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Electrical Engineering Research Laboratory
The University of Texas

Report No. 79

19 March 1956

**Circuit Diagrams and Operational Data
For the Transform Computer**

Prepared Under Office of Naval Research Contract Nonr 375(01)
NR 071 032

ELECTRICAL ENGINEERING RESEARCH LABORATORY
THE UNIVERSITY OF TEXAS

Report No. 79

19 March 1956

CIRCUIT DIAGRAM AND OPERATIONAL DATA
FOR THE TRANSFORM COMPUTER

by

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ABSTRACT

This report is intended to explain the theory, construction, and operation of the transform computer designed and built by the Electrical Engineering Research Laboratory of The University of Texas. Complete circuit diagrams and operational instructions are included, as well as instructions for adjusting and normalizing the resultant power spectra.

I. INTRODUCTION

The transform computer was developed in order to decrease the time consumed in obtaining a power spectrum of a function from a plot of the autocorrelation of that function. Use of this computer has decreased the time required to calculate a power spectrum from approximately four hours, required by a good operator using an electric calculator, to some 20 minutes, including the time required to prepare the computer and enter the data.

II. THEORY

The basic operation of the transform computer is a Fourier analysis of a plot of an autocorrelation function (Figure 1) obtained from the correlation computer described in Report No. 55 of the Electrical Engineering Research Laboratory. This operation results in a power spectrum, or a plot of power as a function of frequency (Figure 2).

Since an autocorrelation function is an even function, the power spectrum may be determined by taking a cosine transform of the autocorrelation function:

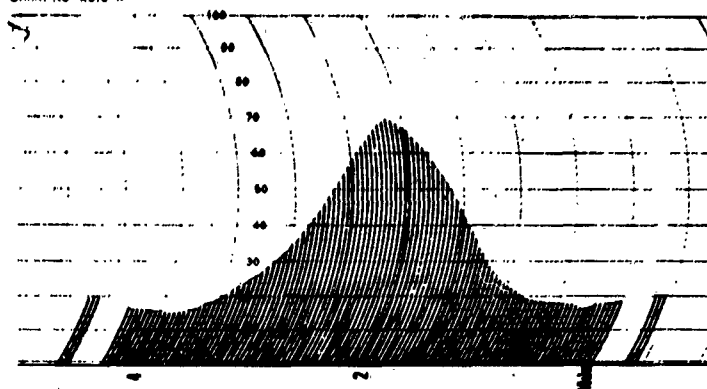
$$F(\omega) = K \int_0^{\tau} A(\tau) \cos \omega \tau d\tau \quad (1)$$

where $A(\tau)$ is the autocorrelation function of length τ , and K is a normalizing factor.

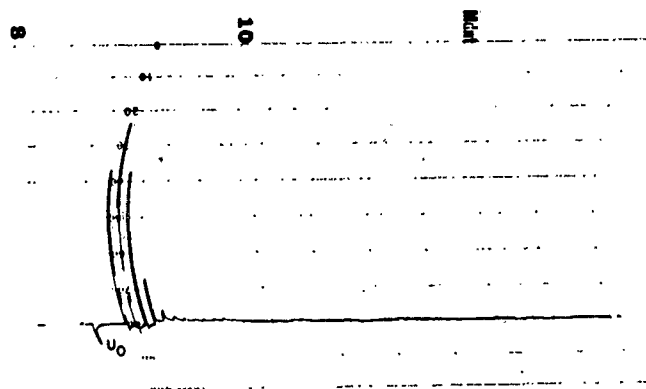
In the transform computer, the cosine transform is taken by means of finite difference integration. Since $A(\tau)$ is sampled at a finite number of points, the power spectrum, $F(\omega)$, may be determined only to some finite frequency. The autocorrelation function is sampled at 48 increments from zero to τ , resulting in a maximum of 24 cycles in the period τ . The minimum frequency which may be detected is $\frac{1}{2}$ cycle in the period τ , in accordance with sampling theory.

Information from 49 points along the right half of the autocorrelation function is entered into the computer. The magnitude of each of these points is then

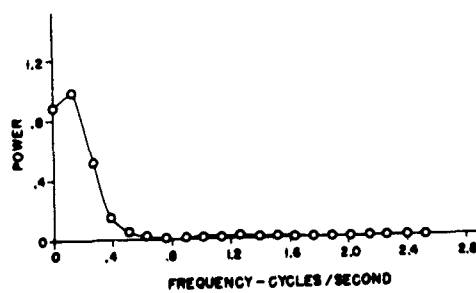
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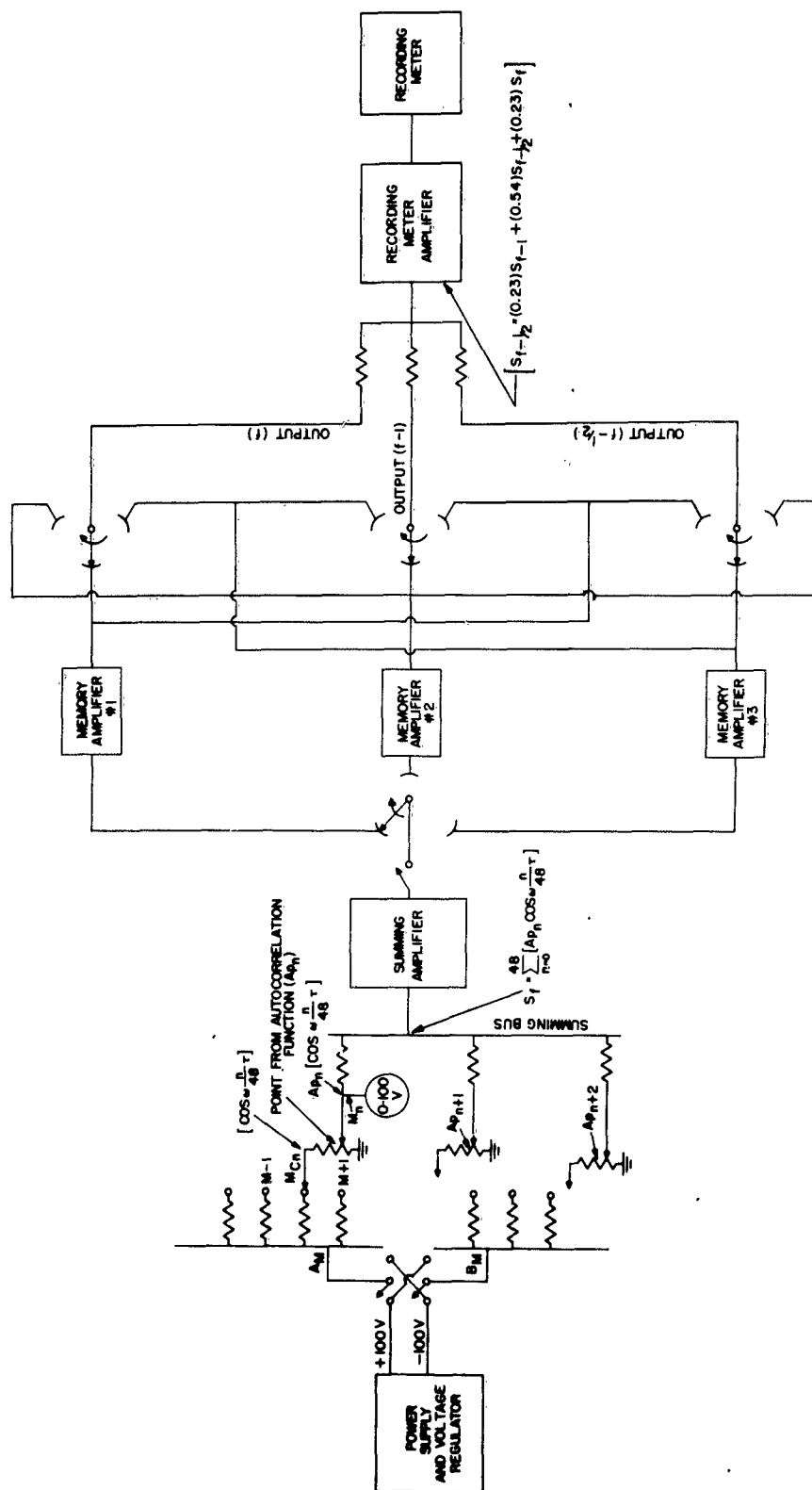
TYPICAL PLOT OF AUTOCORRELATION FUNCTION
FIG. 1



A.
TYPICAL RAW POWER SPECTRUM, AS TAKEN FROM COMPUTER

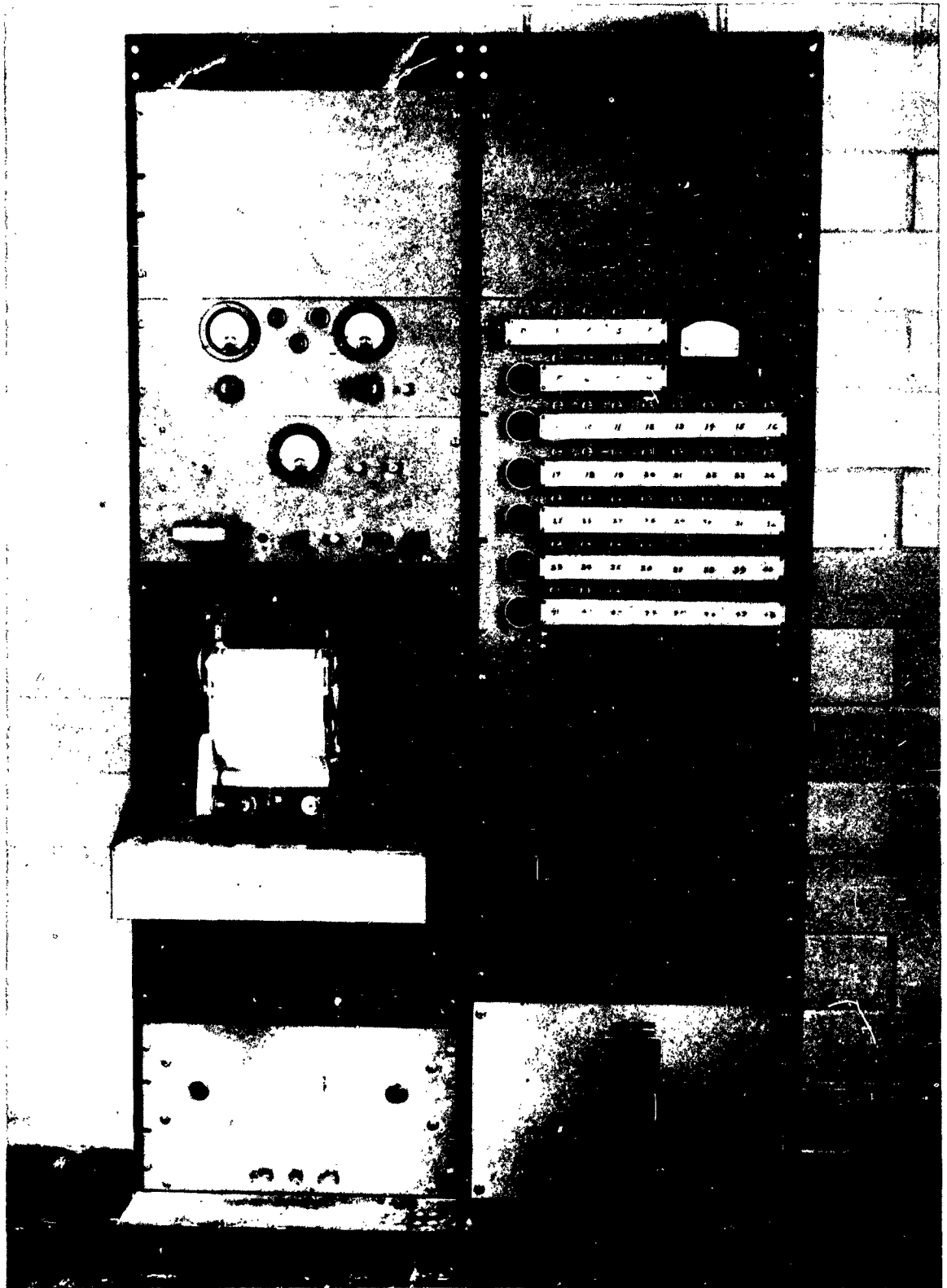


B.
ADJUSTED AND PLOTTED POWER SPECTRUM FROM A
FIG. 2



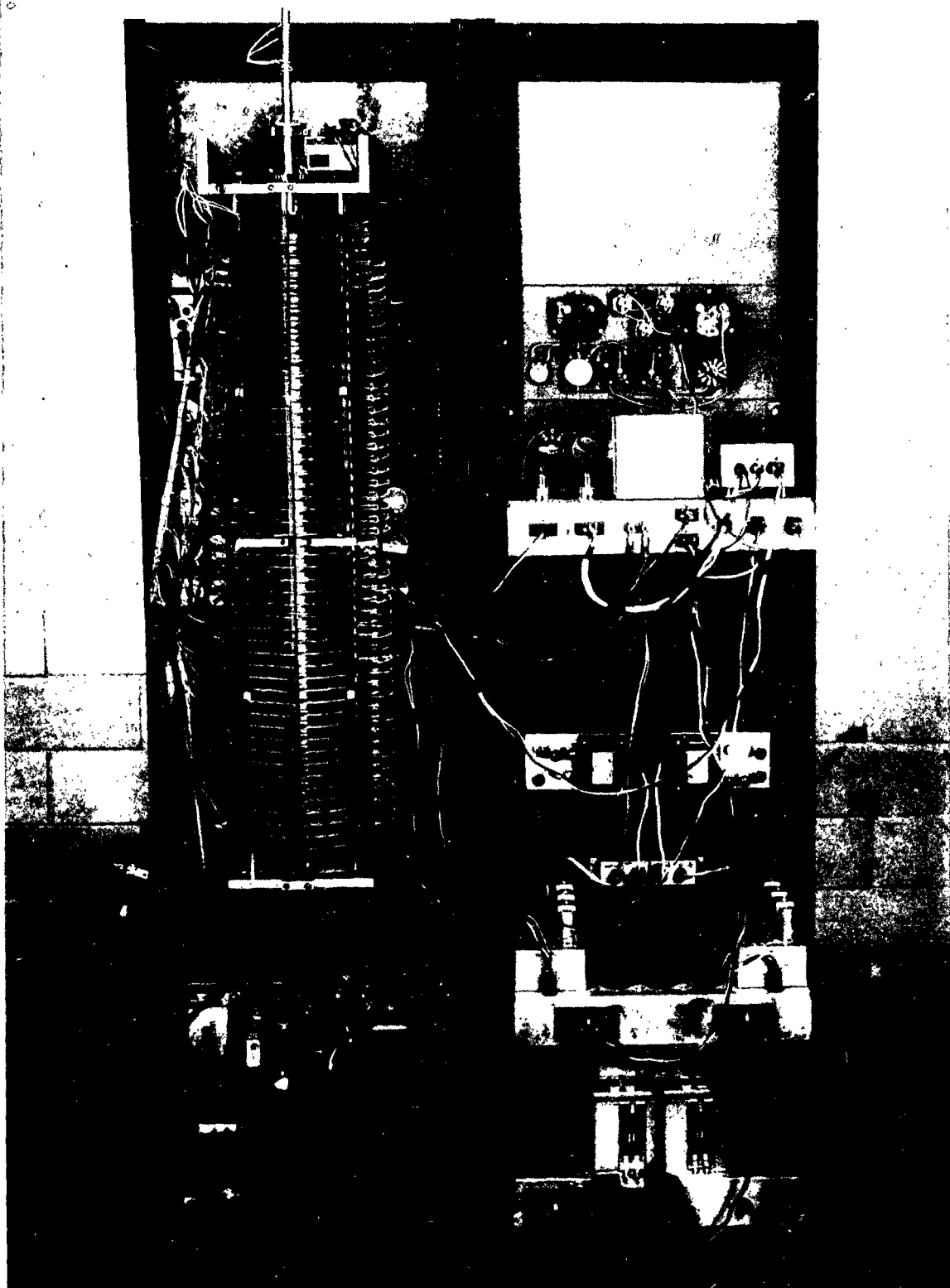
TRANSFORM COMPUTER
FUNCTIONAL DIAGRAM

FIG. 3



FRONT VIEW OF TRANSFORM COMPUTER

FIG. 4



VIEW OF ROTARY SWITCH AND
REAR OF TRANSFORM COMPUTER

FIG. 5

multiplied by a function of a cosine wave and the products are summed, resulting in

$$S_f = \sum_{n=0}^{48} A_n \cos(2\pi f) \left(\frac{n}{48}\right), \quad (2)$$

where A_n is the magnitude of the autocorrelation function at some point n , and n is one of the equally spaced positions along the autocorrelation function, $0 \leq n \leq 48$. The quantity, S_f , taken at some value of frequency, f , is the magnitude of one point of the unnormalized power spectrum. To obtain a complete power spectrum, the value of S_f is calculated for each of frequencies from zero to 24 cycles in the length τ in increments of $\frac{1}{2}$ cycle. The resulting series of points is then normalized with respect to frequency (abscissa) and power (ordinate).

It has been found that the accuracy of a power spectrum is increased by smoothing the curve resulting from the above calculations. In this instance the smoothing is done by the methods presented by J. W. Tukey in "The Sampling Theory of Power Spectrum Estimates." (Reference 3). Essentially, this consists of the following computation for the computer:

$$S'_{f-\frac{1}{2}} = (0.23)S_{f-1} + (0.54)S_{f-\frac{1}{2}} + (0.23)S_f, \quad (3)$$

where S' is the smoothed ordinate of the power spectrum and the subscript, f , denotes the frequency of the cosine wave as before. This equation holds for all but the first and last point ($f = 0$, $f = 24$), where

$$S'_{f=0} = (0.54)S_{f=0} + (0.46)S_{f=\frac{1}{2}}, \quad (4)$$

and

$$S'_{f=24} = (0.46)S_{f=23\frac{1}{2}} + (0.54)S_{f=24}. \quad (5)$$

These operations are accomplished in the computer by means of the memory amplifiers and their associated circuits.

A functional diagram is provided as Figure 3 of this report. This diagram shows the sequence of operations and the nature of the input at each step. Photographs of the transform computer are shown in Figure 4 and Figure 5.

III. CONSTRUCTION

The transform computer may be considered to consist of two main divisions: the data processing section and the power supply section.

The data processing section contains the input panel where the information from an autocorrelation function is entered; the rotary switch which performs the

cosine transform by finite difference integration; and the computing chassis which contains the memory amplifiers, their smoothing filter, and a recording meter amplifier. Control switching in the computing chassis is performed by a section of the rotary switch.

The first unit of the power supply section is the power supply chassis, which rectifies and smooths line voltage to deliver ± 350 volts d-c to the ± 100 -volt regulator chassis. This regulator chassis consists of two voltage control amplifiers, each of which utilizes four paralleled 6AS7 tubes. The ± 100 -volts d-c is taken across a cathode-to-ground resistance, while the -100 volts d-c is taken across a resistor connected from ground to the plate supply bus. The 6AS7 grids are driven by a feedback system utilizing an r-f amplifier unit for each regulator amplifier. Conventional voltage regulator units are plugged into 60-cycle a-c taps on the main regulator chassis to provide ± 250 - and -250 -volts d-c for use in the computing chassis as plate and cathode supplies. The ± 100 -volt d-c is delivered to the rotary switch for use in the cosine transformation. Regulated power supply voltages are metered by the power monitor chassis, which also monitors the operation of the memory amplifier switching circuit.

A. Power Supply.

Circuit diagrams of the power supply are shown in Figure 6. The power supply is equipped with a time delay relay in order that it may be turned on automatically to insure adequate warm-up time. Input voltage to the power supply is regulated by a model 2000-S Sorenson regulator, circuit diagrams of which are not included in this report.

B. Voltage Regulator.

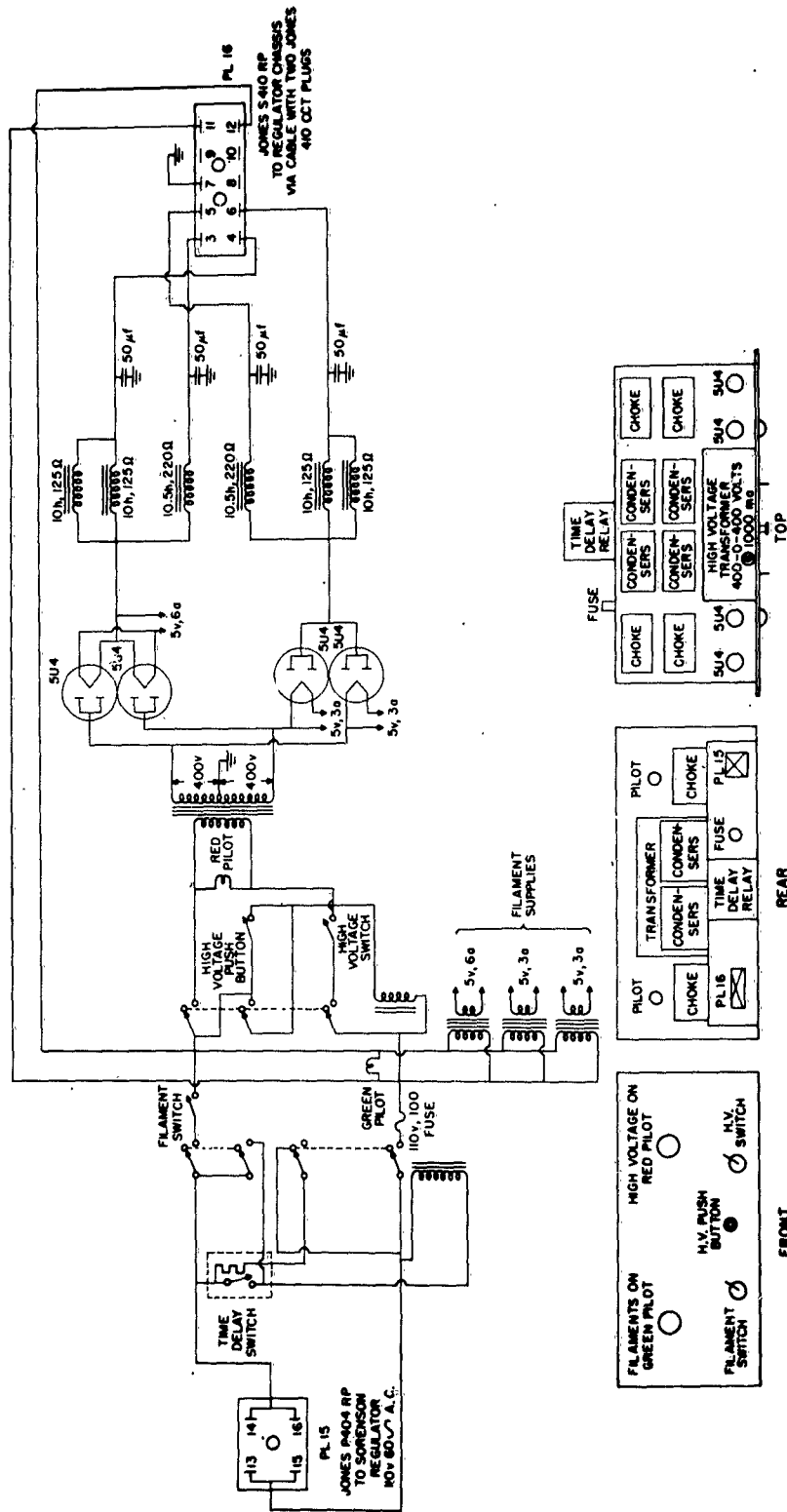
A circuit diagram of the main ± 100 -volt d-c voltage regulator is shown in Figure 7. The unit provides ± 100 -volts d-c at 500 ma for use in the rotary switch and input panel. The grids of this unit are driven by the r-f amplifiers of Figure 8a, which were necessitated by the operation of both a positive and a negative regulator system from a single power supply. These units operate at 456 kc and utilize conventional circuit elements to amplify a control voltage derived from a summation of the regulated 100-volt output and a reference voltage established by an OA2 tube. There are two identical r-f units, adaptation for a particular supply polarity being made within the main regulator chassis. These units must be adjusted to operate with optimum amplification.

The regulated ± 250 -volt d-c supplies are conventional identical packaged units. Circuit diagrams of this supply are shown in Figure 8c.

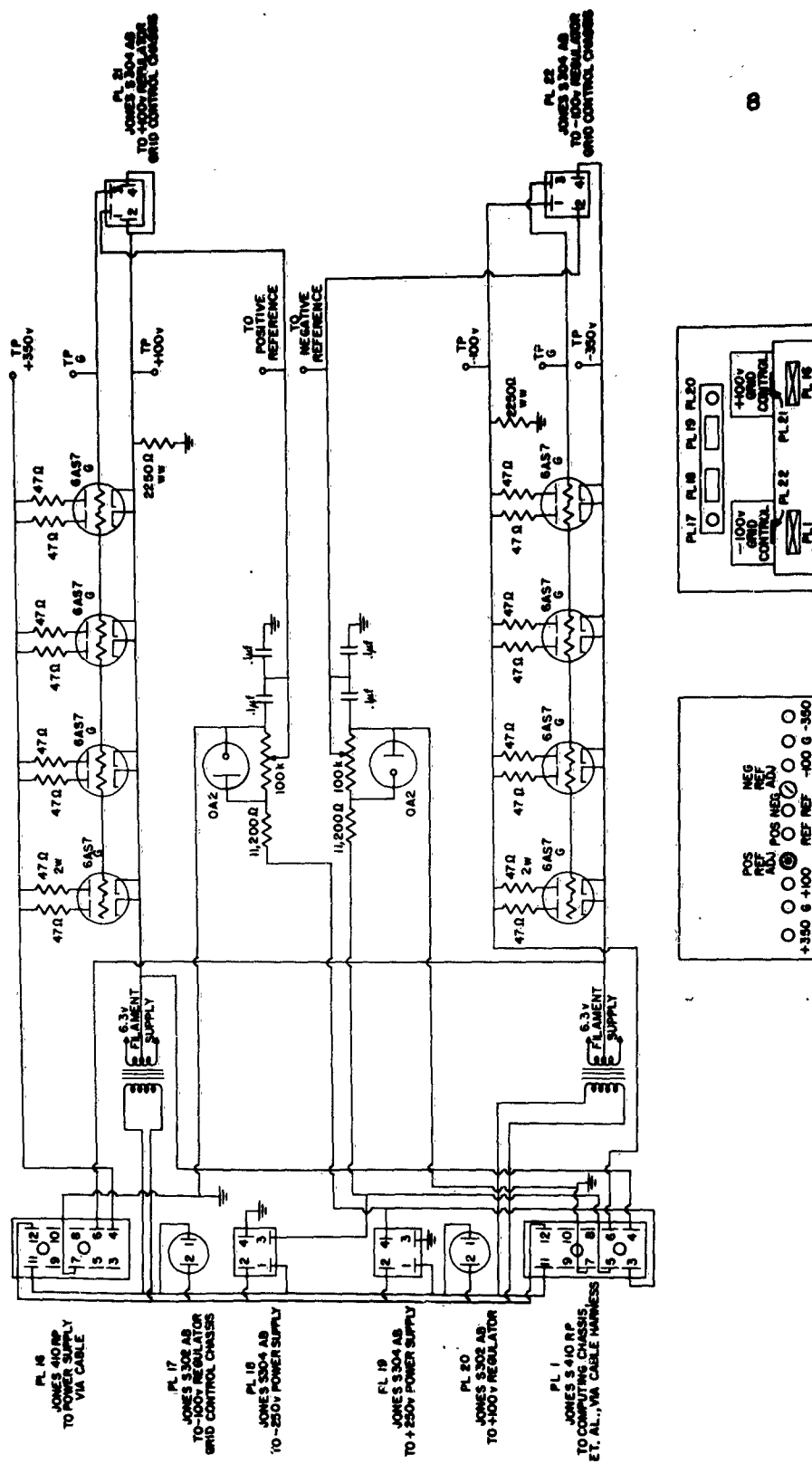
Circuit diagrams of the power monitor chassis are shown in Figure 8b. This unit meters the ± 250 -volt and the ± 100 -volt regulated supplies directly, and meters the unbalance voltage between the ± 100 - and the -100 -volt supplies. The memory amplifier relay monitor lights are connected across the relay coils.

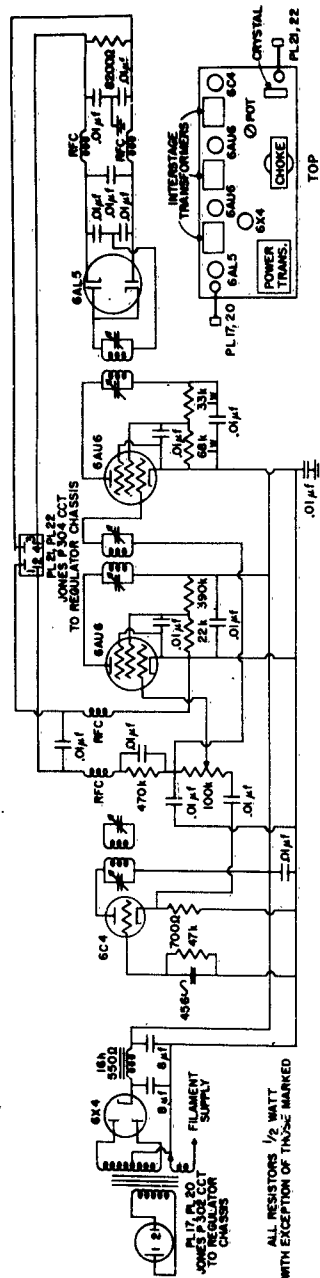
C. Rotary Switch and Input Panel.

The rotary switch consists of a stack of 52, 51-contact rotary switches. The first three switches are control banks operating the memory amplifier relays, the recording meter, and the rotary switch drive motor. The remaining 49 banks serve as wave generators, forming the cosine waves by which the autocorrelation function is multiplied.

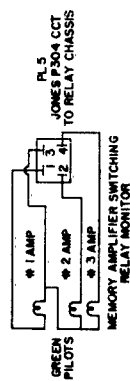


TRANSFORM COMPUTER POWER SUPPLY
FIG. 6

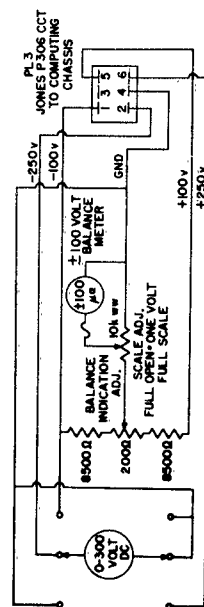




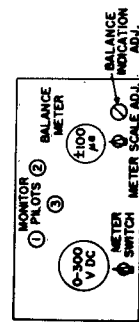
A. GRID CONTROL CIRCUIT FOR ±100 VOLT DC REGULATOR (2 IDENTICAL UNITS)



B.



C. 250 VOLT DC POWER SUPPLY (2 IDENTICAL UNITS)



POWER SUPPLY MONITOR CHASSIS

TRANSFORM COMPUTER VOLTAGE REGULATOR
FIG. 8

The rotor of each of the wave generator banks is in series with a 10,000-ohm potentiometer. Either +100- or -100-volts d-c is applied across this combination, resulting in a voltage across the potentiometer of

$$E_p = (\pm 100) \frac{10,000}{10,000 + R}$$

where R is the series switch resistance shown in Figure 9. This resistance is selected such that the voltage E_p describes a cosine wave of the desired frequency upon progression down the contacts at any switch position. This frequency increases from zero at the first contact position to 24 cycles at the 49th position in steps of 1/2 cycle. The first two contacts, shown as -2 and -1 in Figure 9, were necessitated by the smoothing operations.

If the magnitude at some point along the autocorrelation function is set into a potentiometer as a voltage A_n , the output of the potentiometer is seen to be the product of A_n and the cosine function. Refer to the table of page 12 for a list of resistor (R) values.

The rotary switch is driven in steps by a synchronous motor, through step-down gearing and a Geneva mechanism.

The input panel consists of the series potentiometers, polarity-control switches for these potentiometers, and a circuit to meter the values of A_n entered into the potentiometers.

As mentioned above, the rotary switch controls the memory amplifier relays which are mounted above the computing chassis. The relay chassis circuits are shown in Figure 9.

Circuit diagrams of the rotary switch, the input panel, and their associated components are given in Figure 9.

D. Computing Chassis.

The computing chassis consists of a summing amplifier, three memory amplifiers, the smoothing circuit, and a recording meter amplifier circuit. The summing amplifier and the three memory amplifiers are cathode followers, utilizing 6AU6 tubes.

The output of the wave generator portion of the rotary switch and of the input panel units, equation (2), is fed into the summing amplifier, which serves as an impedance-matching device. From the summing amplifier, the information passes through the memory amplifier switching relays which apply the output at consecutive rotary switch positions to the memory amplifiers in numerical order. The grid-circuit capacitors in each of these amplifiers retain this information until that amplifier is reconnected to the summing amplifier. At the same time the output of the memory amplifiers is fed into the matrix of the smoothing filter circuit, where the calculations of equations (3) through (5) are performed. The smoothed power spectrum then passes into the recording meter amplifier and then to the recording meter. An Esterline-Angus recording ammeter is used to record the output.

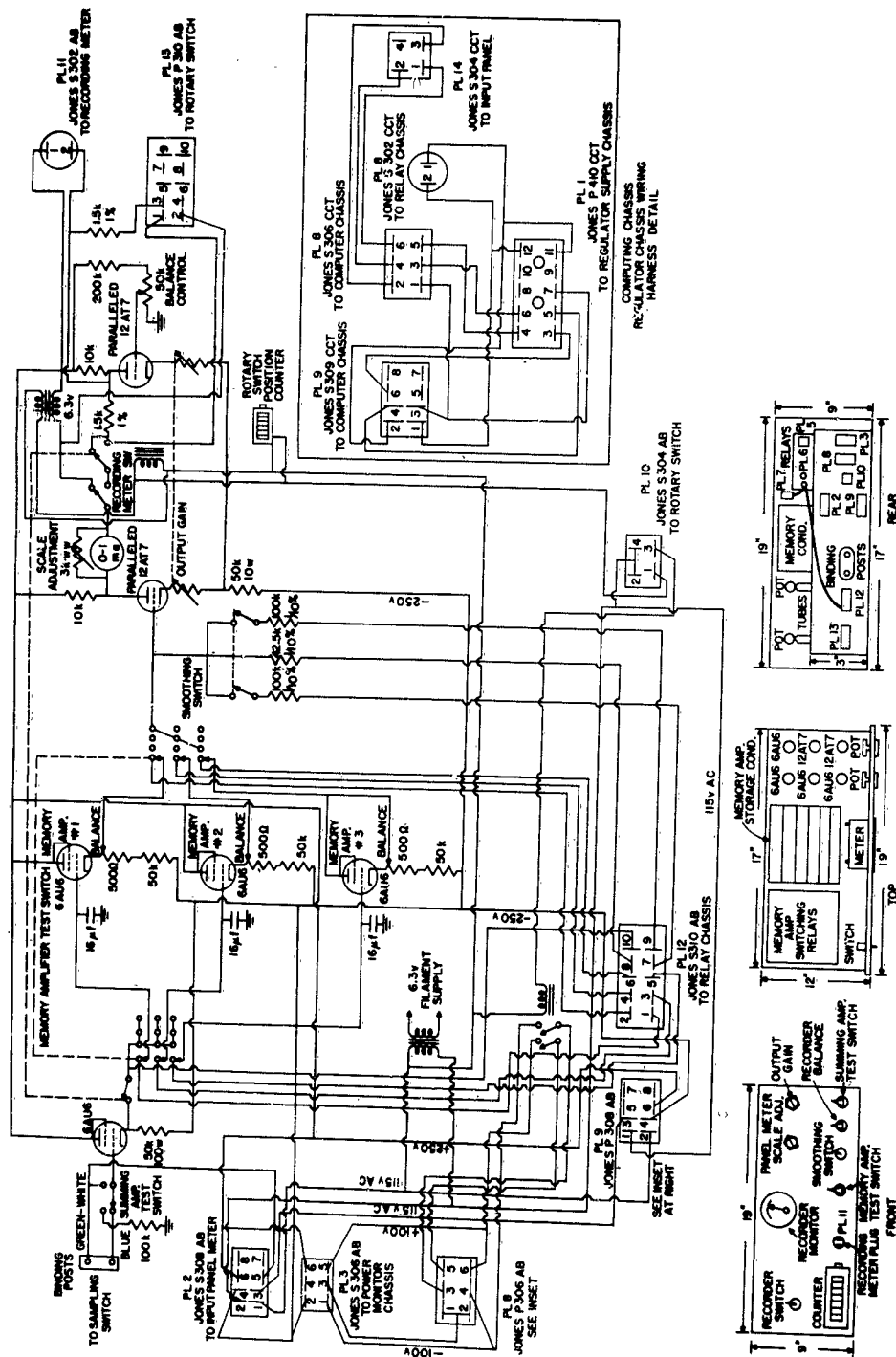
Circuit diagrams of the computing chassis are shown in Figure 10.

TRANSFORM COMPUTER—INPUT PANEL AND ROTARY SWITCH

RESISTOR CHART

Resistor Number - (Contact No.)(Bank No.)

<u>Resistor Number</u>	-	<u>Value in Ohms -1.0%</u>
0, 48	-	0
1, 47	-	20 Ohms
2, 46	-	82 Ohms
3, 45	-	200 Ohms
4, 44	-	390 Ohms
5, 43	-	560 Ohms
6, 42	-	820 Ohms
7, 41	-	1200 Ohms
8, 40	-	1500 Ohms
9, 39	-	2000 Ohms
10, 38	-	2600 Ohms
11, 37	-	3300 Ohms
12, 36	-	4100 Ohms
13, 35	-	5200 Ohms
14, 34	-	6400 Ohms
15, 33	-	8000 Ohms
16, 32	-	10000 Ohms
17, 31	-	12600 Ohms
18, 30	-	16100 Ohms
19, 29	-	21000 Ohms
20, 28	-	28600 Ohms
21, 27	-	41000 Ohms
22, 26	-	67000 Ohms
23, 25	-	143000 Ohms
24,	-	Open



TRANSFORM COMPUTER-COMPUTING CHASSIS
FIG. 10

IV. COMPUTER OPERATION AND CALIBRATION

A. Preparing the Data.

The right half of an autocorrelation function is divided into 48 spaces. If the area under the curve is small, the magnitude of the curve at each of the 49 points, numbered from zero, is then recorded on forms provided for this purpose. One-half of the value of the first and last points is recorded, and the actual value of the remaining points. However, due to the fact that the autocorrelation function often contains a large d-c component, it is sometimes necessary to adjust the data taken from this curve in order that the resultant power spectrum will be more useable. This is accomplished by arbitrarily raising the zero line of the autocorrelation function until the new area under the curve is slightly greater than zero. This area is recorded as A', while the area between the raised zero line and the original zero line is recorded as A". The original area under the curve is recorded as $A = A' + A''$. The ordinates of points along the curve are now measured from the raised zero line.

B. Adjusting the Power Supply.

The computer should be allowed to warm until the power supply and computer circuits are stabilized. Depress the push button on the motor control panel and bring the rotary switch around to the first set of contacts. To accomplish this, the push button is held until the recording meter relay and the counter relay are both heard to close, then released. The meter on the power monitor chassis should now register approximately 100 volts.

The ± 100 -volt d-c supplies should be adjusted once a day while metered at the taps provided on the front of that chassis. Once these adjustments are made, the balance meter on the power monitor chassis should be set to maximum sensitivity and then adjusted to zero. After this has been done once, the voltages may be checked and adjusted using the power monitor chassis. The ± 250 -volt d-c supplies should also be adjusted at this time. All of these voltages should be checked before each run.

C. Entering the Data.

The input panel meter is zeroed and the range of this meter is adjusted to allow the largest magnitude of the data to be entered on a potentiometer set close to its maximum resistance. Data is entered into the potentiometers in numerical order, negative values being attained by reversing the polarity switches. The power supply voltages should be rechecked at this time.

D. Calibrating the Computer.

With the rotary switch still on the first contact, the memory amplifier test switch is turned from NORMAL to its NUMBER 1 position so that the recording meter registers the summing amplifier output directly. The summing amplifier test switch is now set to NORMAL to connect this unit to the rotary switch and input panel. Turn the recording meter switch to ON and adjust the gain to a value great enough to result in almost a full excursion of the recording meter pen at its maximum position. The summing amplifier grid should now be shorted to ground and the memory amplifier test switch turned to the NUMBER 3 position and back to NORMAL to discharge the grid condensers. Now set the recording meter to zero. The gain and zero adjustment procedures must be repeated several times, as these controls interact somewhat.

E. Obtaining a Power Spectrum.

With the summing amplifier test switch at NORMAL, the memory amplifier test switch on the NUMBER 1 position, the input panel meter switches off, and the recording meter switch at AUTOMATIC, start the recording meter. Turn the recording meter switch to ON, then back to AUTOMATIC. The value recorded is noted as U_0 , the algebraic sum of the magnitudes entered from the autocorrelation function. The motor control button is now depressed and held until the second set of switch contacts has been cleared. The motor will cut off when the power spectrum is complete.

V. NORMALIZING THE POWER SPECTRUM

The raw power spectrum is tabulated, numbering the points from zero. Record one-half the magnitude of the first point and the actual magnitude of the remainder of the points. It has been found that the power spectrum approaches zero long before the calculations have been completed. Accordingly, the power spectrum is arbitrarily assumed to be concluded at the 21st point and no further points are tabulated. If the zero of the autocorrelation function was not raised, the power spectrum is ready for normalization.

If the autocorrelation function zero has been raised the quantity $U'' = U'_0 \frac{A''}{A'}$ is then calculated, where U'_0 is the summation of the voltages set into the input panel, found as detailed in Part IV-E of this report. The adjusted unnormalized values of the first two points may now be calculated:

$$T_0 = T'_0 + 0.27 U''_0$$

and

$$T_1 = T'_1 + 0.23 U''_0.$$

T'_0 and T'_1 are the first two points recorded from the raw power spectrum. These equations are derived from those used in the smoothing process within the computer.

If it is desired to force the first point of the unsmoothed power spectrum to zero, compute $U_0 = U'_0 + U''_0$. The new values of the first two points will now be

$$T_0^0 = T_0 - .27U_0,$$

and

$$T_1^0 = T_1 - .23U_0.$$

The unnormalized spectrum area is now calculated as follows:

$$A_s = \frac{1}{2}T_0 + \sum_{n=1}^{20} T_n.$$

The power spectrum may now be normalized. The general expression for the normalizing factor is

$$N.F. = \frac{2\tau[RMS]^2}{A_s}, \text{ where}$$

τ is the delay time in seconds of the original data (see Reference 1), $[RMS]$ denotes the root mean square value of the original data, and A_s is the unnormalized spectrum area. This expression will force the area under the curve of the normalized power spectrum to equal the root mean square value of the original data.

The cut-off frequency, or maximum frequency of the power spectrum, f_c , is arbitrarily set equal to $\frac{10}{\tau}$, as experience has shown the power spectrum usually to be very close to zero before this point is reached. The 21 points of the power spectrum are located at equal increments from zero to this frequency. The normalized power spectrum is the unnormalized curve multiplied by the normalizing factor.

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