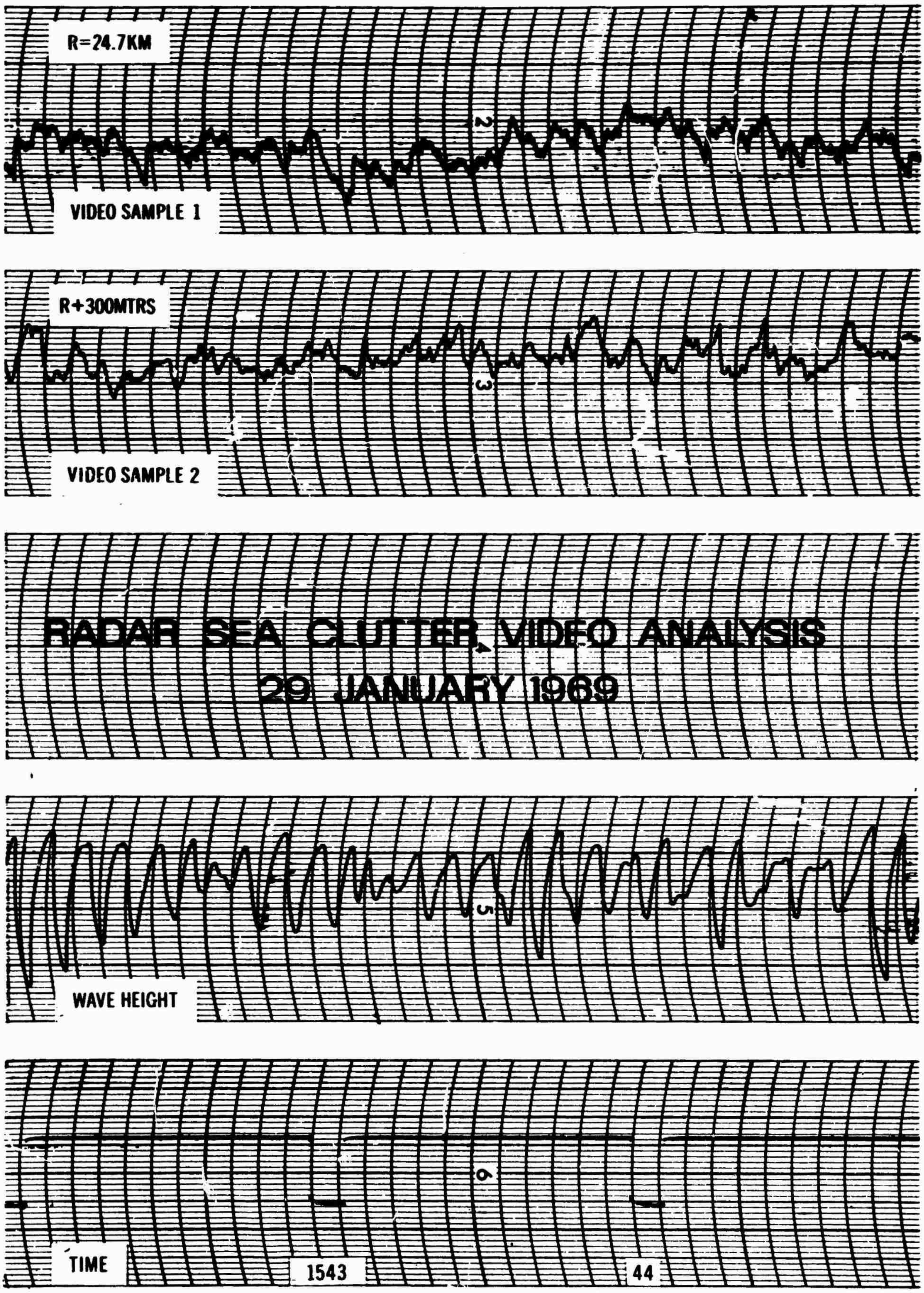


FIG. 2.3 - DATA SAMPLE USING RADAR ANTENNA WITH 2-DEGREE BEAMWIDTH

3.0 THEORY OF OPERATION - SEA STATE ANALYZER

3.1 Technique

The observed correlation between ocean wave periods and fluctuations within radar video noise is utilized as the basis for measurement in the Radar Sea State Analyzer. This requires that the frequency content of the signal waveform of interest, within a specified passband and sampled at a selected range from the radar, be extracted from the broadband signal and noise. A slope detection technique is used to convert this filtered input signal into a train of frequency-dependent pulse widths, and the resultant zero-crossing intervals are then examined for frequency content.

Since the natural ocean wave alternations are neither pure sinusoids nor of precisely uniform duration, an average period value is needed to achieve a reliable, repeatable measurement. Such a value is obtained by having the instrument electronically compute the function:

$$\text{Average} = \bar{X} = \frac{\sum_{i=1}^{N} x_i}{N}$$

A sample size (N) of ten periods is chosen as (a), large enough to yield statistical relevance to the results, and (b), small enough to yield a reasonable elapsed time between successive measurements. The actual function executed by the instrument becomes then:

$$\text{Average period} = \bar{P} = \frac{\sum_{1}^{10} P}{10}$$

The useful outputs of the analyzer are:

1. A digital display of the measured average period, expressed in seconds and tenths of seconds.
2. Binary-coded-decimal electrical outputs of this same period information for further computations, analyses, etc. These outputs comprise both a stored value for the most recently

completed computation, and a real-time, changing value.

3. Analog chart recording of the filtered, range selected signal variations as a function of time.

3.2 ELECTRONIC CIRCUIT FUNCTIONS

A block diagram of the device is shown in Fig. 3.1. The input video signals are sampled at the radar pulse-repetition rate and at an equivalent range established by the delay generator. This filtered signal is applied to (1) the analog chart recorder and (2) to a slope detector/bandpass filter where the frequency-dependent pulse train is generated. A decade counter determines when ten periods of the input data have occurred. This counter output pulse drives a flip-flop which alternately enables one of the AND gates; which in turn permits clock pulses to be passed to the active readout module. The alternate gate inhibits pulses to the store module. At transition change time, the pulse shaper resets the appropriate module so that a new count may be commenced.

Clock pulses are generated by a 100 KHZ crystal oscillator and 5 serially connected decade dividers, yielding output pulses at a one-per-second rate.

3.3 CIRCUIT DIAGRAMS

Circuit diagrams of various sub-elements and logic blocks are included in Figures 3.2 through 3.10.

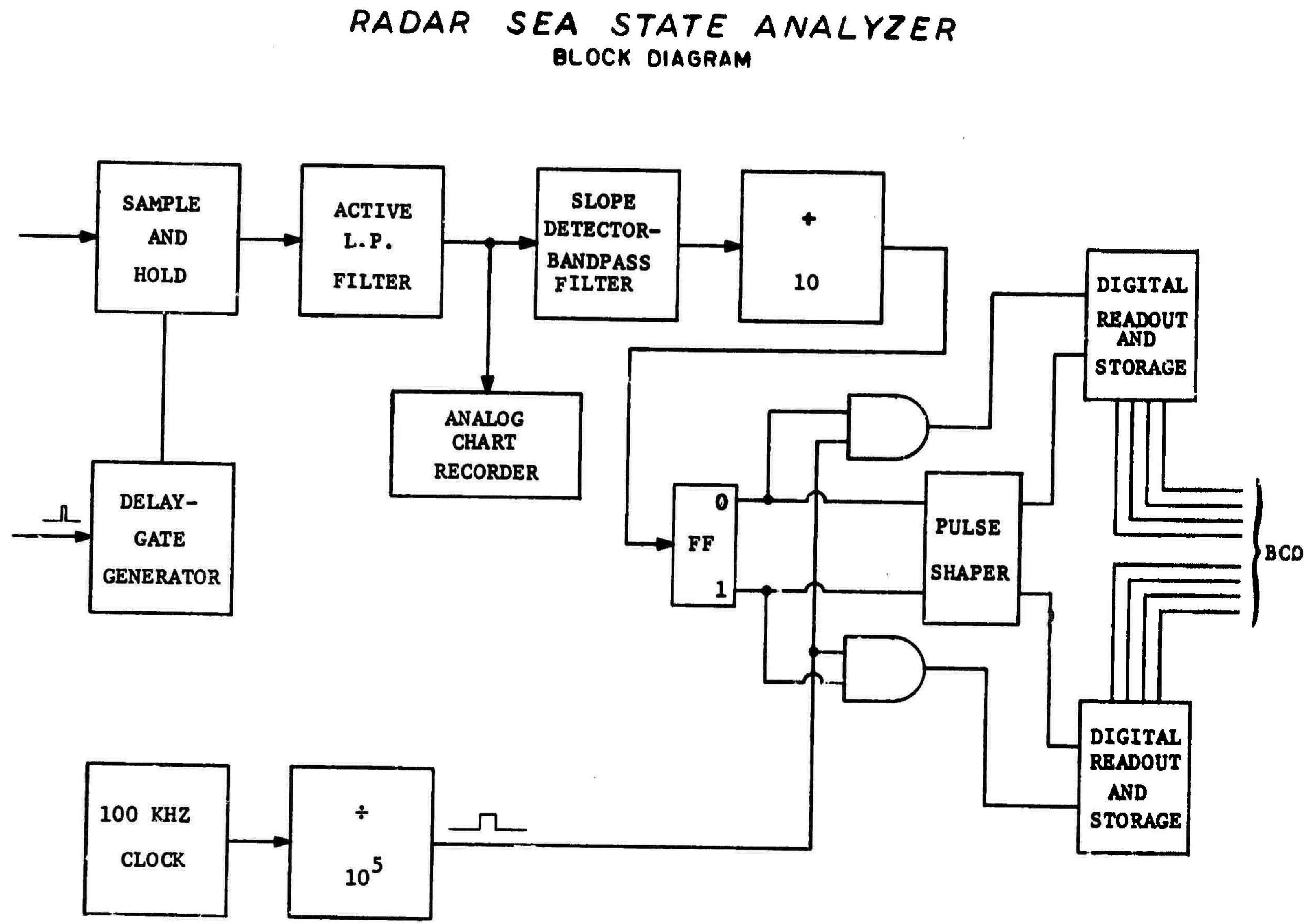


FIGURE 3.1 - BLOCK DIAGRAM

RADAR SEA STATE ANALYZER

CARD NO.1

DUAL REGULATOR

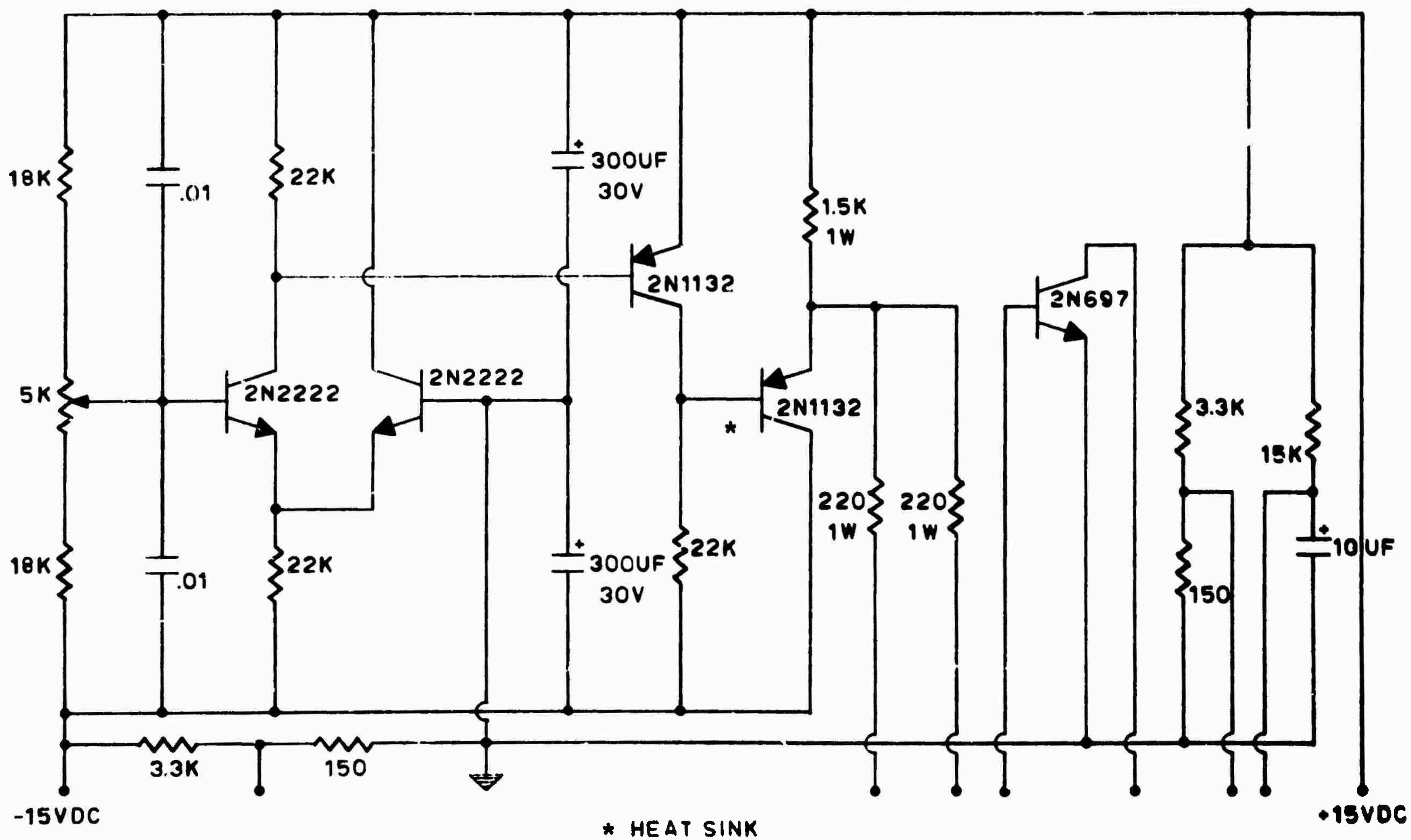


FIGURE 3.2 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER
CARD NO.2
BUFFER AND LAMP DRIVER

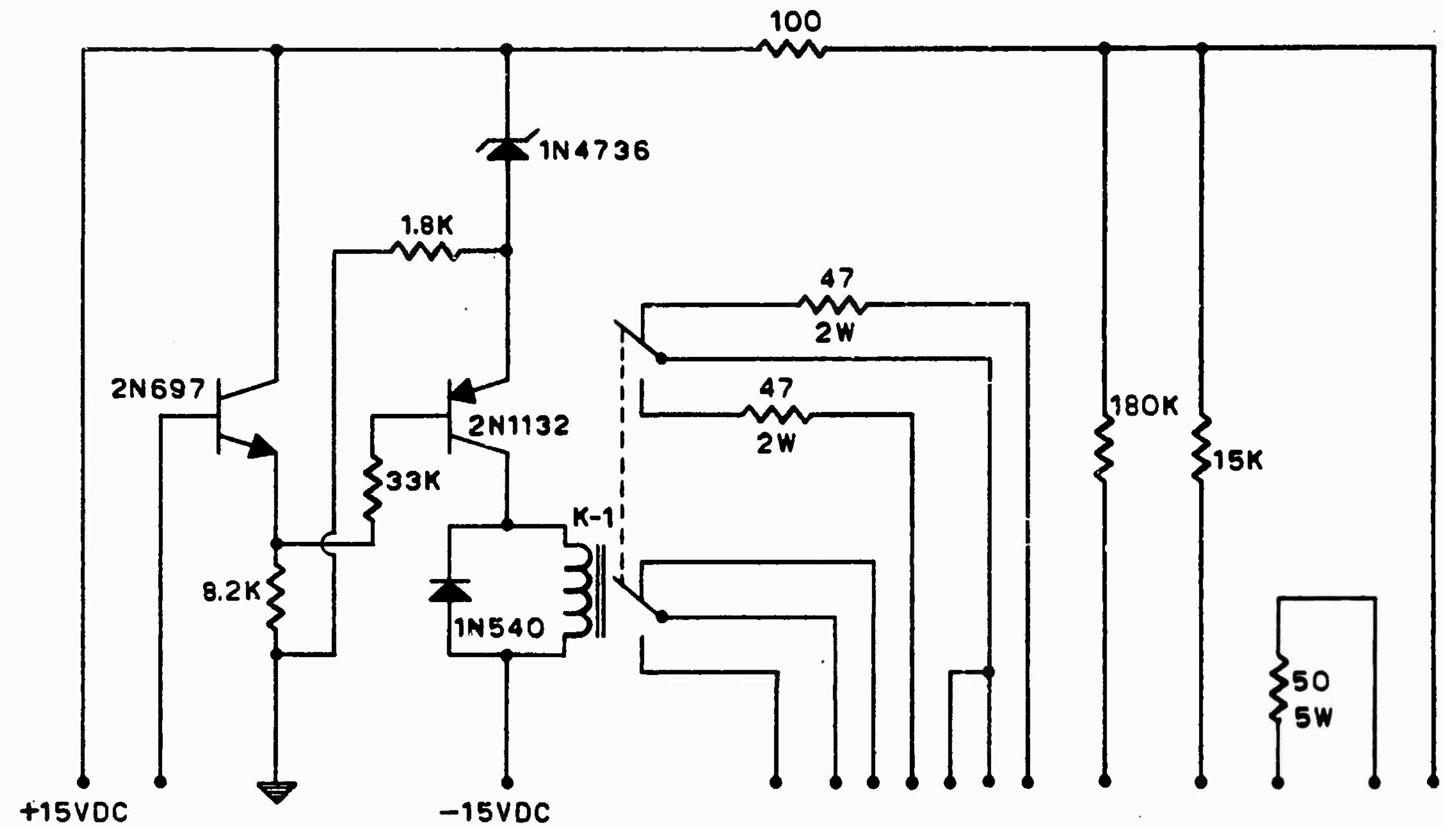
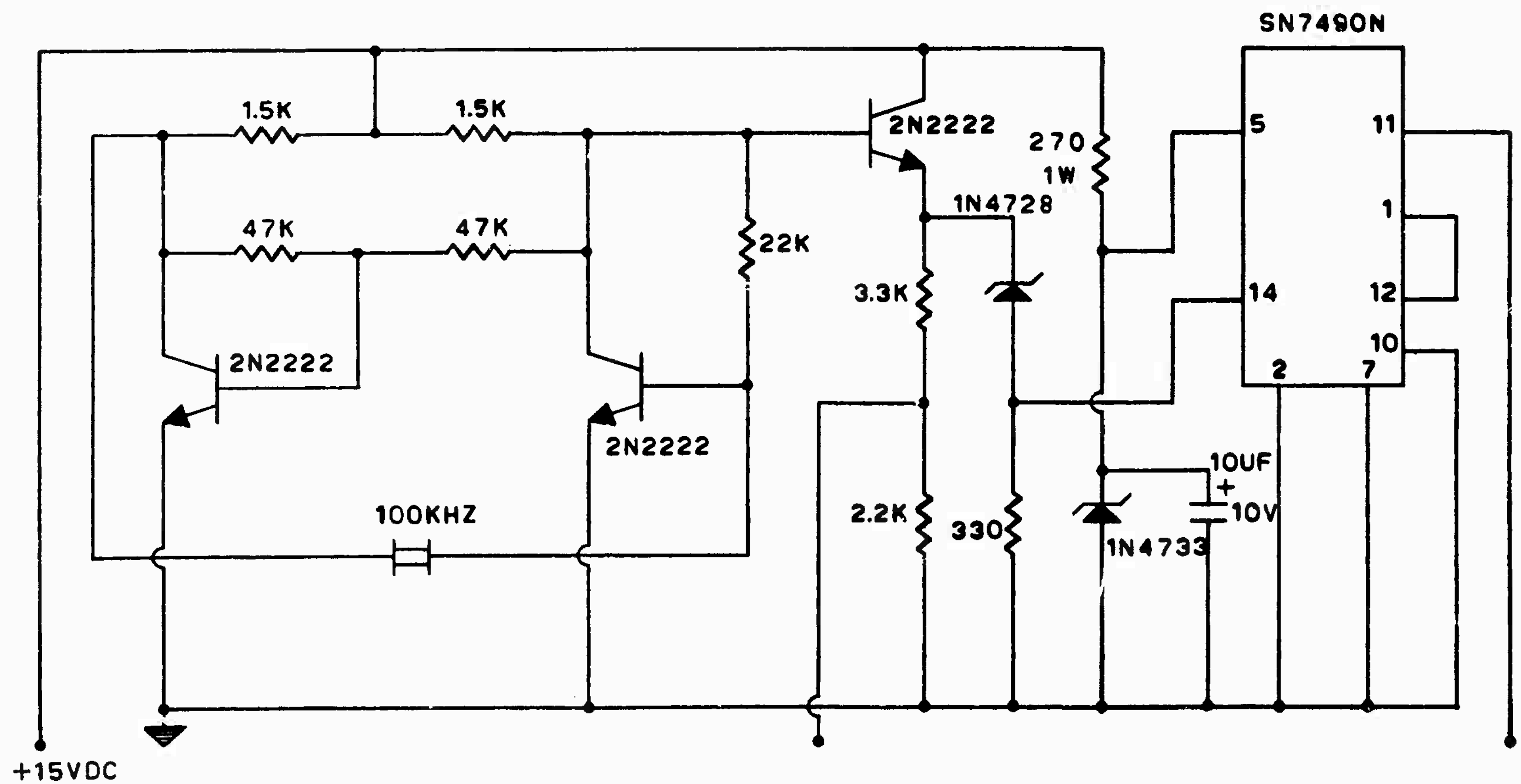


FIGURE 3.3 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER

CARD NO.3

SYSTEM CLOCK



RADAR SEA STATE ANALYZER
CARD NO. 4
10^4 DIVIDER

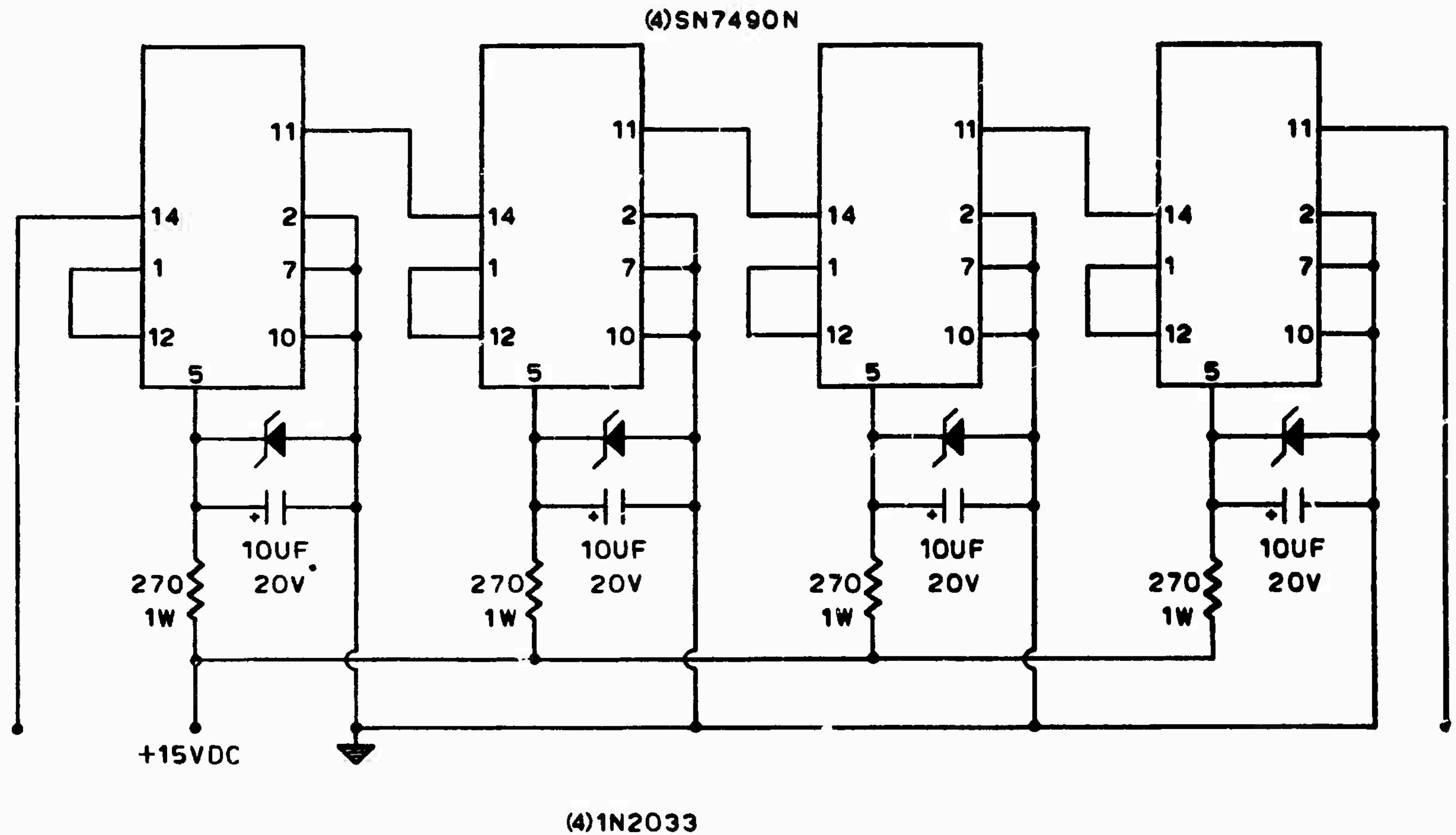


FIGURE 3.5 - SCHEMATIC DIAGRAM

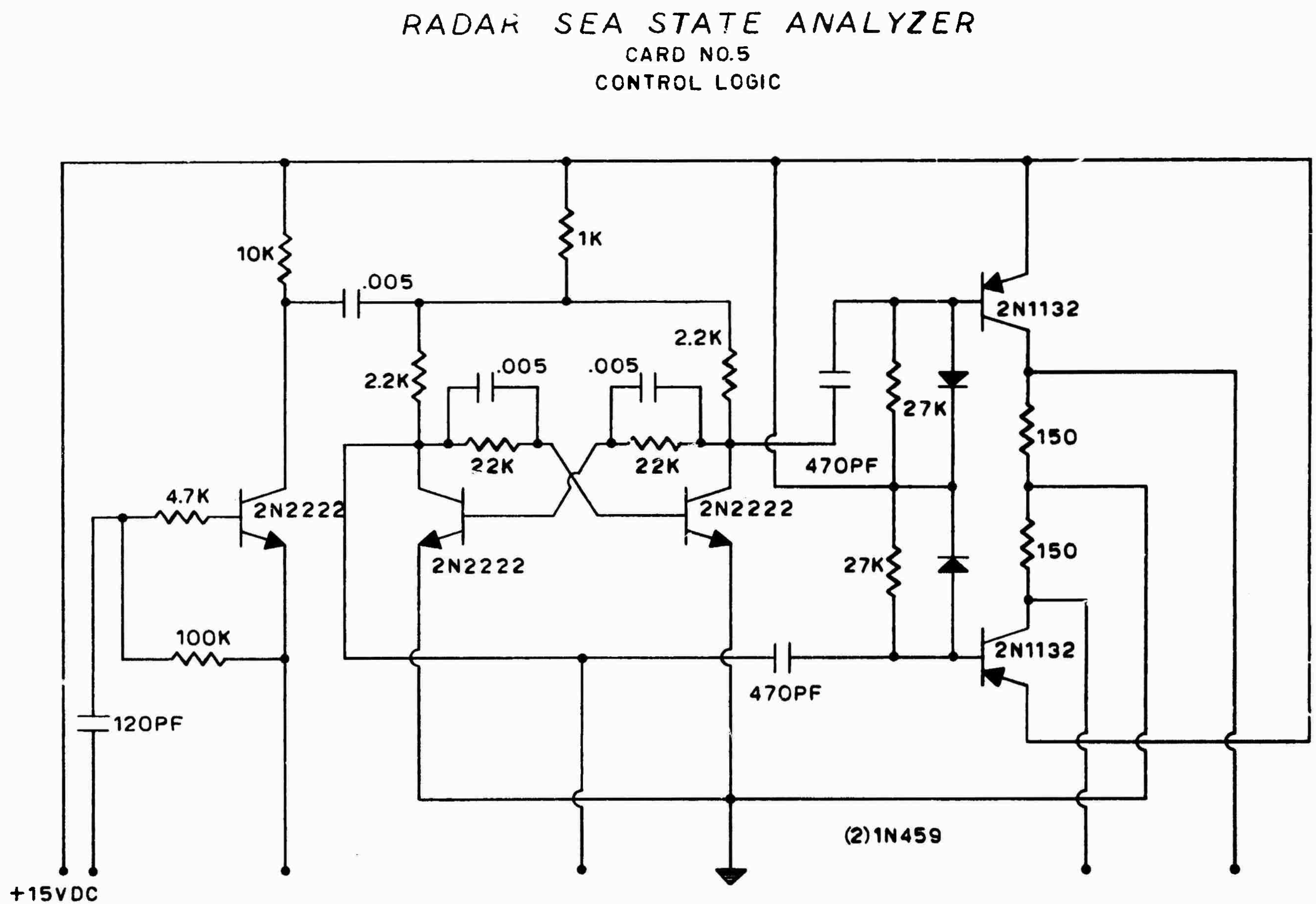


FIGURE 3.6 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER

CARD NO.6

SLOPE DETECTOR AND FILTER

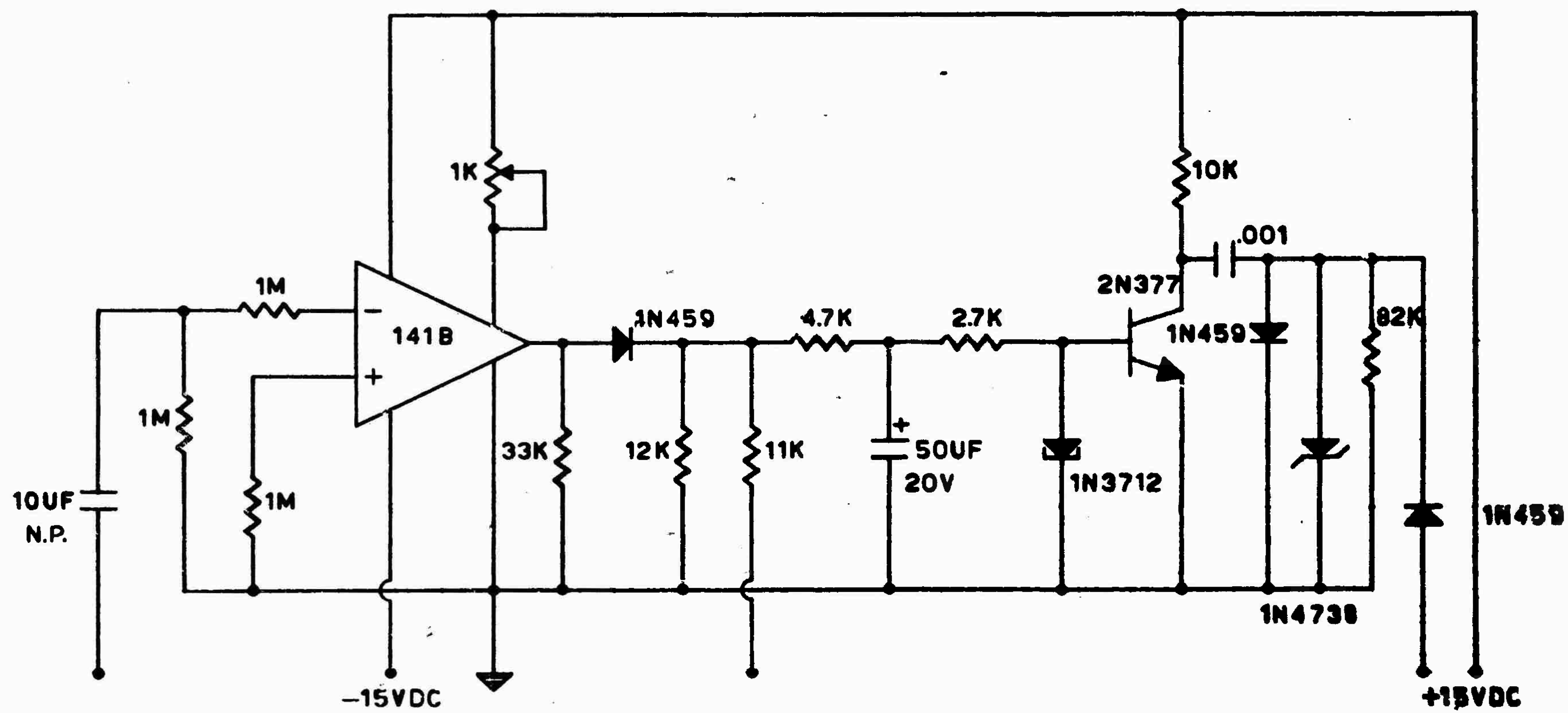


FIGURE 3.7 - SCHEMATIC DIAGRAM

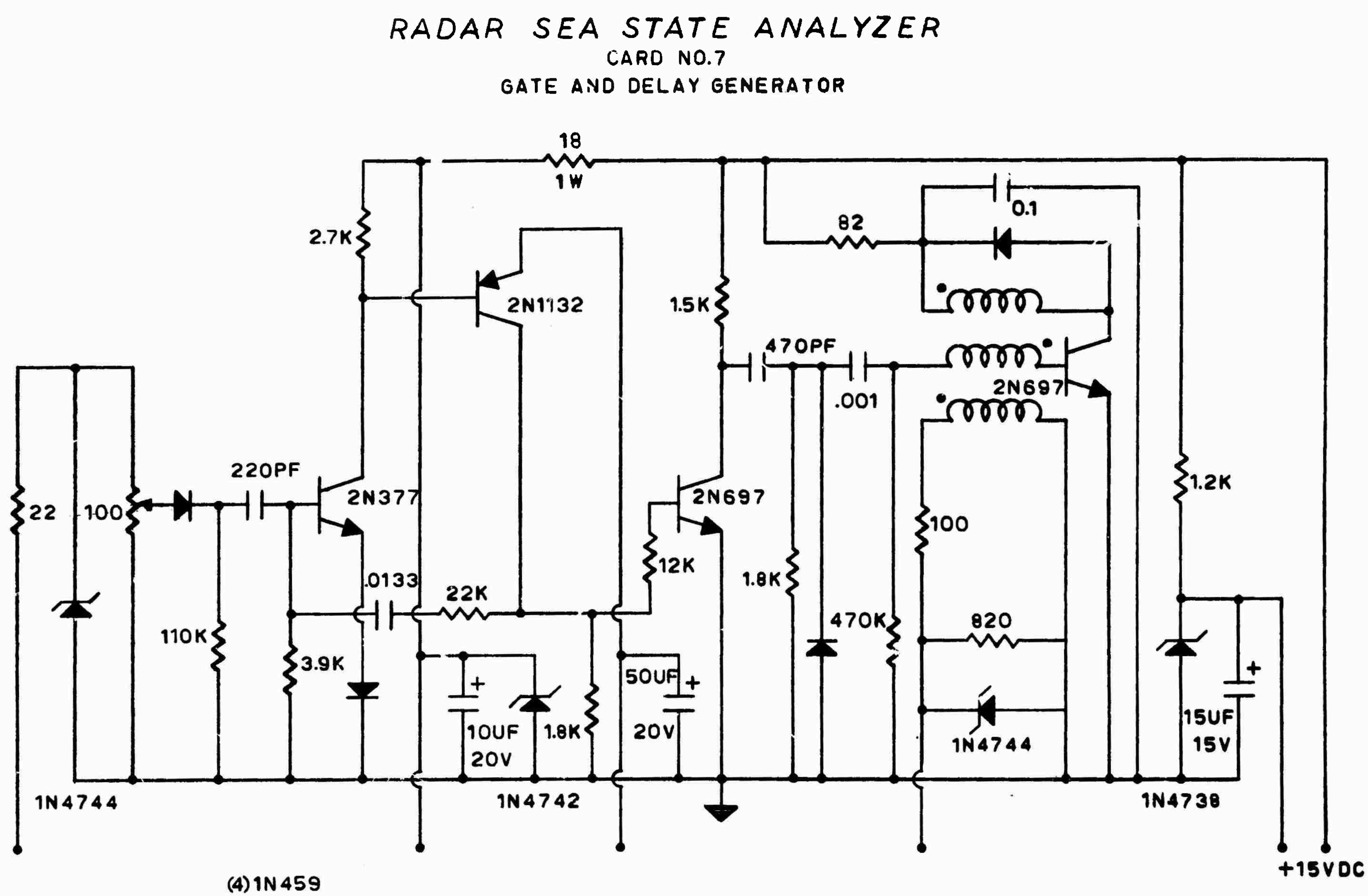


FIGURE 3.8 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER

CARD NO.8

SAMPLE-HOLD AND ANALOG DRIVER

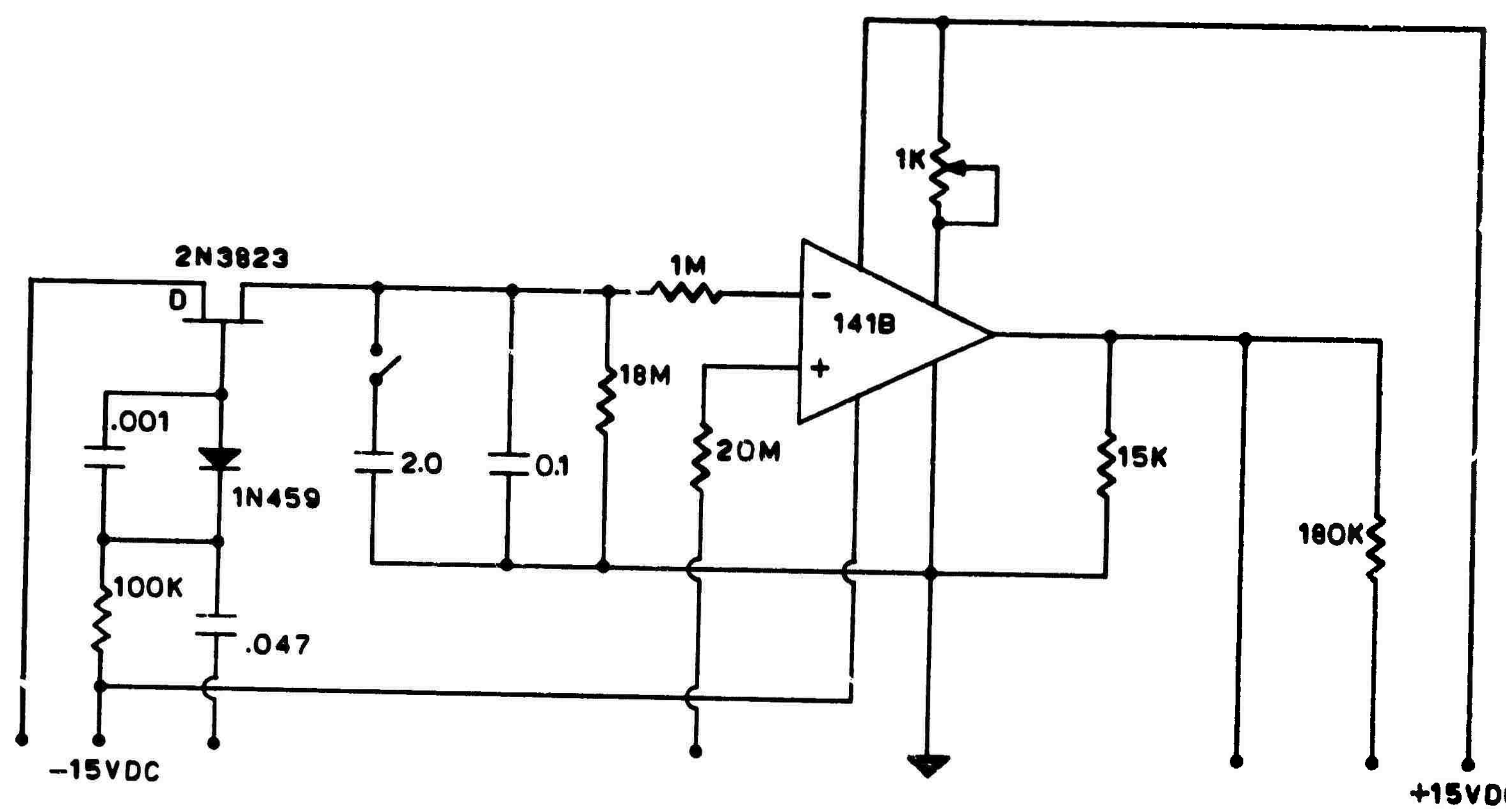


FIGURE 3.9 - SCHEMATIC DIAGRAM

RADAR SEA STATE ANALYZER

REGULATOR CONTROL-LV POWER SUPPLY

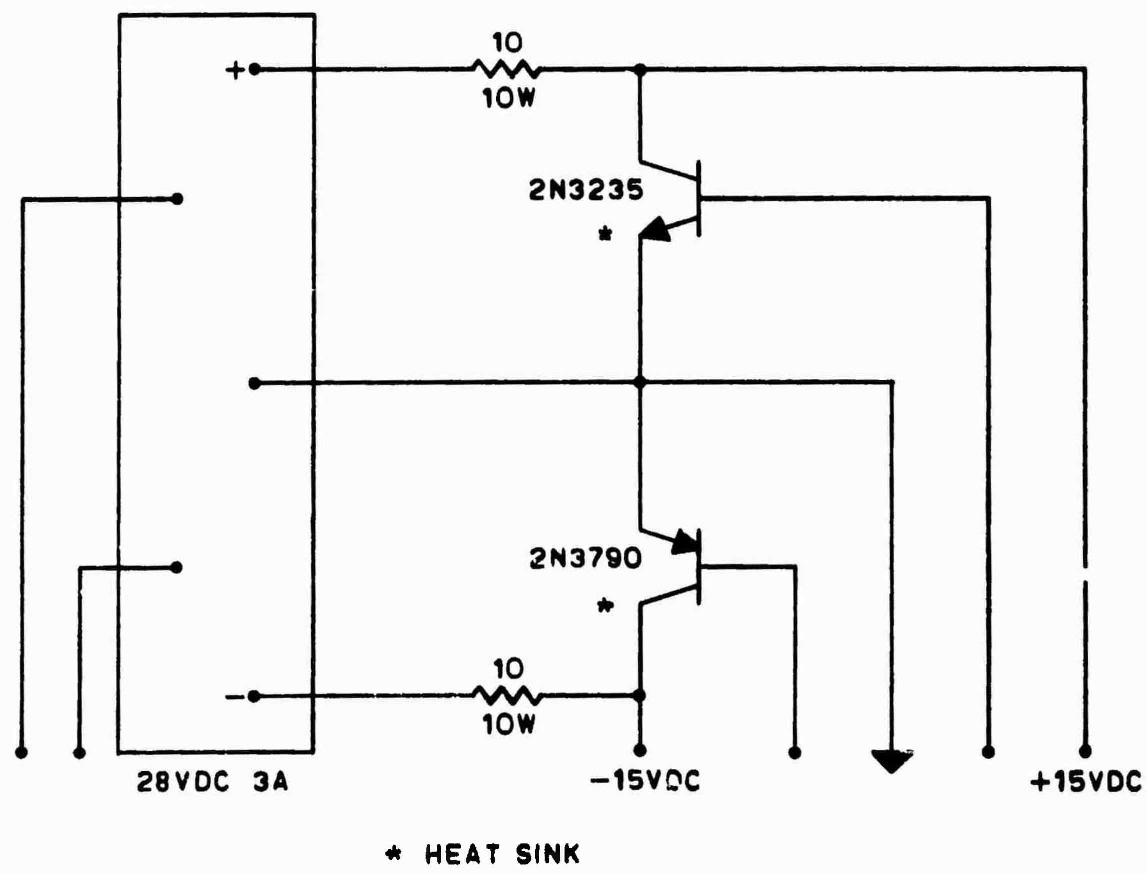


FIGURE 3.10 - SCHEMATIC DIAGRAM

4.0 INSTALLATION

4.1 Inputs

This device is self-contained (see Fig. 4.1) and requires only input signals from the radar with which it is to be used in order to function.

These inputs are applied to BNC connectors on the rear apron, see Fig. 4.2.

Input	Amplitude	Polarity	Duration	Source Impedance
Video	NLT 2V Peak	Positive	N/A	To drive 75 Ω
Trigger	NLT 10V Peak	Positive	NLT 1 μsec	To drive 75 Ω

AC Power	115 VAC, single phase, 50 watts
Dimensions	26" W. x 14" H. x 16" D.
Weight	63 pounds

4.2 Outputs

Electrical outputs from the unit are available on the stripline connectors at the rear on the digital display modules, see Fig. 4.3.

These outputs are BCD, 1248 Positive True Logic, TTL Compatible.

Binary "1" = +5 volts

Binary "0" = +0.2 volts

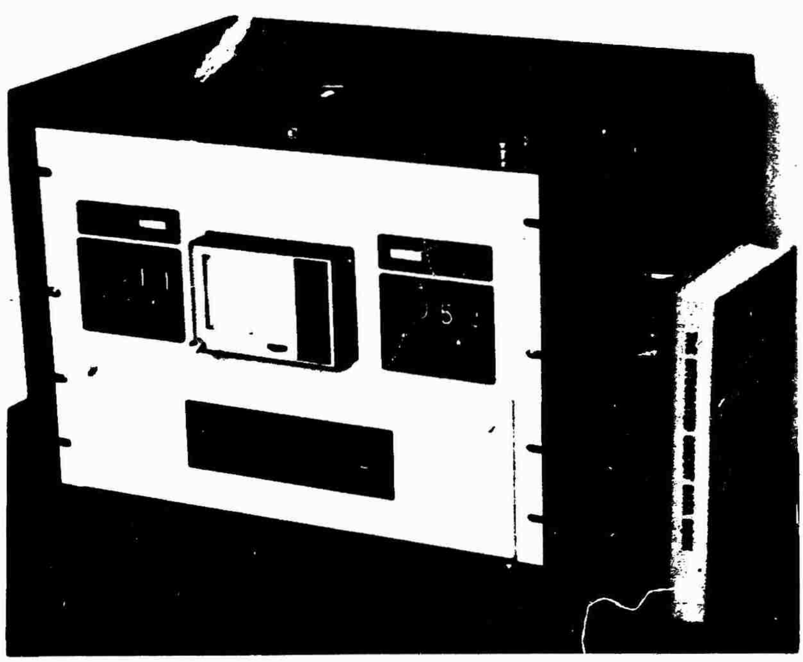


Fig. 4.1 - Radar Sea State Analyzer

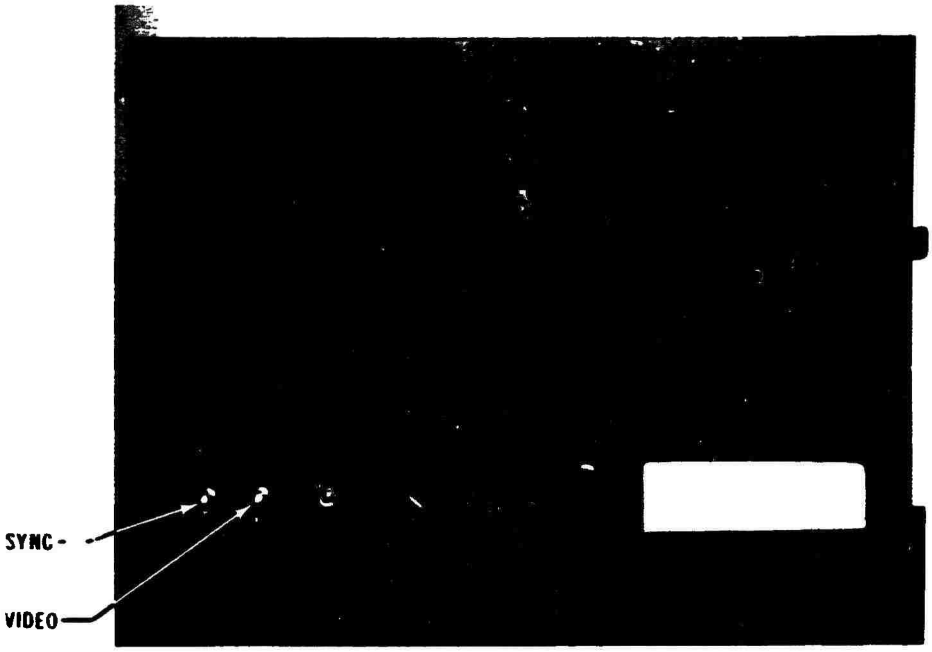


Fig. 4.2 - Rear View

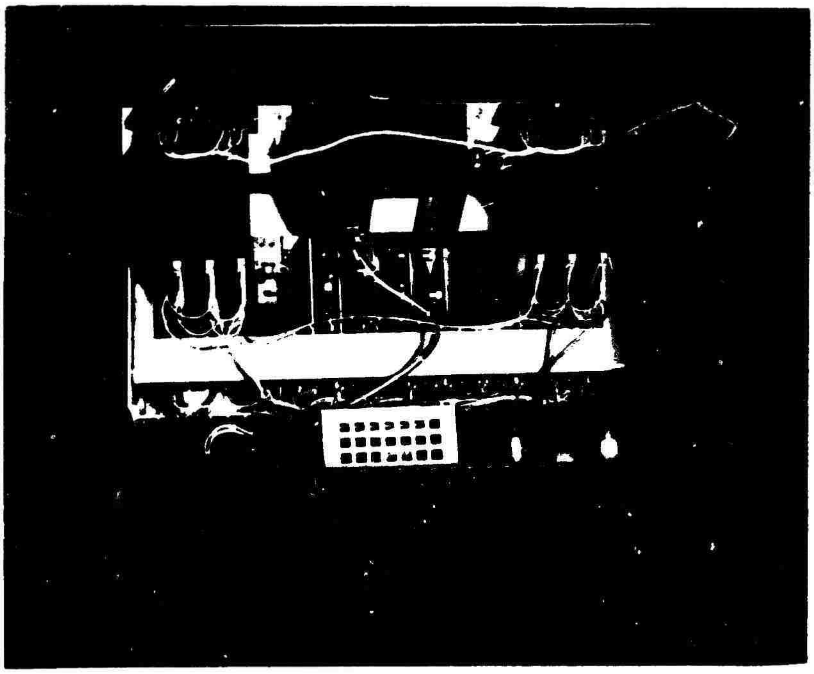


Fig. 4.3 - Top Interior View

5.0 OPERATION AND ADJUSTMENTS

5.1 DIGITAL WAVE PERIOD

There are two sets of digital readouts for wave period in seconds and tenths. These are the front panel displays labeled AVERAGE PERIOD IN SECONDS. One of these is on hold and presents the average wave period most recently computed while the other is computing the period for the new sample. When the new average period is computed, it is held and the two units switch functions with the initial unit going into the compute mode.

5.2 CONTROL PANEL FUNCTIONS

The control panel is located behind the hinged lower cover, (see Fig. 5.1 and 5.2) and contains the following controls, indicators, and test points. The numbers below correspond with the numbers on Figure 5.2.

1. START. The analyzer is turned on by pressing the START button, which becomes illuminated when the unit is on. Successive pressings turn the analyzer off, on etc.

2. DELAY. This control varies the position of the sampling gate, and is adjusted to position the gate at the distance where an analysis is desired.

3. LEVEL. Adjusts the amplitude of the radar video signals applied to the sampling circuitry.

4. RECORDER ON-OFF. Energizes the analog strip chart recorder.

5. EVENT MARK. Places a reference mark on the analog chart recording when pressed.

6. CALIBRATE. Adjusts offset voltage to sample-and-hold circuitry.

7. RESET, LEFT AND RIGHT. Pressing these buttons resets the appropriate display to zero.

8. Δ SLOPE. When illuminated, indicates that a zero-crossing in the input data has occurred.

9. PERIODS COUNTED. Displays the number of periods counted in a particular computing sequence.

10. BNC TEST POINTS.

    A. GATE. Allows oscilloscope monitoring of the sample gate position.

    B. SYNC. Provides synchronizing pulse to a monitor oscilloscope.

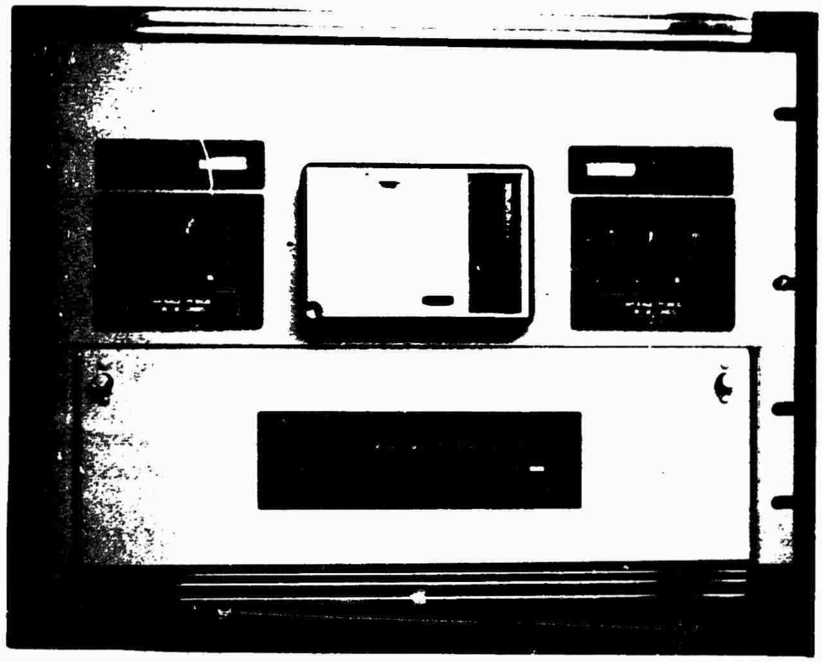


Fig. 5.1 - Front View

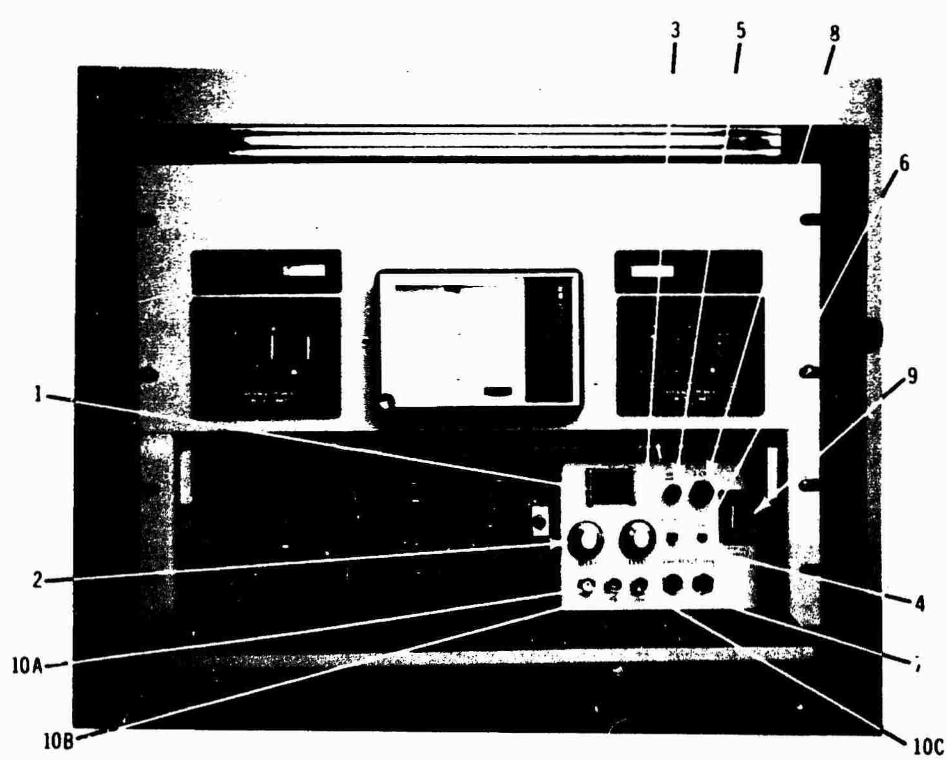


Fig. 5.2 - Front View, Control Panel Exposed

C. VIDEO. Allows oscilloscope monitoring of the radar video signals applied to the analyzer.

5.3 ADJUSTMENT AND OPERATION PROCEDURE

A suggested procedure for initial set-up of this instrument with a given radar system follows:

5.3.1 Preliminary Radar System Adjustments

(1) With the radar antenna rotating, observe a PPI display to determine the presence of "sea return".

(2) Note a particular azimuth and range among these signals where a wave period measurement is desired.

(3) Stop the radar antenna along this selected azimuth.

5.3.2 Analyzer Adjustments and Operating Procedure

(1) Connect input radar signals to the analyzer as discussed in Section 4.

(2) Connect a dual-trace oscilloscope to the GATE and VIDEO test points. Connect synchronizing input to the oscilloscope to SYNC. test point.

(3) Turn analyzer ON by pressing START button. Disregard any readings on the display modules.

(4) Turn recorder switch to OFF.

(5) Turn LEVEL control full CCW (minimum dial reading).

(6) Adjust the oscilloscope sweep speed and vertical inputs to display simultaneously (a) the video input encompassing the distance to the "sea return" of interest, and (b) the GATE generated by the analyzer (video level at test point is unaffected by position of LEVEL control).

(7) Adjust the DELAY control to position the gate at the same distance as the desired "sea return" analysis point.

(8) Turn RECORDER switch ON.

(9) Increase LEVEL control until recorder needle varies approximately ± 5 mm (1 cm peak to peak) as the input data fluctuates. Verify that the Δ SLOPE indicator is alternately illuminated and off as the input varies. This adjustment and check provides the proper input amplitude to the sampling and logic circuitry.

(10) RESET both left and right modules. The PERIODS COUNTED display should begin to register an increasing number at a rate determined by the input data - generally, several seconds between changes.

(11) Observe the operation for several computations and readout transfers to insure that input adjustment is satisfactory. Unless sea conditions are changing rapidly, the successive computed periods should remain about constant.

(12) If a permanent analog record is not desired for a particular sampling, the RECORDER may be turned off. This does not interfere with the digital computation and normal operation will continue.

(13) When a particular measurement is completed, the unit may be turned off (by pressing START button) and radar antenna rotation resumed. Future measurement requires only stopping antenna, turning on unit and verifying that sample gate is at the desired position.

After any LEVEL or DELAY adjustments, the analyzer should be RESET to insure that computation begins from proper starting point.

6.0 INTERPRETATION OF READOUT

It is assumed that the radar antenna will remain stationary in azimuth and elevation when measurements are being made with the Radar Sea State Analyzer. The proper antenna elevation angle will depend upon the height of the antenna above sea level. Assuming that the antenna is within a few tens of feet above sea level, an elevation angle near zero degrees should be satisfactory. This is not a critical adjustment and can be chosen within reasonable tolerances. However, the same elevation angle should be used each day in order to compare signal amplitudes from day to day.

6.1 DIGITAL WAVE PERIOD

The wave period in units and tenths of seconds can be read directly from the front panel of the instrument as described in Section 5.1. If time permits, an average of several readings can be taken to give a longer-term average wave period. Since each digital readout is already an average of ten periods, further averaging by the operator will represent multiples of this number. Simultaneous average wave periods taken from radar data and a wave sensor converge to closer agreement with increased time averaging, as would be expected.

The average wave period in seconds can be used to determine the wavelength in feet and the wave velocity in knots with the aid of the graphical presentation of the theoretical relationship between wave lengths, velocities, and periods of wind-driven gravity waves in deep water, Figure 6.1, Bigelow and Edmondson [51]. A copy of this graph is attached to the instrument. As an illustration of the use of the graph, an observed average wave period of 10 seconds gives approximately a wavelength of 500 ft and a wave velocity of 30 knots.

6.2 ANALOG CHART READOUT

An analog chart readout is provided to aid the user in estimating relative wave heights, Figure 6.2. However, it also provides a permanent record that can be retained if such is desired. The wave period for a specific chart recorded sample can then be analyzed in other ways, if necessary. For example, rates-of-change of wave period for a particular time interval may be computed. The analog chart presents the same data that are used by the digital

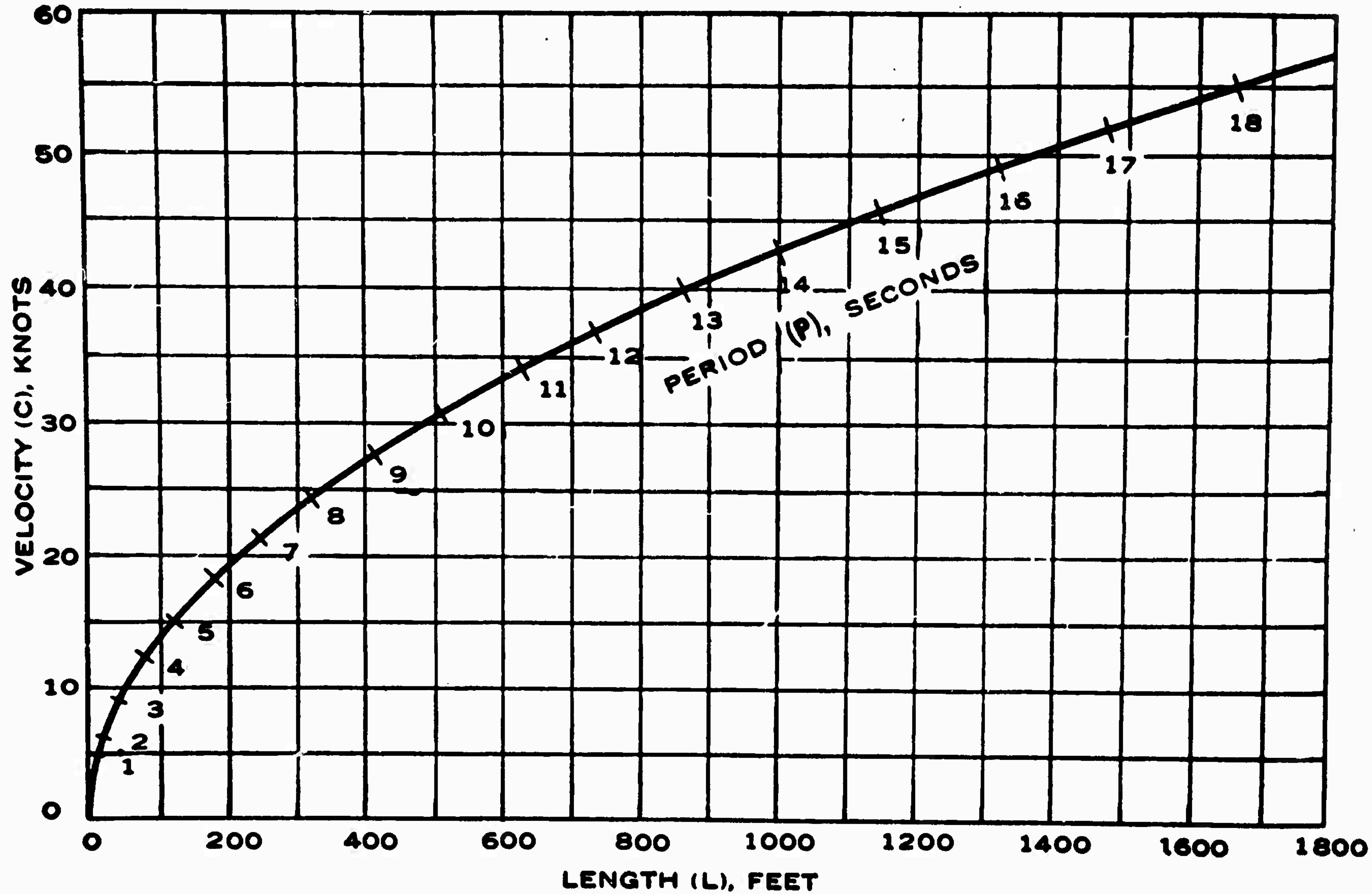


FIG. 6.1 - **Graphical presentation of the theoretical relationship between wave lengths, velocities, and periods in deep water.**

wave period computer to calculate the wave period in real time. Assuming that the sea state analyzer is turned on and off at certain intervals of time in order to obtain and record the sea conditions, then on and off date and time marks may be entered on the chart to show when the data were taken.

Since the signal amplitude is a function of wave height, radar parameters, antenna azimuth with respect to the direction of the waves, wind speed and direction, and analyzer adjustments, all of these will have to be considered in estimating wave height from the amplitude of the recorded signals. Some of these variables can be greatly reduced or eliminated by standardizing operating procedures. If the antenna is directed upwind, the primary variable that will affect the estimation of wave height from the signal amplitude will be wind speed. For a given wave height, the radar signal amplitude will be greater when the wind is increasing, or strong and steady, than when it is decreasing. Also, the relationship between signal amplitude and wave height is non-linear. The signal amplitude rises rapidly with increasing wave height up to a few feet and then shows a slow increase in amplitude if the waves continue to grow. However, if radar and analyzer adjustments are unchanged, increasing signal amplitude corresponds to increasing wave height.

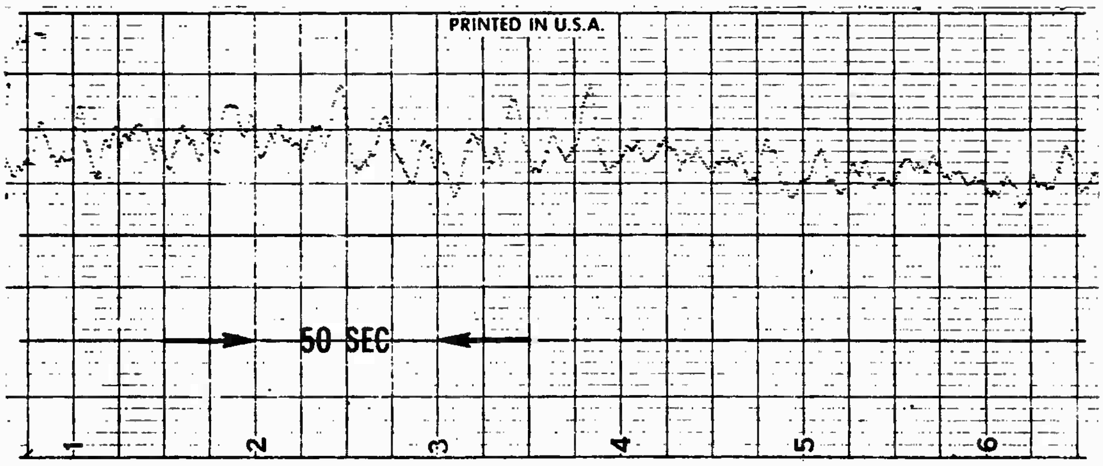


FIG. 6.2 - ANALOG CHART RECORD

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13. ABSTRACT

The theory and description of a Radar Sea State Analyzer are presented. Installation, operation, adjustments, and readout interpretation instructions are also included. The instrument is the product of three years of research to obtain sea state information by using an existing radar as the remote sensor. This device is an attachment to the radar and examines the "sea return" signals at a selected range within the limits of the radar horizon. The outputs are available in digital and analog form. It is small in size and uses modern semi-conductor techniques, integrated circuits, etc. to achieve stability, accuracy and reliability.

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