RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

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RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

by

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THESIS

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PREFACE

The purpose of the project described in this thesis has been to develop a spectrum analyser for use in processing the data from the radio telescope at this University. This project is part of the work carried on by the Laboratory of Millimeter Wave Propagation and Astronomy of The University of Texas under the sponsorship of the National Aeronautics and Space Administration on research grant NsG-432.

I want to express my sincere and deep appreciation to Mr. C. W. Tolbert who conceived the idea and recognized the need of this project and the entire staff of the Laboratory of Millimeter Wave Propagation and Astronomy for their counsel, advise, and patience.

September, 1965 John H. Sizelan

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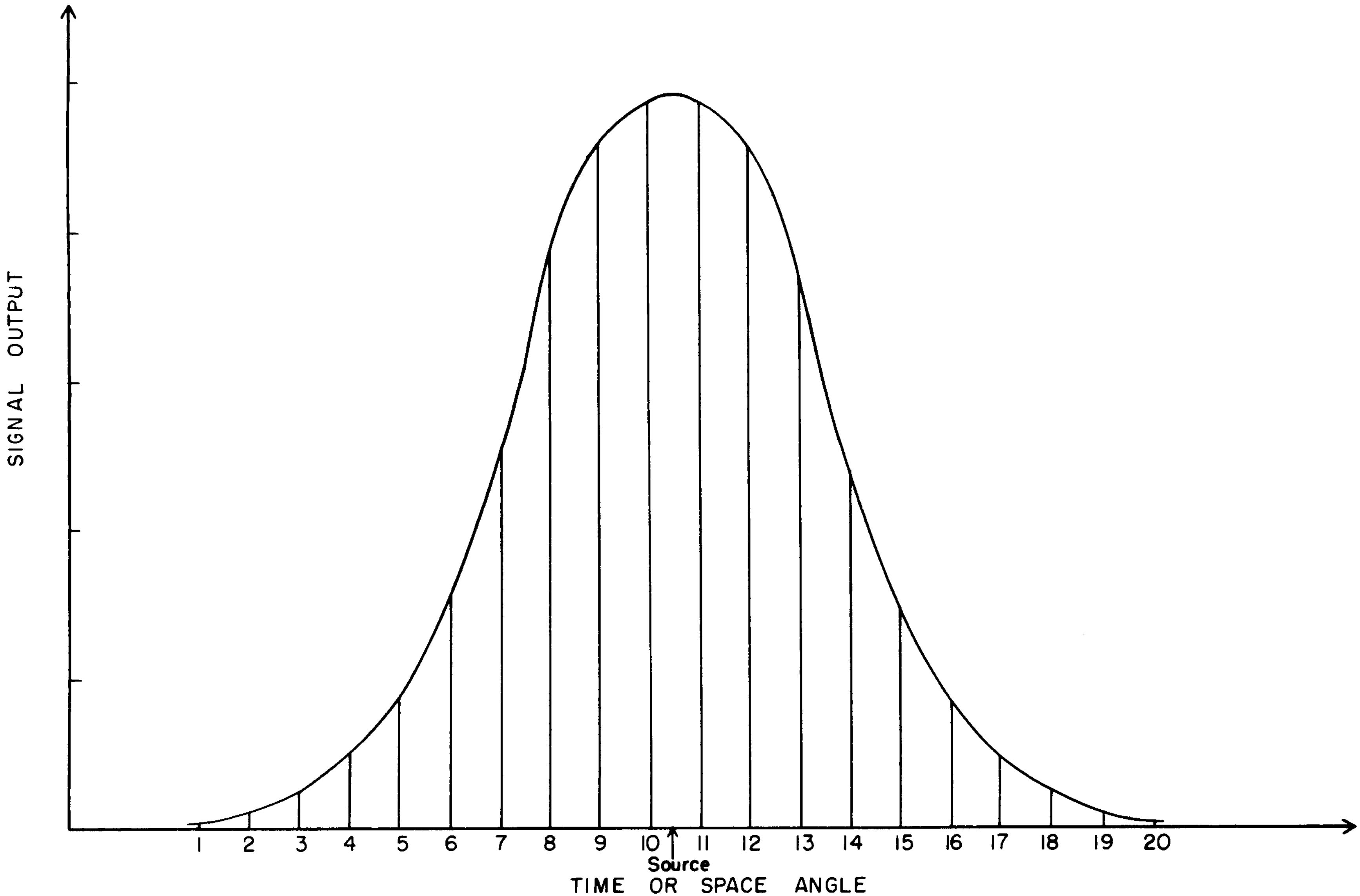
I. INTRODUCTION

The signal to noise ratio of a coherent signal superimposed on incoherent noise can be improved by a factor of n if n runs of the composite signal (coherent signal and incoherent noise) are added synchronously. The reason for this is that the incoherent noise power will increase by a factor of n whereas the coherent signal power will increase by a factor of n squared.

As a radio telescope scans a small source at constant velocity the output of the receiver will be Gausian distributed but as many scans are summed the signal will appear as shown in Fig. 1. Of course the output of a single scan will be well defined only if the signal to noise ratio out of the receiver is high. In practice, particularly at millimeter wavelengths, the signal to noise ratio of a single scan may be less than unity and a summing method is needed to increase the signal to noise ratio.

In order to accomplish the summation of numerous scans, the receiver output must be sampled at regular time intervals during a scan and the summation performed on corresponding times of successive scans. Because of disturbing factors such as clouds or rapid changes in water vapor content of the atmosphere which invalidate certain scans, it is necessary to obtain a visual record of each scan.

In the past, paper chart records have been sampled and numerical summation performed. This is a very tedious process and subject to



CHARACTERISTIC OF RADIO TELESCOPE WHEN SCANNED ACROSS A POINT SOURCE AT CONSTANT VELOCITY

FIG. 1.

some error in data readoff. It is the purpose of this study to develop a device for automatically processing the data from the receiver.

The requirements of this device are 1) to sample the data, 2) to store the data for comparison with later scans, 3) to sum data from corresponding times of a large number of scans, and 4) to present the composite scan. The unique requirement of the device is to perform these functions at the receiver site with a minimum of components.

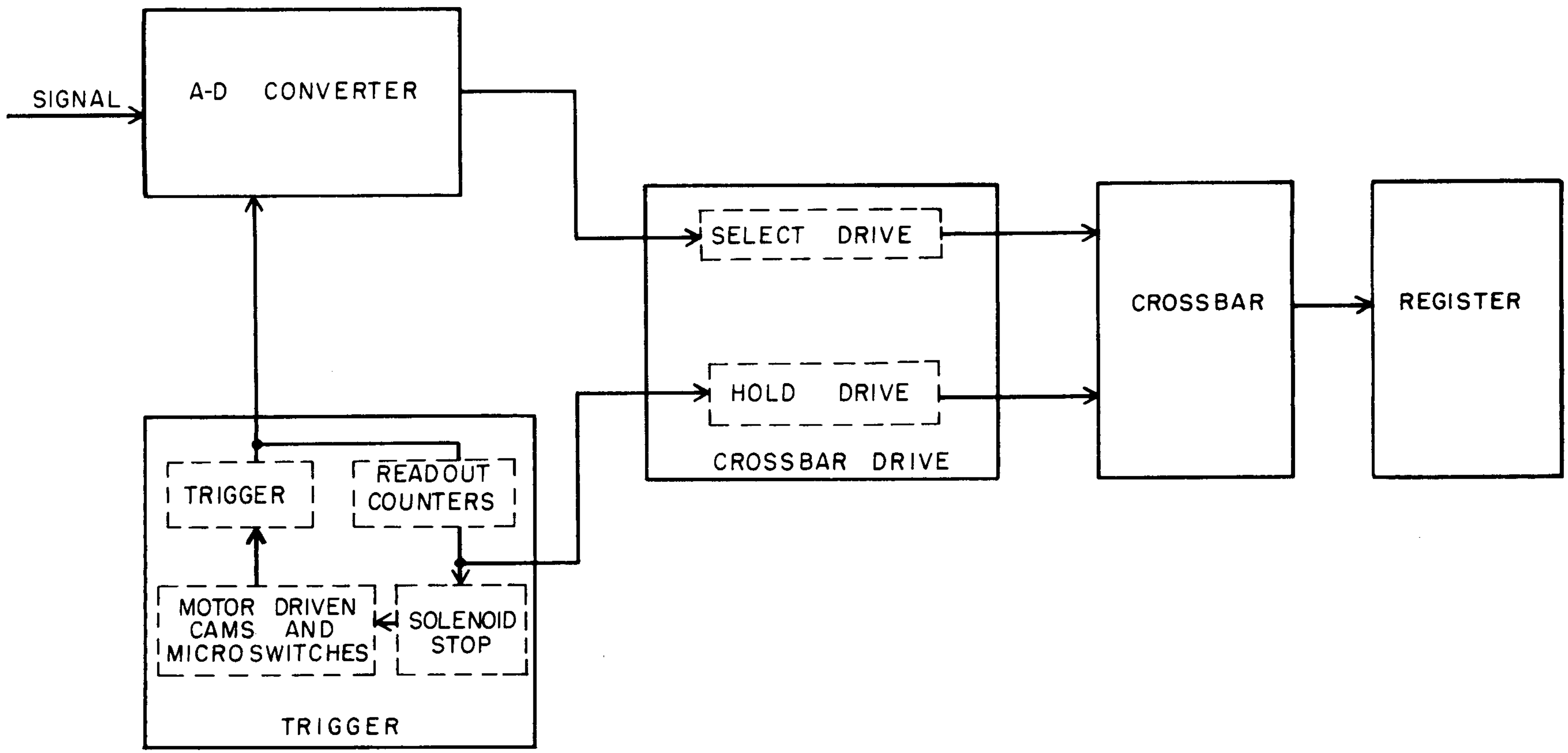
A block diagram of the device described in this thesis is shown in Fig. 2.

. The trigger determines the instants when samples of the signal are taken. In it a motor driven cam-microswitch assembly produces a short negative pulse to the analog to digital converter.

The analog to digital converter consists of a galvanometer driven by the signal which directs a light beam on a series of photodiodes which gate the pulses out of the trigger.

In the crossbar drive transistorized monostable multivibrators triggered by pulses out of the converter control the select relays of the crossbar. Drive amplifiers controlled by the trigger assembly drive the hold relays of the crossbar.

The crossbar stores the information of one scan and controls the register which displays the composite scan. The register consists of 500 magnetic counters arranged in 20 columns of twenty-five each.



BLOCK DIAGRAM RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

FIG. 2.

II. ILLUSTRATION OF THE SUMMING TECHNIQUE

To define the signal in Fig. 1, 20 samples of the signal are taken as shown in the figure. Each of the samples is to be stored separately in order that in succeeding scans each sample can be compared to its respective sample in previous scans. Each of the samples is compared by the following method:

Consider the case where the signal level is digitized into 25 equal parts. Choose the example where 10 scans are made on the signal and the levels of the n'th sample of the series of scans be: 19, 12, 18, 15, 11, 16, 14, 18, 13, 18.

Consider now a column of 25 counters for the n'th sample, each counter represents a level of the signal and each counter is so wired that all counters below the matching signal level advance one count on command for the n'th sample of each scan. For the n'th sample of the 10 scans: all counters below and counter 11 will read 10 because that level was always equalled or exceeded and counter 20 and all above it will read 0 because these levels were never equalled. Fig. 3 shows the resulting counter display after 10 scans.

Note the median value is between 15 and 16 because that level was equalled or exceeded half the time or 5 times out of the 10. The median value will be the most probable value of the signal.

The other 19 samples will be processed in the same manner in 19 other columns of counters.

Counter No.	Counter Indication
25	0
24	0
23	0
22	0
21	0
20	0
19	1
18	4
17	4
16	5
15	6
14	7
13	8
12	9
11	10
10	10
9	10
8	10
7	10
6	10
5	10
4	10
3	10
2	10
1	10

Fig. 3 Example of Counter Display for the n'th Sample after 10 Runs.

III. DESIGN

Data storage times of the order of hours with an accuracy of 2% are required of the system. Digital processing was therefore selected.

The first instrumentation requirement was an analog to digital converter. Several types of converters were considered. For instance a digital voltmeter was considered and rejected because of cost and complication of AND and OR gates necessary to obtain the 50 pieces of information required for an accuracy of 2%. A servo driven commutator was considered and rejected because of cost and difficulty of manufacture. The galvanometer-photodiode converter was selected as the most efficient method considering reliability, cost, availability of parts, and visual display.

A system frequency response of 5 cps for the spectrum analyser was selected as suitable for processing the data of those observations requiring the use of the analyser. (5 cps to faithfully reproduce the signal out of an integrating network of time constant 1 second.)

A block diagram of the system is shown in Fig. 2 and a complete system drawing in Fig. 11. The timer determines the instants when samples are taken. The analog to digital converter changes the input signal into digitized form. The crossbar stores the information of one run, the information of which can then be inserted into the counters of the register.

The timer consists of: 1) a series of microswitches actuated by cams driven by a synchronous motor, 2) associated circuitry to produce a negative pulse when the appropriate microswitch operates, 3) three magnetic readout counters controlled by the aforementioned pulses, and 4) a solenoid driven motor stop controlled by the readout counters.

Because sampling intervals as long as 30 seconds were required the motor driven cam-microswitch arrangement was used. This method has obvious advantages over other methods considering simplicity and cost.

As each run consists of 20 samples, each of which must be stored separately, magnetic readout counters were considered the best way to count sampling pulses. The readout counters could then be used to count the 20 pulses and also determine where each sample is stored.

The analog to digital converter consists of a mirror galvanometer which directs a light beam on a series of photodiodes. The galvanometer is driven by the input signal and the photodiodes act as gates for the negative pulses out of the timer.

The galvanometer required a period of 0.2 seconds by the fact that the maximum interesting frequency was five cycles per second. The photodiodes had to have a high on-off impedance ratio and a fast response time under conditions of 0 to 150 degrees Fahrenheit. As the minimum on-off time of a single photodiode is 4 milliseconds (0.2 sec./50 photodiodes) a response time of 0.4 milliseconds was desirable to allow time for a trigger pulse to pass.

The crossbar drive consists of transistorized multivibrators and drive amplifiers to drive the select relays of the crossbar and drive amplifiers to drive the hold relays. The select circuits are controlled by the pulses out of the converter and the hold circuits are controlled by the readout counters.

The crossbar consists of two standard 10 x 10 crossbar switches with six pairs of contacts per position. The crossbar was selected for a short term memory because of cost and reliability.

Another method was considered at first. It consisted of 500 capacitors charged through diodes each of which would advance its respective register counter by one at the end of the run. This method was rejected, however, when it was found that 125 microfarad capacitors were needed and electrolytic capacitors would not hold their charge for the time required (8 minutes).

The register consists of 500 magnetic counters arranged in 20 columns of 25 each. The counters were selected because of their low cost, compact size, and low power requirement.

The register is controlled by the crossbar and the register relay. The counters are wired so that all counters in a column below that one selected by the crossbar will advance with the operation of the register relay.

Twenty samples of the input signal are taken on each run, each of which is stored in one of the 20 hold columns of the crossbar. The select relays of the two crossbar switches are connected in parallel producing in effect one 10 x 20 crossbar. The 10 select relays read the digital information out of the converter.

At the end of the run the register button may be depressed thereby putting the information stored in each of the 20 hold columns of the crossbar in its respective column of register counters. Alternately the release button may be depressed removing all information from the crossbar.

IV. INSTRUMENTATION DETAILS AND OPERATING PROCEDURE

There are six cam driven microswitches driven by the two RPM synchronous motor. The cams have 1, 2, 3, 6, 10, and 15 lobes respectively so that sample intervals of 30, 15, 10, 5, 3, and 2 seconds are available. The sample interval selector switch selects which of these six microswitches are used. The -24 volts switched by these switches operates a trigger circuit which produces a 2 millisecond negative pulse. The trigger circuit is disabled by the ground furnished by the readout counters at the count of 20 and enabled again by depressing the start button which removes this ground.

The stop solenoid is energized to start the synchronous motor. It is also controlled by the 20th count of the readout counters and the start button.

The three readout counters are magnetic counters with electrical readout terminals. They are equipped with a transfer switch which closes at the count of nine and a reset switch which opens at the count of zero. They are driven by the amplified output of a 0.2 monostable multivibrator triggered by the pulses out of the trigger circuit. As the readouts of these counters advance only on release of their armatures the readout is in effect lagging the trigger by 0.2 sec. This allows time for the select relays of the crossbar to operate before the hold relays are energized.

The ready light lights when the readout counters are in the start position (i.e. 000, 200, 400, 600, 800).

The reset button applies -24 volts to the inputs of the three readout counters through each's respective reset contacts. By this method all counters can be set to zero by a maximum of nine operations of the reset button.

The A-D converter mirror galvanometer has a period of 0.2 sec. There are 50 photodiodes arranged around the galvanometer to gate the 2 millisecond pulse from the trigger circuit. (50 for an accuracy of 2%.) The photodiodes illuminated by the light beam from the galvanometer are low impedance (4 Kohms or lower) allowing the trigger through.

Only 25 outputs are taken from the 50 photodiodes to reduce the cost of the register. Which 25 is determined by which range plug is used. The expand plug parallels adjacent diodes into pairs thereby resolving the signal into 4% accuracy; the low plug uses diodes 1-25; the mid plug uses diodes 14-48; the high plug uses diodes 26-50. The latter three resolve the signal to 2%.

It was considered necessary to provide a short term memory to store the information of one run in order that the information of the last run may or may not be inserted into the register at the discretion of the operator. Two telephone crossbar switches were selected for this purpose.

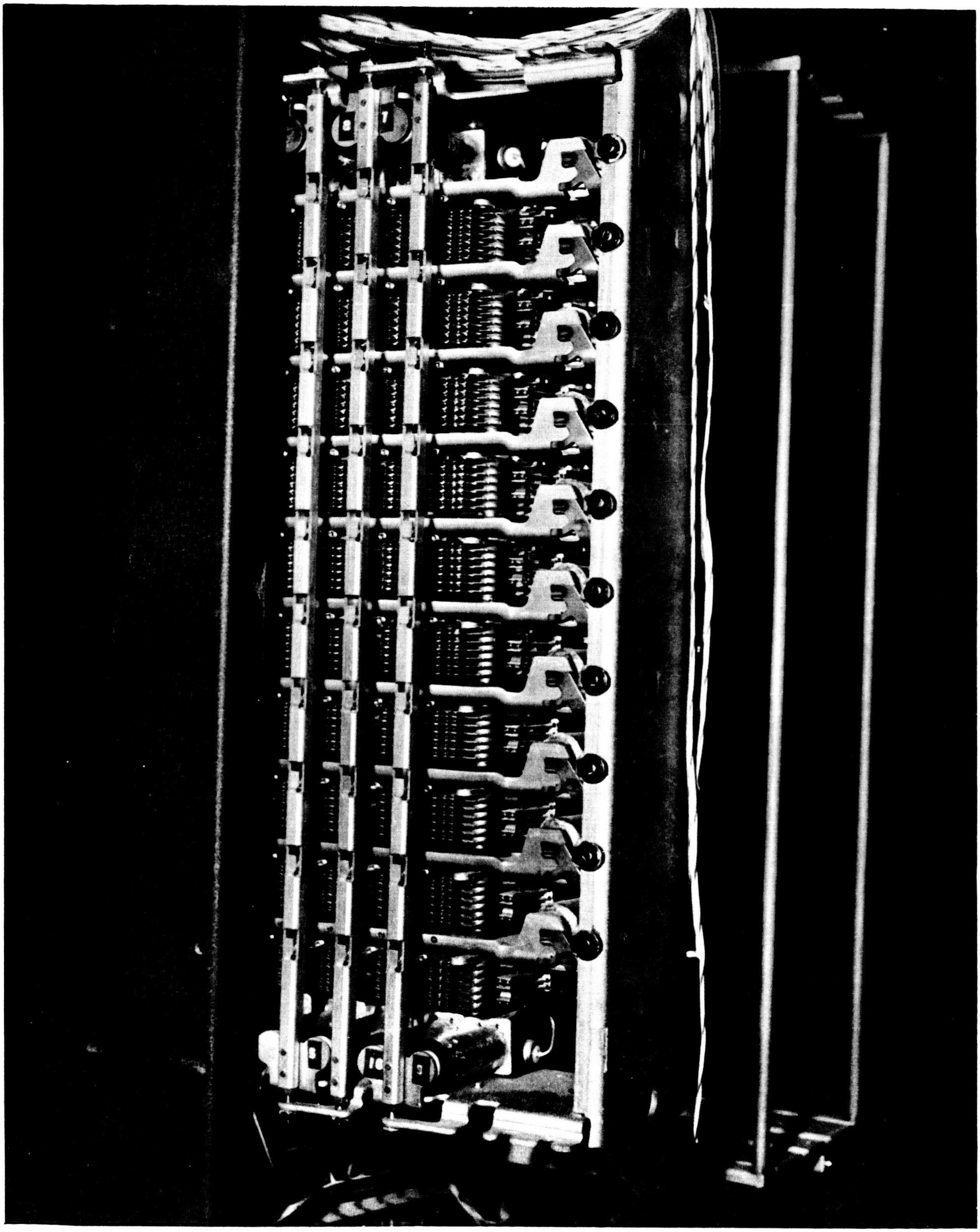
Each of the two crossbar switches consist of 100 positions with six pairs of contacts per position. (See Fig. 4) The positions are arranged in a 10 x 10 matrix and are controlled by 10 select relays and ten hold relays. Each of the select and hold relays also control two pairs of auxiliary contacts which operate when its respective relay operates.

Each select relay operates an arm which selects one of 10 rows of positions which can be operated. (They do not operate the positions.) Each hold relay actuates an arm which operates those positions selected by the select relays in that particular hold column and holds those positions operated regardless of succeeding actuation or deactuation of any of the select relays. Therefore a position can be released only by releasing its associated hold relay.

It should be noted that the 60 pairs of contacts associated with each hold column of positions are not independent but are internally connected as shown on the system drawing (Fig. 11).

The register consists of 500 magnetic counters with manual reset arranged in 20 columns of 25 each. They are controlled by the crossbar and the register relay. The crossbar furnishes a ground to the proper counters and the register relay furnishes -24 volts to all counters. The register relay is controlled by the register button.

As there are 25 pieces of information to be stored for each sample (25 outputs from the range plug) and only 10 select relays, more than one relay must operate to store some pieces of information. OR gates



CROSSBAR SWITCH

FIG. 4.

are used to channel this information to the proper select relays as shown on the system drawing.

For proper storage of the information out of the converter: first the select relays must operate, second the proper hold relay must operate and hold, and third the select relays must release to make ready for the next sample. This is accomplished by operating the select relays with a 0.4 sec. monostable multivibrator. One set of auxiliary contacts on the hold relays are wired in to keep the hold relays energized.

As it is possible for two photodiodes to be illuminated at the same time provision must be made to select one of them. This is done by means of a cutoff circuit to adjacent select multivibrators (see system drawing). In this way should two adjacent multivibrators be triggered the negative voltage on the collector of one (which is wired to the base of the second transistor of the adjacent multivibrator) will release the adjacent multivibrator within 0.1 sec. This is sufficient time before the hold relay operates.

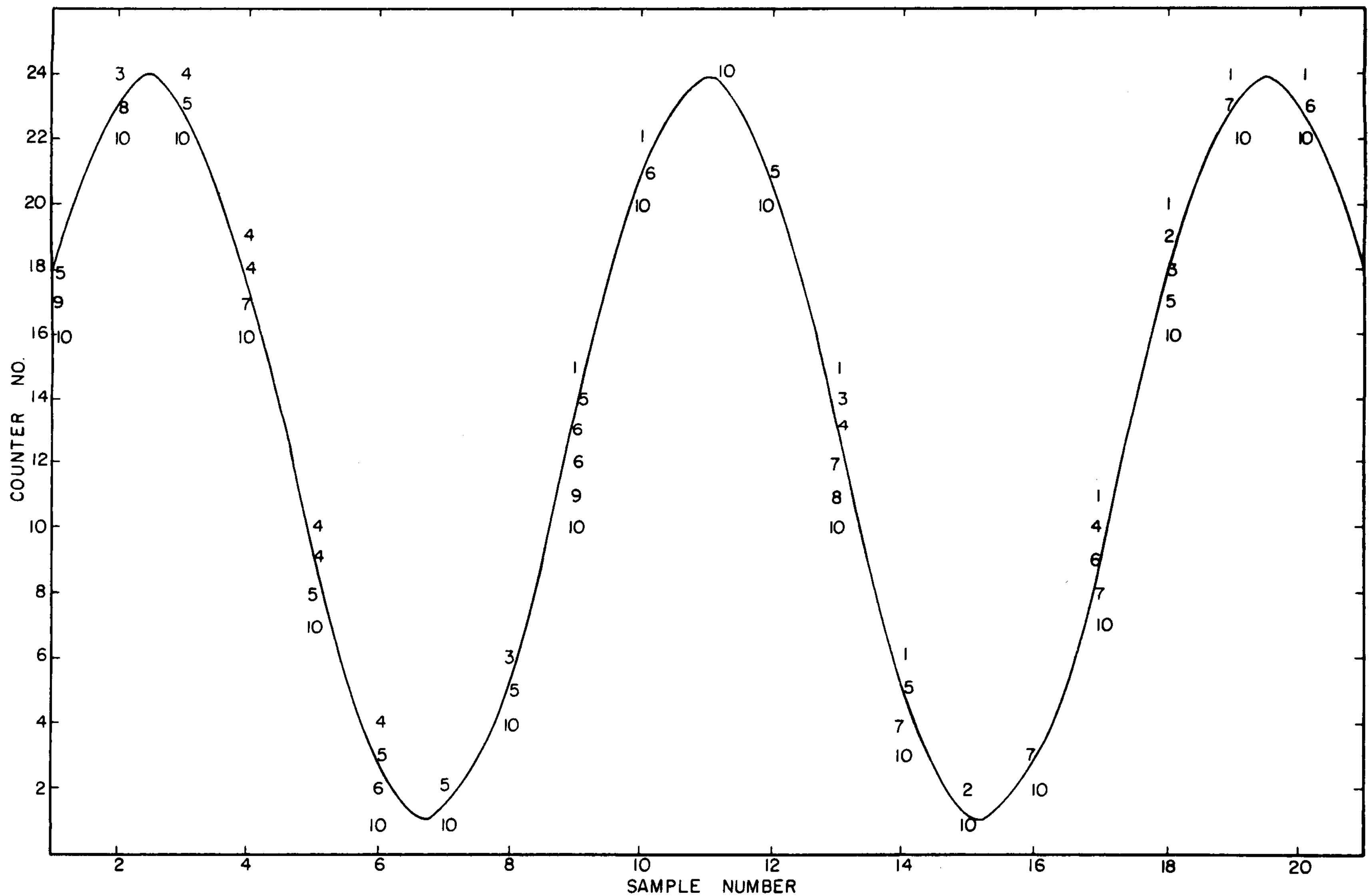
A release button is provided to release all hold relays. It removes -24 volts from all hold relays.

An option is provided to obtain the spectrum of a single signal. Replacement of the red program plug with the gray one accomplishes this. This is done by storing all twenty samples in one column of the register counters.

Replacement of the plugs results in: 1) removal of -24 volts from all hold relays except number one, 2) control of hold relay one is switched from the readout counters and hold contacts to a 0.4 sec. monostable multivibrator delayed from the trigger pulse by 0.2 sec. (accomplished by triggering the 0.4 sec. multivibrator by the differentiated and rectified output of the readout counter drive), 3) one set of auxiliary contacts on hold relay one is used to trigger a 0.1 sec. monostable multivibrator the amplified output of which applies -24 volts to all register counters in column one. Therefore each sample results in the operation of the proper select relays as before, the operation of hold relay one after 0.2 seconds, the application of -24 volts for 0.1 second to the register counters of column one, and the release of the crossbar 0.6 seconds after the initial trigger pulse. The system is then ready for the next sample which will be stored by the same procedure.

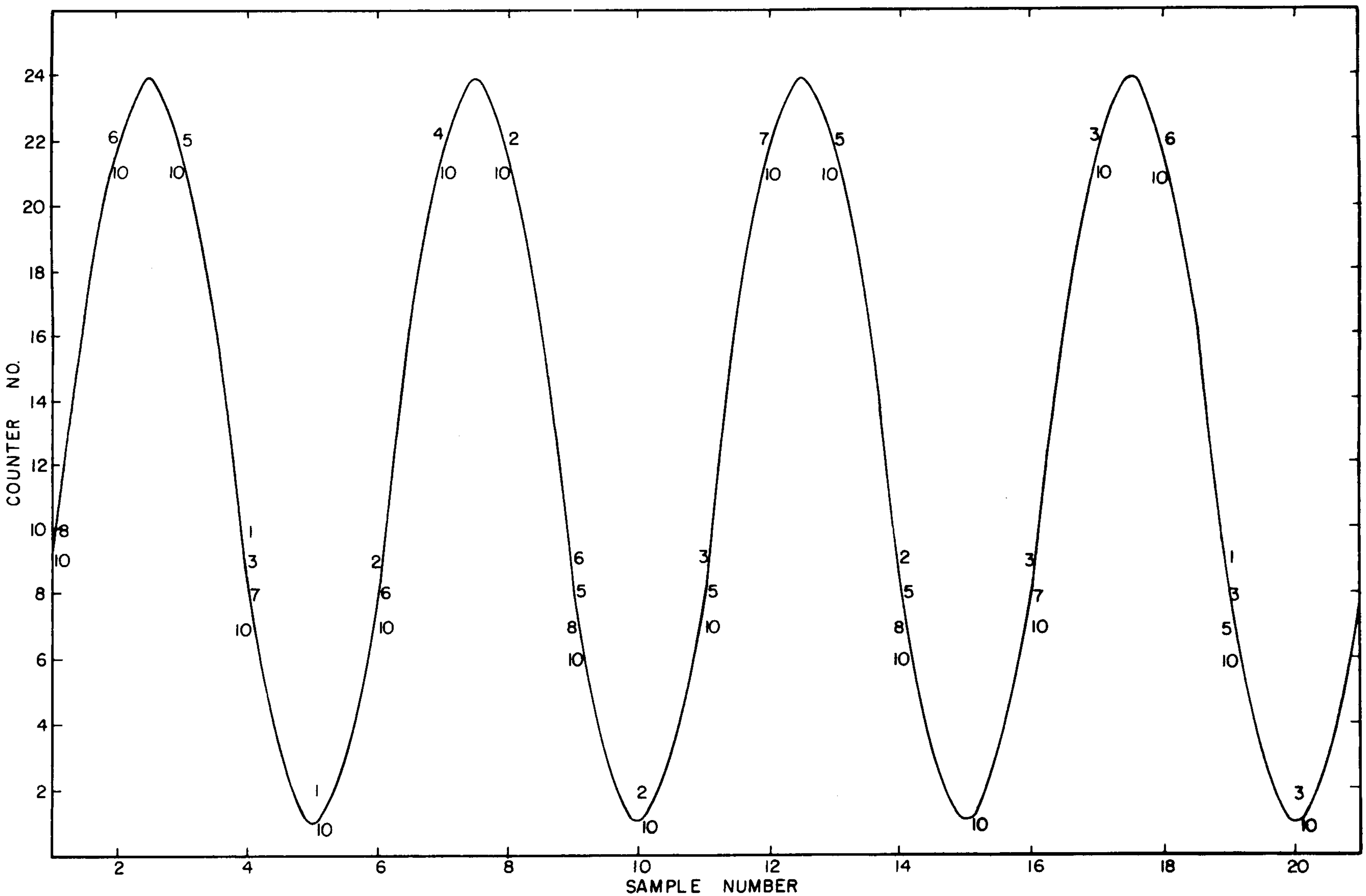
V. SPECTRUM ANALYSER TEST AND PERFORMANCE

The system was driven by a noisy cosine driving voltage of period 17 seconds, 10 seconds, and 4.45 seconds. The results are shown in Fig. 5, 6, and 7. Ten runs were made for each period. The noise was caused by roughness and unsymmetries of the sine potentiometer used to generate the voltage and a degree of randomness of the phase of the driving voltage. As the system works well for a driving voltage of period 4.45 sec. it will operate well for a signal whose maximum frequency component's period is 15 seconds. This is the maximum frequency expected in normal operation of the system.



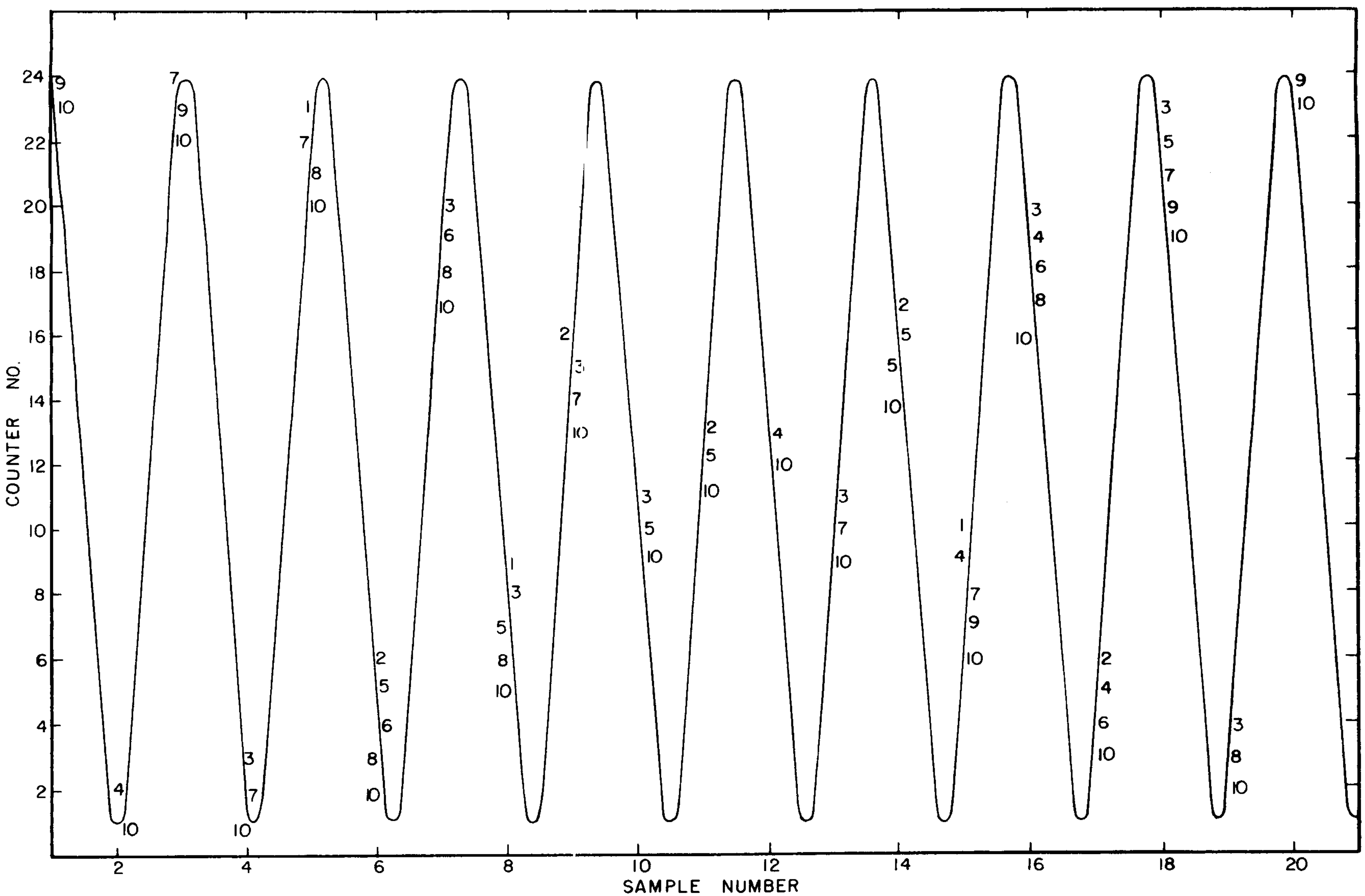
RESPONSE OF SPECTRUM ANALYSER DRIVEN BY COSINE SIGNAL OF PERIOD 17 SEC.
NUMBERS INDICATE COUNTER READINGS. ALL COUNTERS $\substack{\text{ABOVE}\\\text{BELOW}}$ NUMBERS INDICATED READ $\substack{0\\10}$.

FIG. 5.



RESPONSE OF SPECTRUM ANALYSER DRIVEN BY COSINE SIGNAL OF PERIOD 10 SEC.
NUMBERS INDICATE COUNTER READINGS. ALL COUNTERS $^{\text{ABOVE}}_{\text{BELOW}}$ NUMBERS INDICATED READ $^{0}_{10}$.

FIG. 6.



RESPONSE OF SPECTRUM ANALYSER DRIVEN BY COSINE SIGNAL OF PERIOD 4.45 SEC.

NUMBERS INDICATE COUNTER READINGS. ALL COUNTERS ABOVE / BELOW NUMBERS INDICATED READ 0 / 10.

FIG. 7.

VI. DISCUSSION

It might be thought that this method of increasing the signal to noise ratio is not needed and that a limitless improvement in the signal to noise ratio can be obtained by simply filtering the noise from the signal with elementary RC networks. Extending the integration time of the radiometer yields diminishing improvement in signal to noise ratio for long integration periods because of the increasing noise amplitude as a function of decreasing frequency in radio telescopes. This low frequency noise is caused by slow fluctuations in gain and slow variations in local oscillator frequencies.

Modulating the signal from the source by pointing "on" and "off" the source or by scanning across the source will displace the frequencies containing information to higher frequencies of the radio telescope noise spectrum. Demodulation or dc restoration is required of the modulated signal from the source. This is accomplished by synchronously averaging the "on" and "off" data or the scans across the source.

The major advantages of this system are:

By allowing many runs to be made on a source it increases the effective integrating time of the signal while the signal is heterodyned out of the low frequency noise of the receiver.

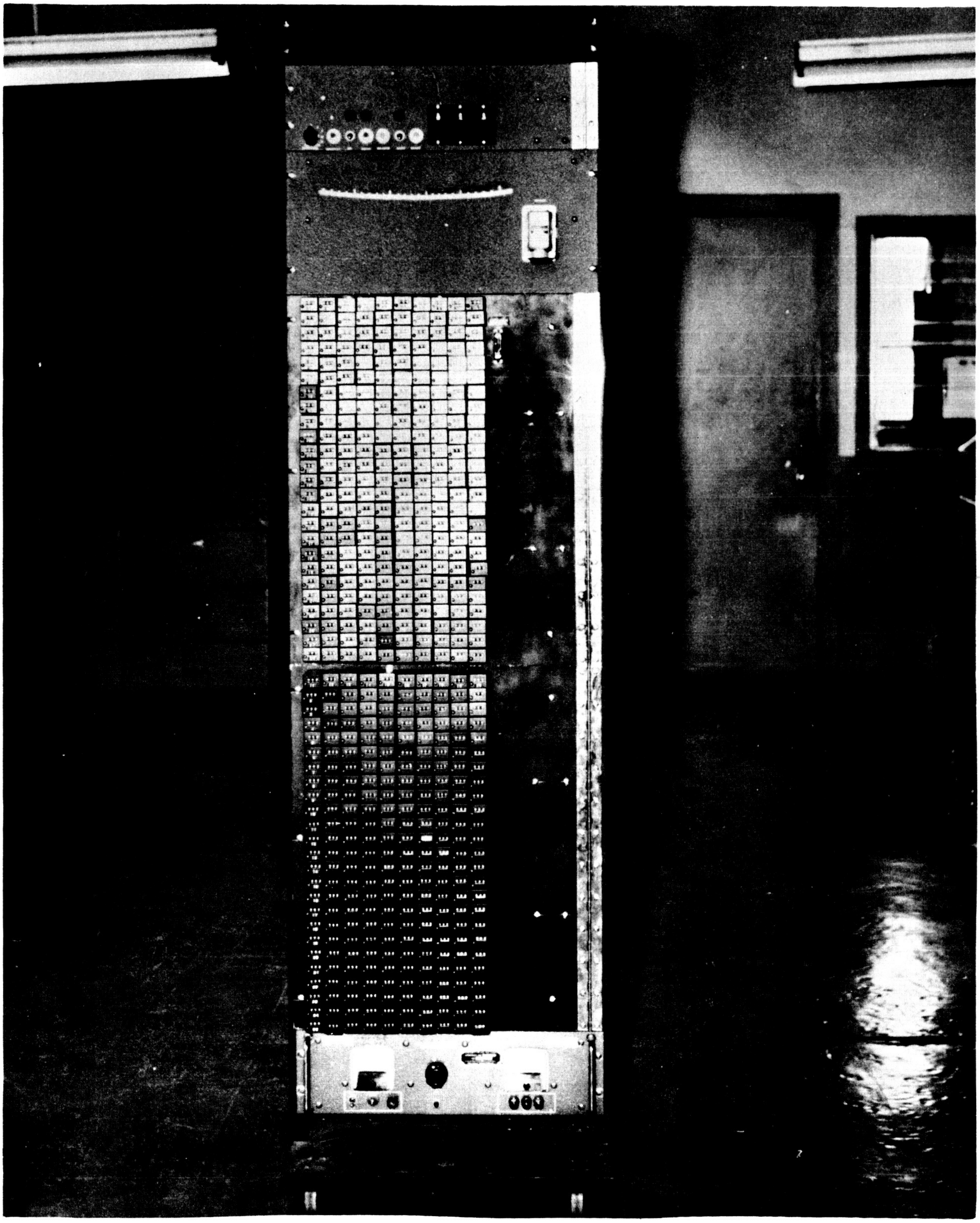
It furnishes the operator with an instant indication of the signal to noise ratio of the composite signal of all previous runs on a source.

It saves many man-hours of processing data manually.

Should it become desirable to use a system such as this at much faster sampling rates major modifications must be made. The use of the cross-bar limits the sampling interval to about 0.5 seconds. As the major cost of this system lies in the register, doubling the cost of the converter and short term memory results in a relatively small increase in total cost.

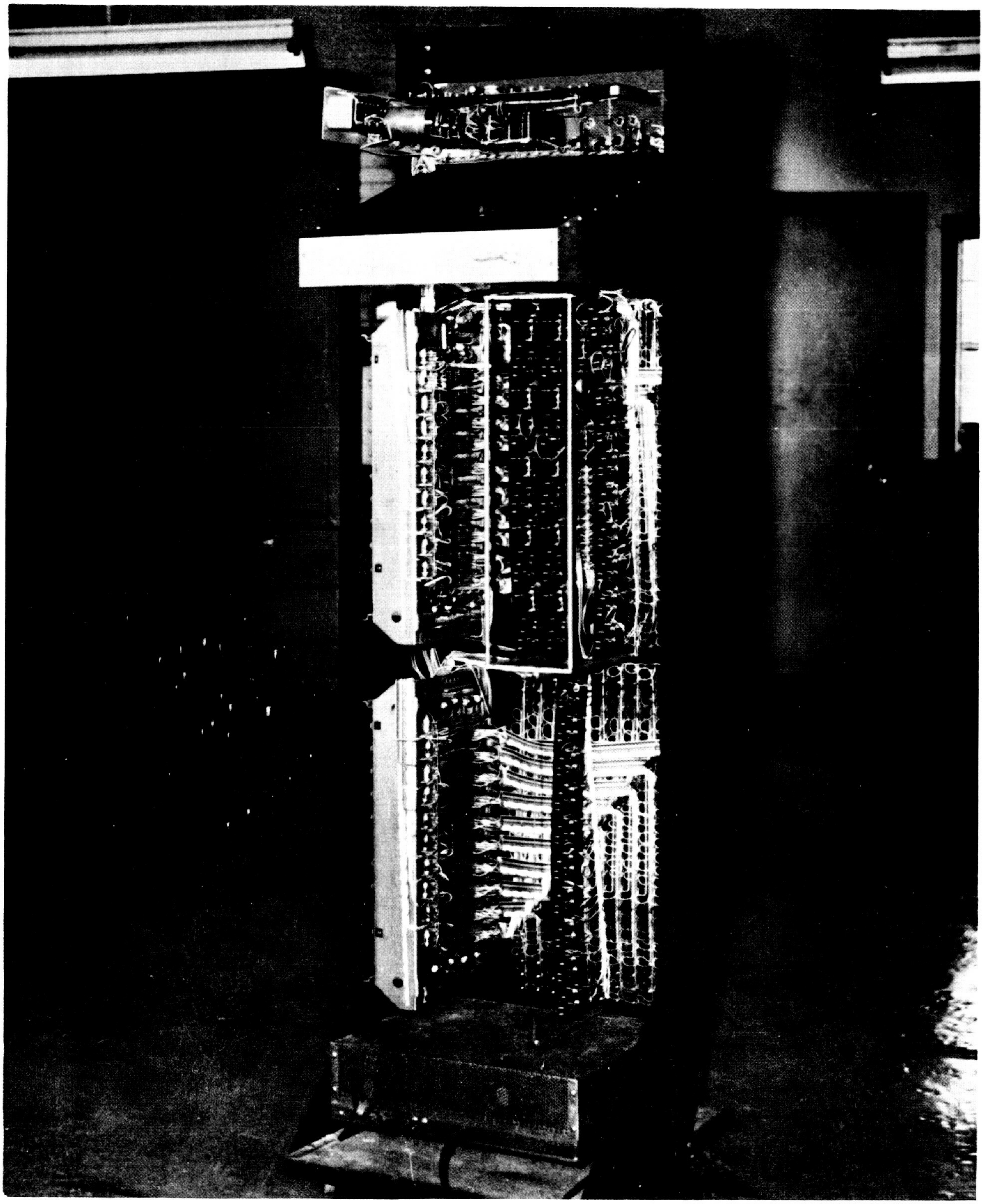
The use of a small and fast galvanometer such as used in optical recorders and small fast photodiodes would increase the speed and decrease the size of the converter. This would at least double the cost of the converter and increase its complexity because temperature compensation would probably be required for the photodiodes.

The short term memory would probably consist of 500 capacitors charged through diodes. The capacitors can be discharged through the register to advance it at the end of each run. Because of the fast sampling rates the time required for the short term memory to remember will be decreased and cheap electrolytic capacitors could be used. 150 micro-farad capacitors would hold a sufficient charge for about 2 minutes when charged to 24 volts.



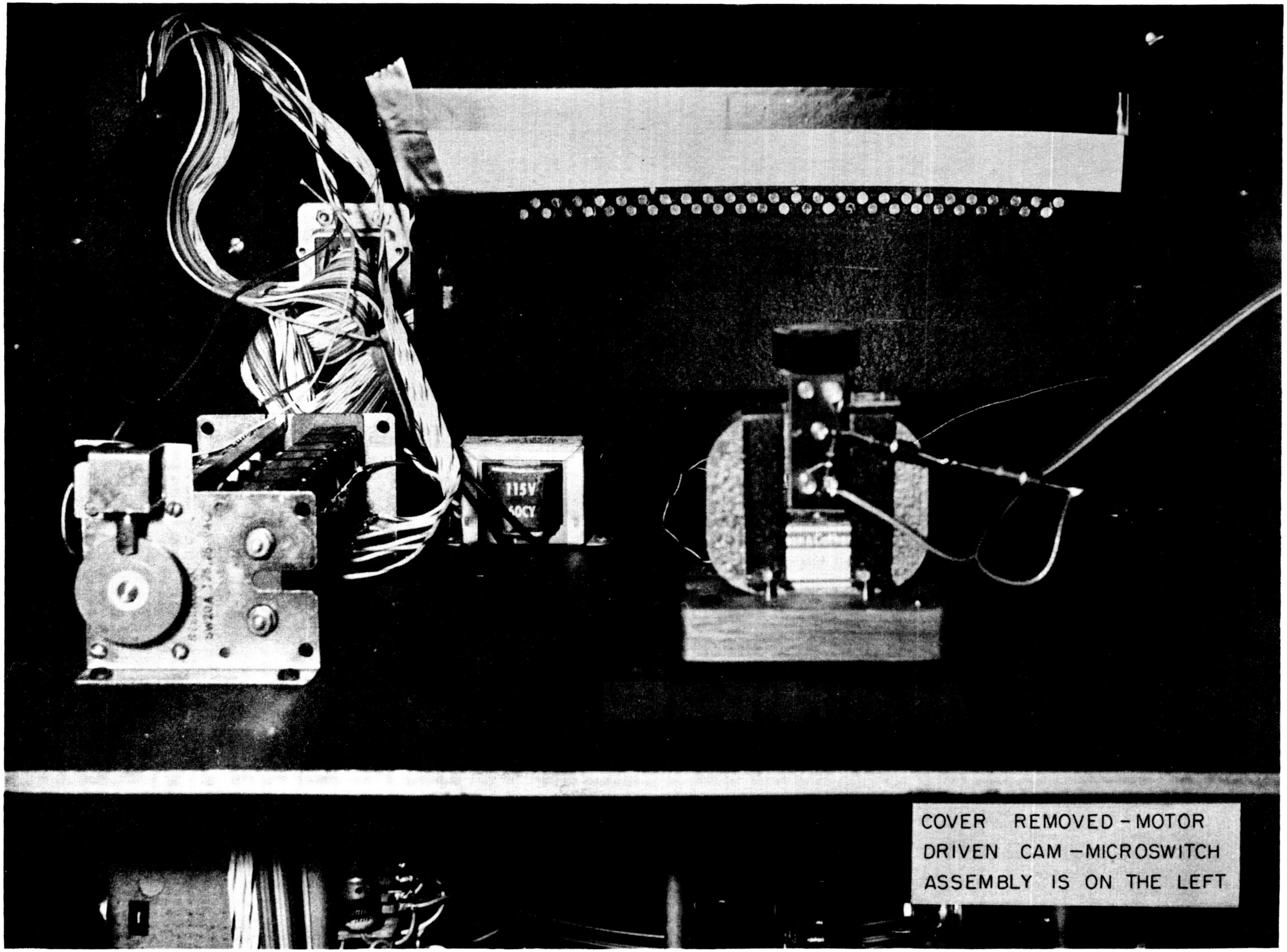
FRONT VIEW OF RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

FIG. 8.



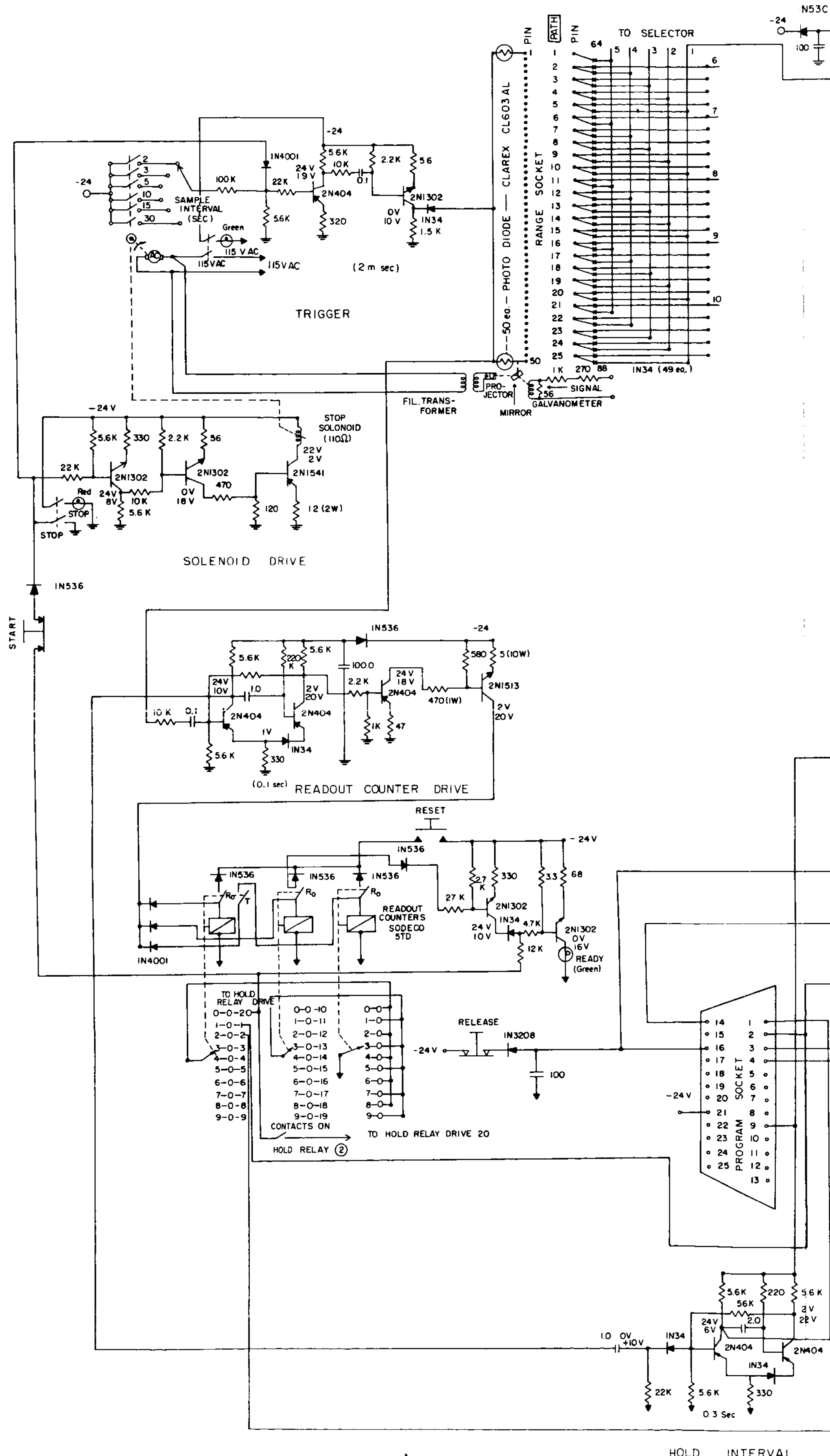
REAR VIEW OF RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

FIG. 9.

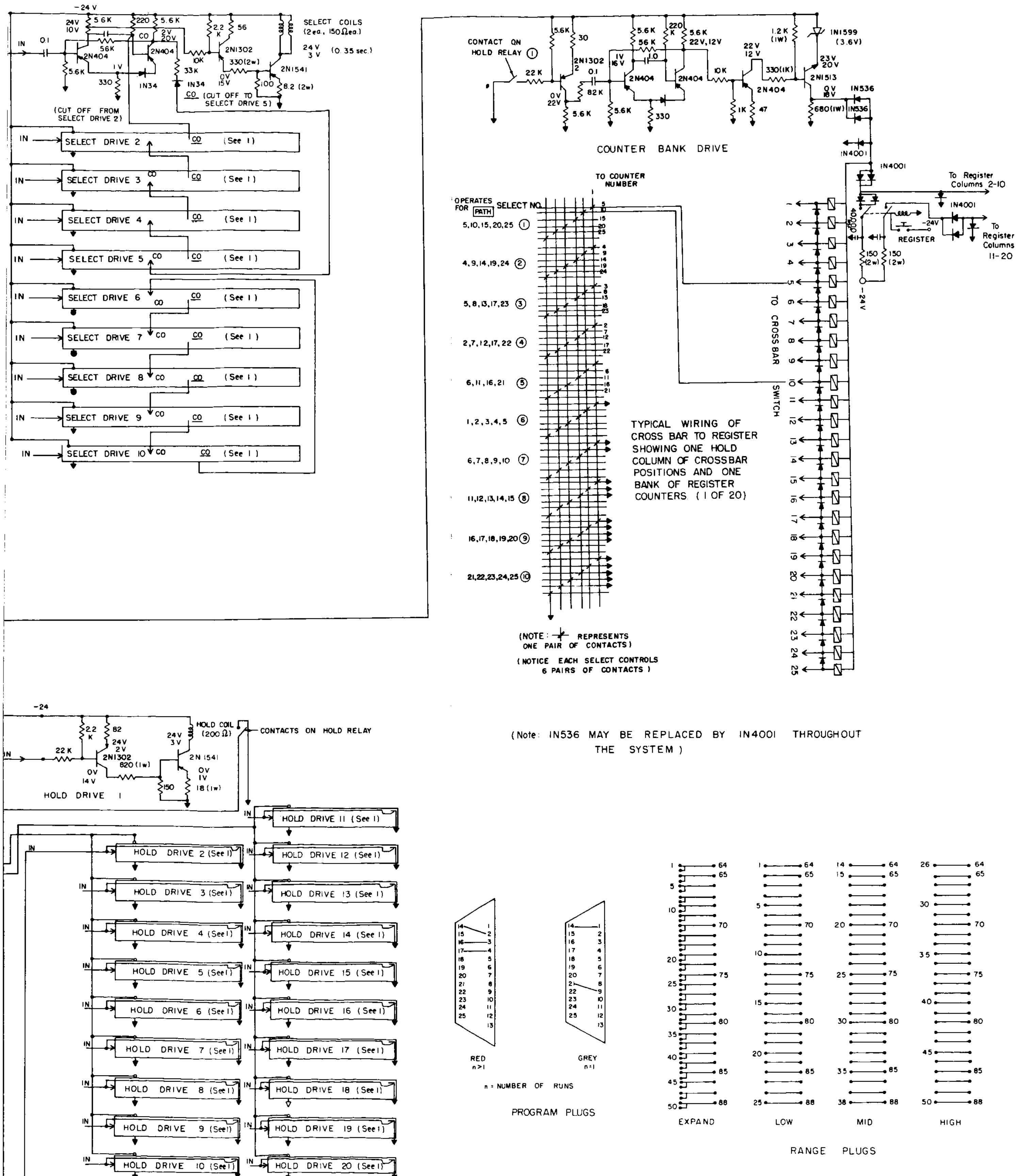


ANALOG TO DIGITAL CONVERTER

FIG. 10.



TRIGGER
SAMPLE INTERVAL (SEC)
SOLENOID DRIVE
STOP SOLONOID (110Ω)
START
STOP
READOUT COUNTER DRIVE
RESET
READOUT COUNTERS SODECO 5TD
READY (Green)
RELEASE
TO HOLD RELAY DRIVE
CONTACTS ON HOLD RELAY 2
TO HOLD RELAY DRIVE 20
PROGRAM SOCKET
HOLD INTERVAL
TO SELECTOR
50 ea. — PHOTO DIODE — CLAREX CL603AL
RANGE SOCKET
PIN
PATH
FIL. TRANSFORMER
PROJECTOR
MIRROR
GALVANOMETER
SIGNAL
IN34 (49 ea.)



SYSTEM DRAWING

RADIO ASTRONOMY SIGNAL SPECTRUM ANALYSER

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FIG. 11.

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VITA

John H. Sizelan was born in Brownsville, Texas, on March 1, 1935, the son of Dr. Fred Cameron Sizelan and Josephine Coons Sizelan. After completing high school at St. Joseph's Academy, Brownsville, Texas, in 1951, he entered The University of Texas. In 1954 he entered the United States Air Force for a four year enlistment. In 1958 he returned to The University where he received his B.S.E.E. in 1961 while working for the Defense Research Laboratory, Austin, Texas. In that year he accepted employment with Collins Radio Company, Dallas, Texas, and later entered the Graduate School of The University of Texas. In February, 1965, he accepted employment with the Laboratory of Millimeter Wave Propagation and Astronomy of The University of Texas where he is currently employed.

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This thesis was typed by Mrs. Wanda S. Turner.

The figures were drawn by Mrs. M. Jean Gehrke.