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A LOW FREQUENCY SPECTRUM AND AMPLITUDE DISTRIBUTION ANALYZER

by

D. B. Staake

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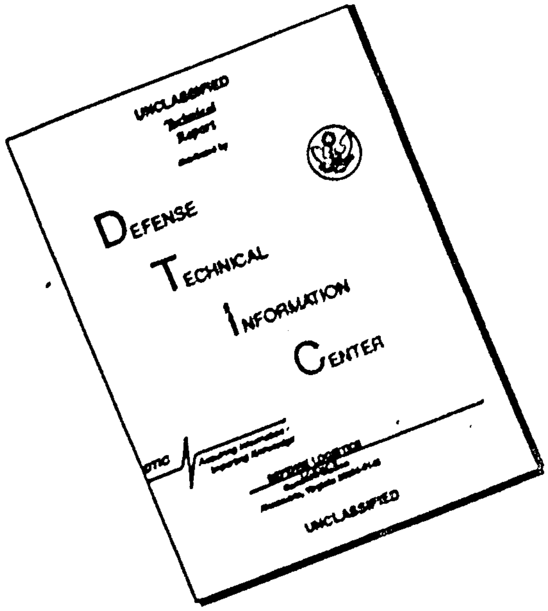
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March 15, 1954

A LOW FREQUENCY SPECTRUM AND AMPLITUDE DISTRIBUTION ANALYZER

by

D. B. Staake

CONTENTS

LIST OF ILLUSTRATIONS

Figure

A LOW FREQUENCY SPECTRUM AND AMPLITUDE DISTRIBUTION ANALYZER

INTRODUCTION

In the analysis of time varying signals, two of the important characteristics are the frequency spectrum and the amplitude distribution. The need for equipment to plot these curves automatically from data recorded in the field led to the development of the equipment described in this report. Most of the data to be analyzed were recorded on magnetic tape so that it might be preserved for analysis at a later date. Some data which had been recorded on Brush recorders and some data plotted by hand have been recorded for analysis. This is accomplished by manually following the plotted curve with a curve follower built for the purpose.

The frequencies of interest in these data were in the region below a few cycles per second. The magnetic tape techniques are well suited for this job because of the frequency multiplication possible by speeding up the playback of the tape.

The equipment, as it is now used, operates over the frequency range of about 0.04 to 5 cycles per second. The data recorded on the tape must be of sufficient length to give the required accuracy.* A given data sample is formed into a closed loop of tape in order to give a repeating function for analysis.

The outputs of the system are recorded on a six-channel Brush recorder. Duplicate circuitry is provided so that two signals recorded simultaneously on the same tape can be analyzed (both spectra and amplitude distribution) at the same time. Thus, there are four outputs on the Brush recorder: two spectra and two amplitude distribution curves. The block diagram of the system is shown in Figure 1. A general view of the equipment is shown in Figure 2.

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*APL/JHU CF-2040, Errors in Power Spectra Due to Finite Sample, by L. M. Spetner, June 30, 1953.

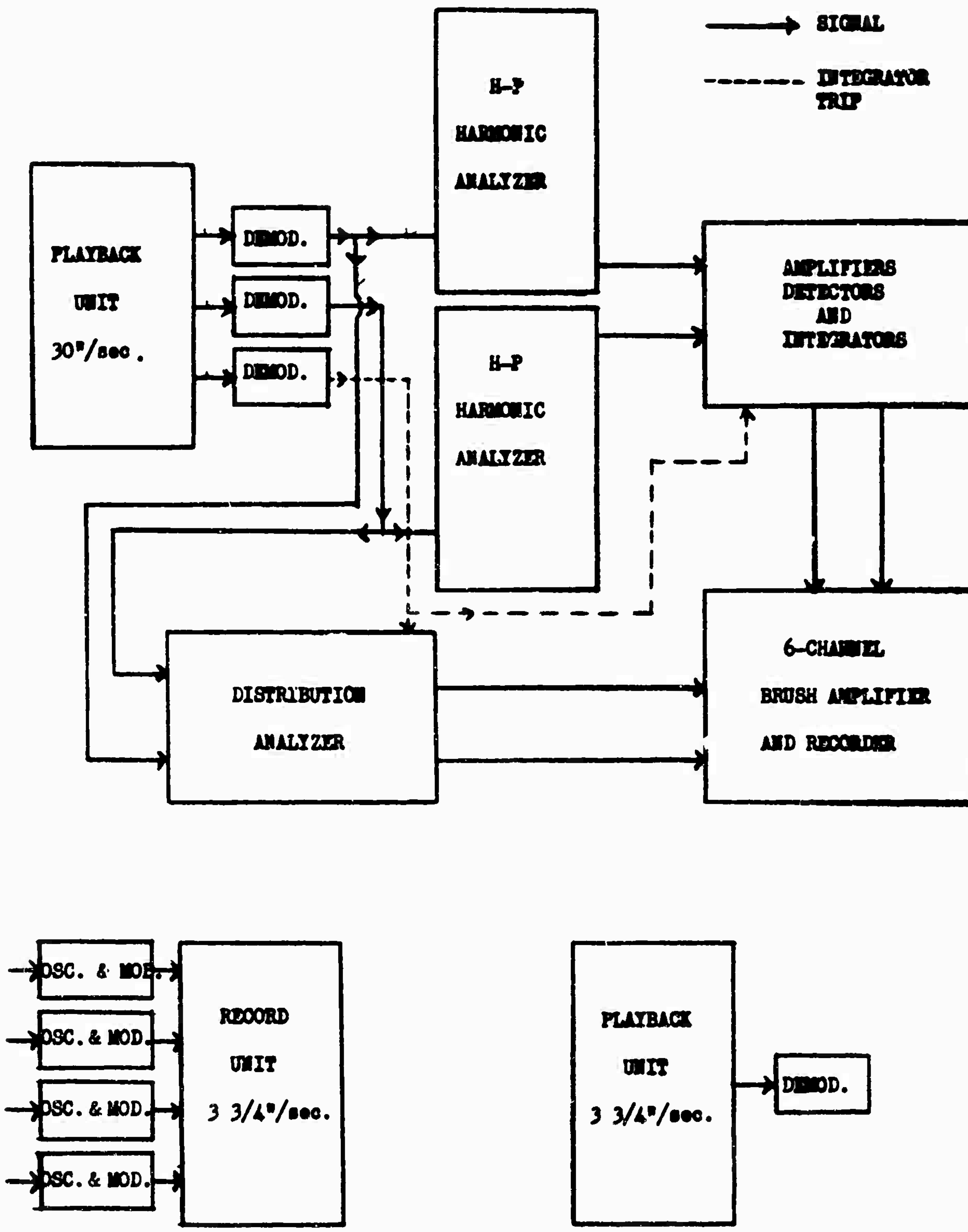


Fig. 1 BLOCK DIAGRAM OF DATA RECORDING AND SPECTRUM AND AMPLITUDE DISTRIBUTION ANALYZER

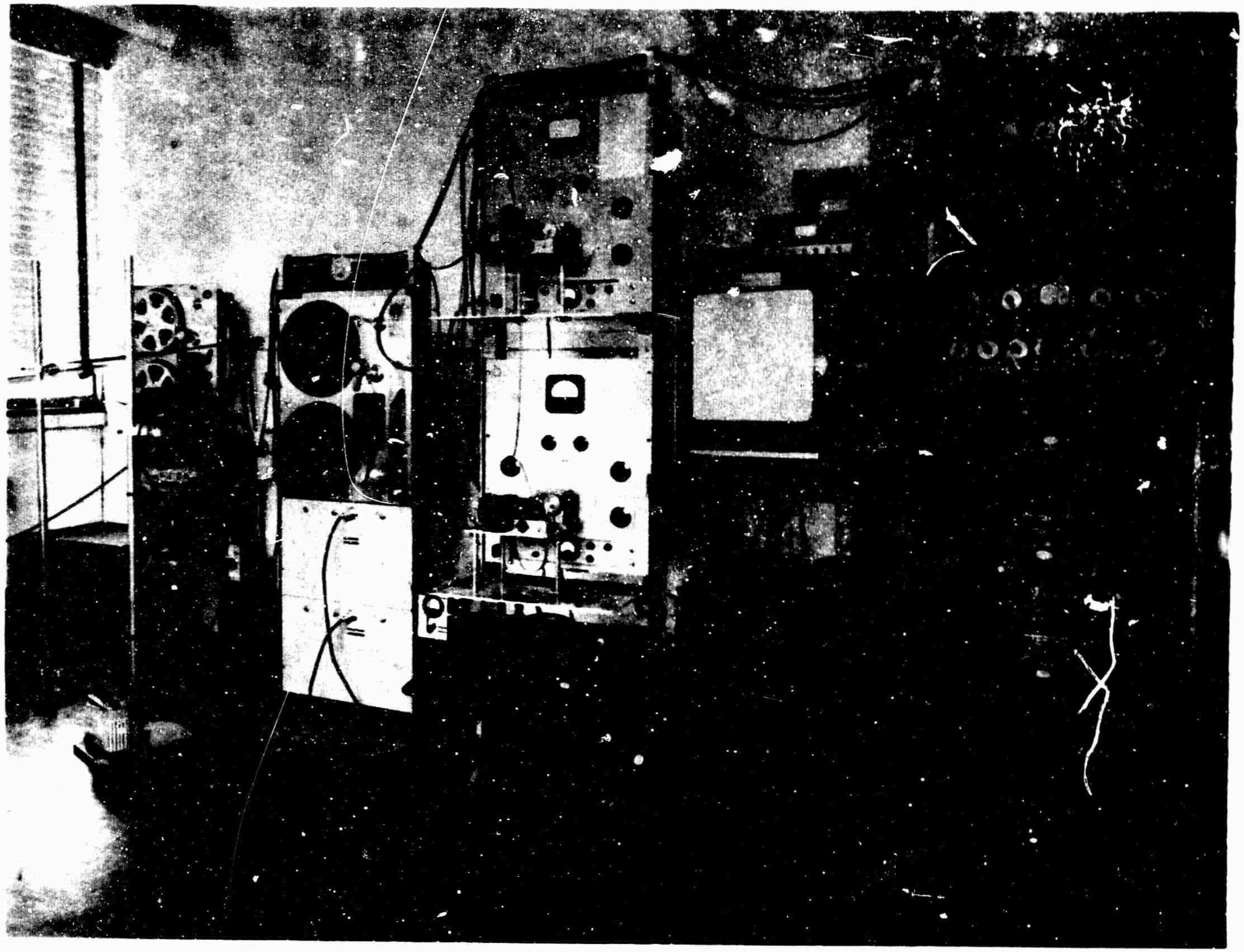


Fig. 2 GENERAL VIEW OF ANALYZER EQUIPMENT

DESCRIPTION OF THE EQUIPMENT

The equipment consists of the following major units:

1 - Ampex S-3167 Unit (See Figure 3)

This machine is a four-track two speed FM carrier type tape recor utilizing 1/2 inch tape. It is designed for recording only and provides for recording on four channels simultaneously. It is de to operate at 3 3/4 in/sec tape speed and will also operate at 7 in/sec. This is not a standard Ampex production unit but is simil to Ampex Model 306. The carrier frequency of the unit is 3.375 k

1 - Ampex Model S-3169 Unit

This machine is a four-track two speed FM carrier type playback un utilizing 1/2 inch tape. It provides for simultaneous playback of two channels since only two demodulators were purchased. With the addition of two more playback amplifiers, power supplies, and cabl the other two channels could be used. This machine is designed to play back the data recorded on the S-3167 (above) with no speed ch This is not a standard production model but is similar to the Mode The frequency response (+1 to -3 db) is 0 to 500 cycles.

1 - Ampex Model S-3168 Unit (See Figure 4)

This unit is essentially the same as S-3169 except that it was desi for speeds of 30 in/sec or 60 in/sec (15 in/sec is also available). Its frequency response is 0 to 3000 cycles (± 1/2 db) or 0 to 5000 cycles (+1 to -3 db). This provides several choices of speed-up ra for the data analysis.

1 - Ampex Model 375, 60-cycle Power Supply (See Figure 3)

This unit is designed to supply a constant frequency voltage for operating the record or playback motors from unstable power sources. This unit is very useful for recording data in the field where port power is used. This unit will deliver 70 watts of 60-cycle power f sources having a frequency in the range of 50 to 400 cycles.

2 - Hewlett-Packard Model 300A Harmonic Wave Analyzers (See Figure 5)

These are heterodyne-type analyzers operating over the frequency ran of 20 to 16,000 cycles. One of these is used in each of the two spectrum channels. These units have drive motors attached so that frequencies can be scanned slowly.

1 - APL Dual-channel Spectrum Chassis (See Figure 6)

This unit amplifies, detects, and integrates the outputs of the harmonic analyzers. The outputs are recorded on the six-channel recording system.

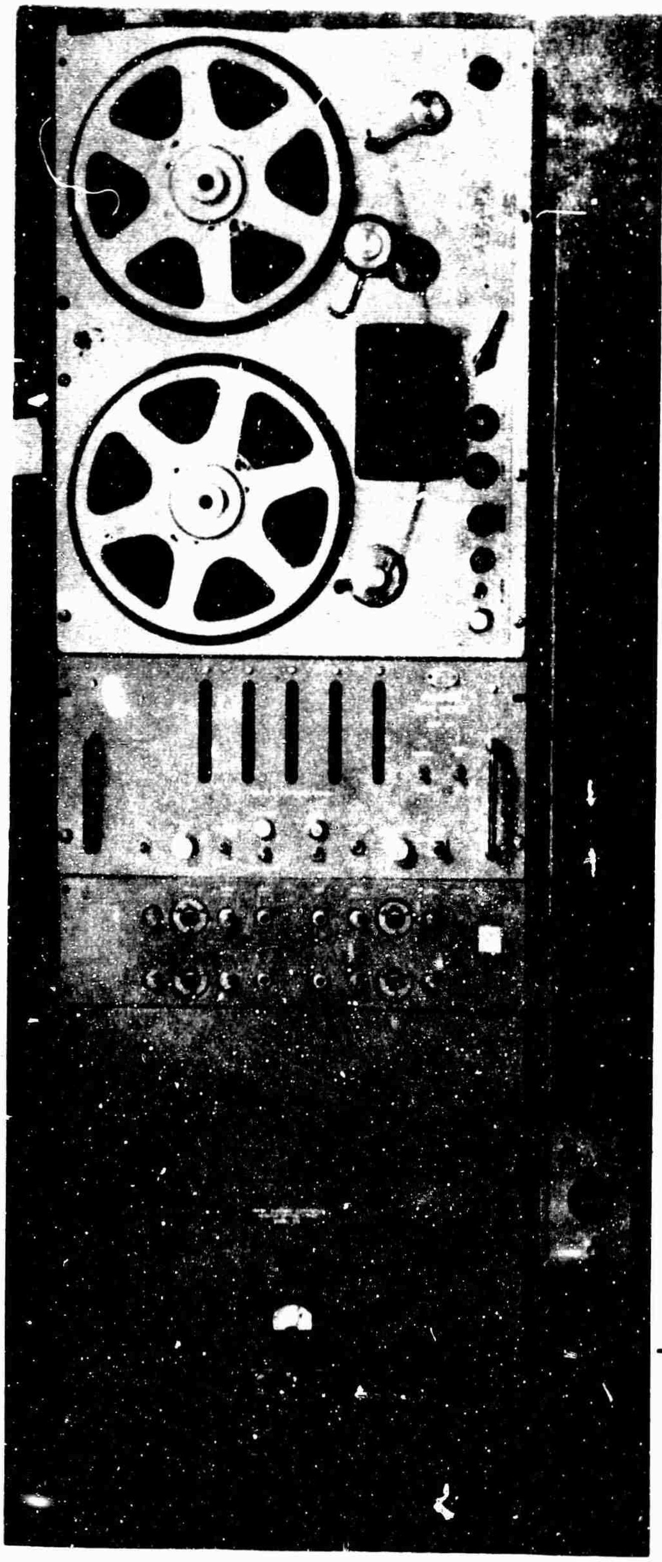


Fig. 3 RECORDING RACK

Fig. 4 PLAYBACK RACK

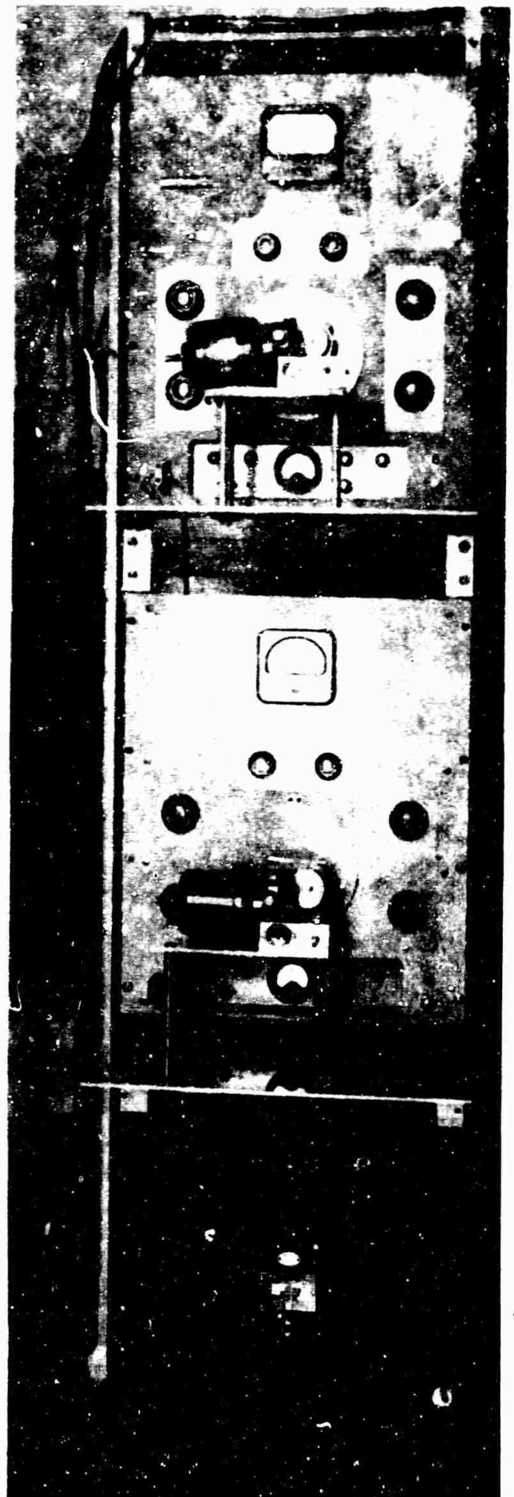


Fig. 5 HARMONIC ANALYZER RACK

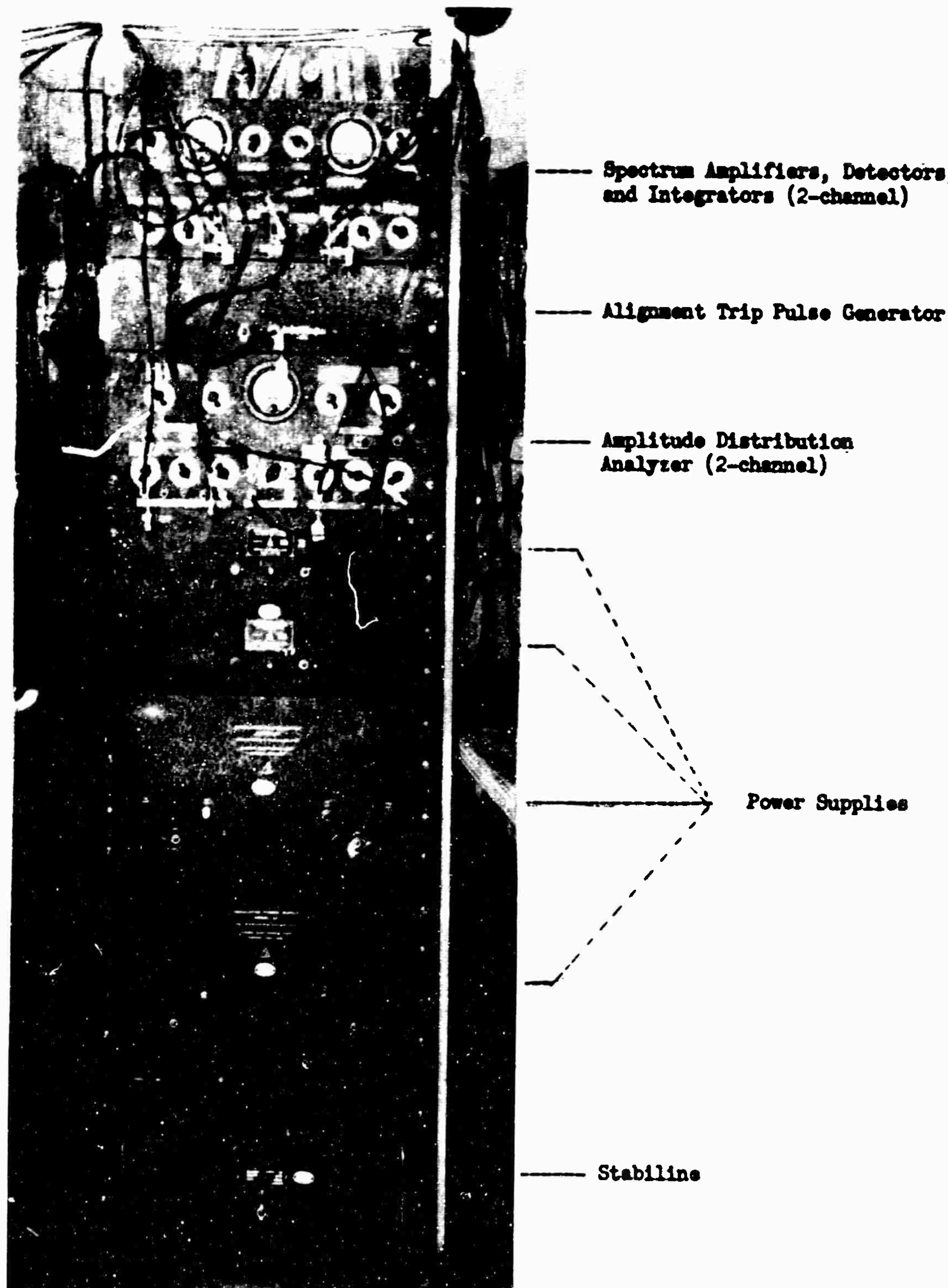


Fig. 6 ANALYZER RACK

1 - <u>APL Dual-Channel Distribution Analyzer</u> (See Figure 6)

This unit takes the data directly from the playback unit and determines the amount of time that the magnitude of the signal is below a reference level. The reference level is varied by a clock motor so that the complete distribution curve is obtained at the output.

1 - <u>Six-Channel Brush Recording System</u>

This system consists of a six-channel Brush recorder and two dual-channel Brush d-c amplifiers for recording the outputs of the spectrum analyzers and distribution analyzers.

THEORY OF OPERATION - TAPE EQUIPMENT

The following general description of the present use of this equipment is intended to show the principles of operation. Considerable versatility has been built in, so that the tape speeds and frequency ranges are typical but not necessarily limiting values. The limiting values are discussed under limitations.

The data which have been analyzed to date were recorded in the field using the Ampex Model 3167 Record Unit. Recordings were made at 3 3/4 in/sec tape speed. The FM carrier frequency was 3.375 kc and the deviation for maximum signal was about 40 percent. The frequency of the 3.375 kc oscillator is varied as a function of the amplitude of the data signal. Such a signal, assuming sinusoidal carrier (amplitude A) and a single sinusoidal data input, can be expressed by:

$$e = A \sin (wt + m \sin w_s t)$$

where $w = 2\pi$ x carrier frequency

$w_s = 2\pi$ x data signal frequency

$$m = \frac{\text{frequency deviation}}{\text{data signal frequency}}$$

This can be expanded in terms of Bessel functions of the first kind and n^{th} order as follows:

$$e = A\, J_o(m) \sin wt$$
$$+A \sum_{n=1}^{n=\infty} J_n(m) \left[\sin (w + nw_s)\, t + (-1)^n \sin(w - nw_s)t\right]$$

This represents the carrier and an infinite number of side bands separated from the carrier by w_s and by multiples of w_s. Increasing the tape speed by some factor k will multiply every component frequency by the factor k resulting in:

$$e = A\,J_o(m)\,\sin kwt + A\sum_{n=1}^{n=\infty} J_n(m)\left[\sin k(w + nw_s)t + (-1)^n \sin k(w - nw_s)t\right]$$

This, by analogy, represents a carrier of frequency kw, frequency modulated by a data signal kw_s. This signal when demodulated gives a signal whose wave shape is the same as the data signal but whose frequency has been multiplied by k.* A complicated data signal represented by its Fourier series could be substituted for the simple sine wave above. The result upon demodulation would be the same, that is, an unchanged shape with time base changed by the factor k.

The speed-up ratio k is limited here by the tape speeds available and the carrier frequencies to which the recording oscillators and playback demodulators can be tuned. In the analyses to date the value of k has been 512. This is obtained as follows: (1) The data were recorded in the field at 3 3/4 in/sec. (2) This signal is played back at 30 in/sec and re-recorded on the 3 3/4 in/sec recorder (8 to 1 speed-up). (3) This tape is formed into a closed loop and played back at 30 in/sec (64 to 1). (4) It is again recorded at 3 3/4 in/sec and allowed to run for 8 loops of the tape (to obtain a loop long enough to handle easily). Then this second re-recorded tape is formed into a second closed loop. (5) It is played back at 30 in/sec for analysis giving another factor of 8 to 1 or a total speed-up factor of 512. The original data samples were of four minutes duration or 900 inches. The first loop formed was about 112 inches and when played back at 30 in/sec takes 3 3/4 seconds per revolution. The second re-recorded loop is also about 112 inches (the speed-up is 8 to 1 but the first loop is run 8 times to form the second loop). The second loop is run for analysis at 30 in/sec and runs 3 3/4 seconds per revolution.

For spectrum analysis the Hewlett-Packard 300A harmonic analyzer is used. Its frequency range is 20 to 16,000 cycles per second. With the 512 speed-up ratio its real time frequency range is thus 0.039 to 31 cycles per second. However, the upper frequency is limited to 5000 cycles (9.7 cycles real time base) by the frequency response of the demodulator. Extension of the low frequency limit is discussed under spectrum analyzer tests.

The recording and playback systems are described in detail in instruction books and will not be covered in this report. The rest of the system was built and assembled by APL and will be described in detail in the following paragraphs. It will be assumed that the data are now available in the frequency range 20 to 5000 kc (about 0.04 to 9.7 cycles real time). In tests to date frequencies to about 2000 cycles only have been encountered. See Appendix I - Operation of the Tape Equipment.

---

*Note that m is unchanged because in the speeded up signal

$$m = \frac{k\Delta f}{kf_s} = \frac{\Delta f}{f_s}$$

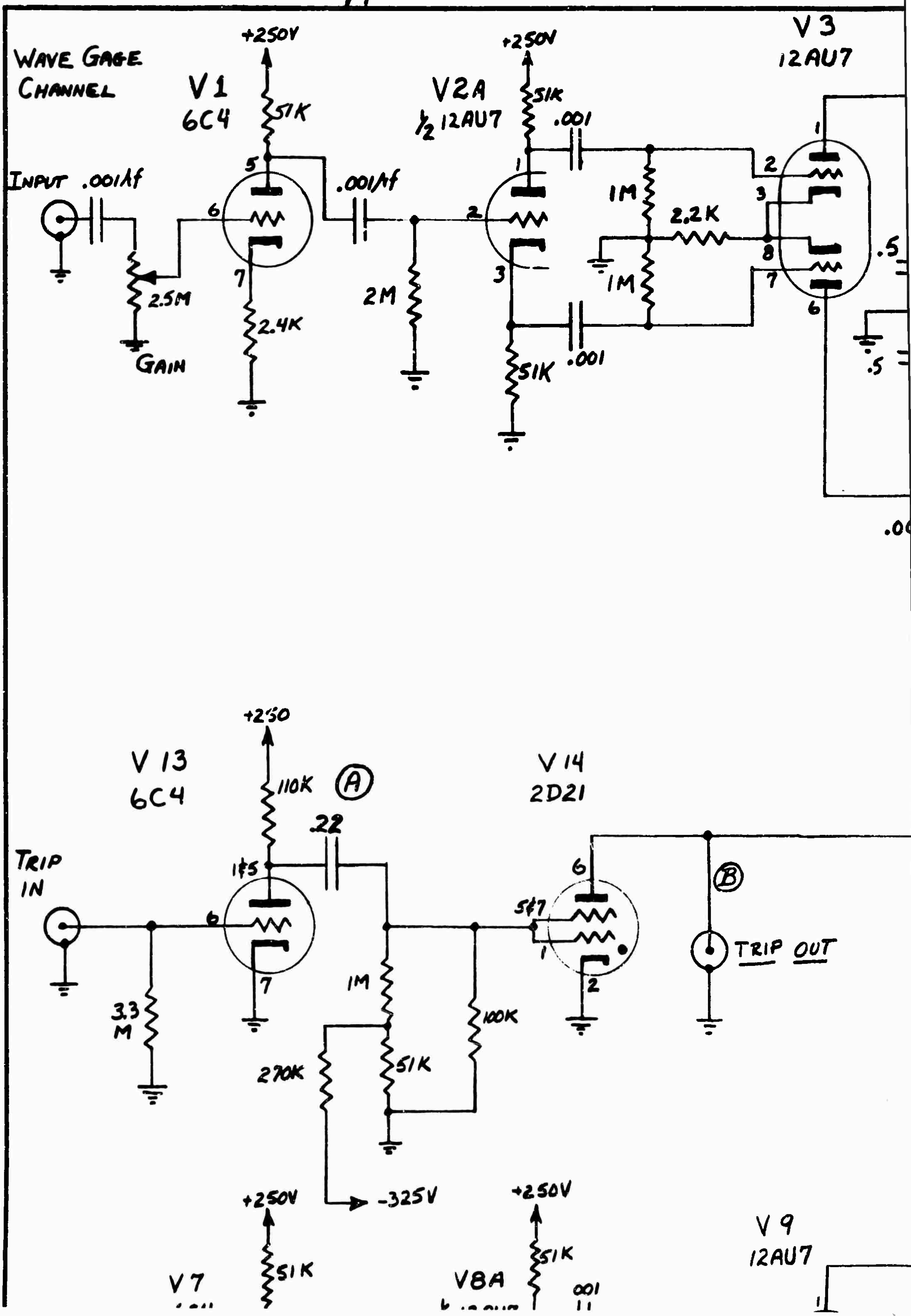
THEORY OF OPERATION - SPECTRUM ANALYZER

The data are fed from the playback unit to the Hewlett-Packard 300A harmonic wave analyzer. This unit operates on the heterodyne principle. The local oscillator frequency is set by the main tuning knob. The L.O. frequency is the dial reading plus 20 kc. The signal and L.O. are mixed in a balanced modulator where the L. O. frequency is suppressed and sidebands are produced at (L.O. + dial setting) and (L.O. - dial setting) with amplitude proportional to the magnitude of the component of the signal at the frequency of the dial setting. Thus (L.O. - dial setting) is always 20 kc. This 20 kc sideband is selected by a 20 kc bandpass filter* whose output is amplified and measured by a VTVM. The amplitude of this signal varies during the tape loop revolution. In order to obtain the average value of the particular frequency component during the tape cycle it is necessary to integrate the output of the 20 kc filter over one tape cycle. This is accomplished in a unit built for the purpose by APL. The input to this unit is the 20 kc signal from the filter. It is amplified and peak detected in a push-pull amplifier and detector system shown in Figure 7. Push-pull and negative feedback techniques are used to obtain amplitude linearity. A push-pull cathode follower drives the push-pull detector which has a single ended output. The amplitude of the signal at this point is proportional to the amplitude of the data component at the frequency to which the wave analyzer dial is set. This signal is integrated in a Miller integrator which is arranged so that it may be discharged to its quiescent operating point by a trip signal supplied either by a signal from a photocell arrangement or by a signal from one of the unused tape channels. The output of the integrator is fed to a Brush amplifier and recorder. The signal here builds up to a voltage which is proportional to the average amplitude of the particular frequency component during one cycle of the tape loop. Two such channels are provided so that two signals may be handled simultaneously. Figure 7 is a schematic of these circuits. V1 - V6 constitutes one channel, V7 - V12 the other. V13 and V14 are an amplifier and thyratron combination to trip the recycling relays K1 and K2. Alignment procedures for this chassis are contained in Appendix II. Examples of spectra obtained are shown in Figures 17 and 18. For continuous automatic data analysis the harmonic analyzer tuning knob is rotated by a motor and gear train at a constant slow speed such that during one cycle of the tape loop the change in frequency is small. (At least three tape loops per bandwidth of the filter at the highest frequencies used, more at lower frequencies.)

---

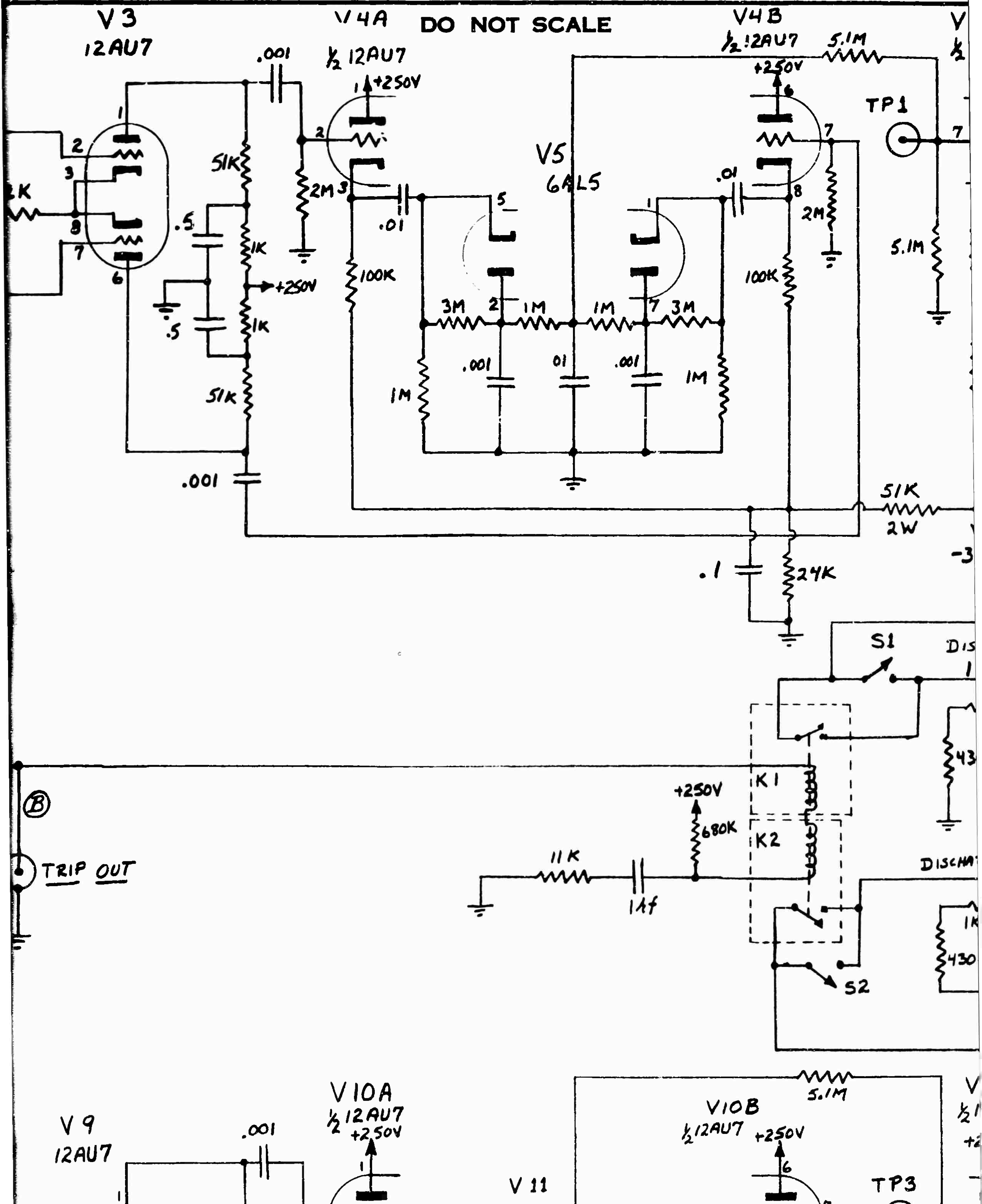
*Half bandwidth variable from 30 cycles to 145 cycles at the 40-db points.

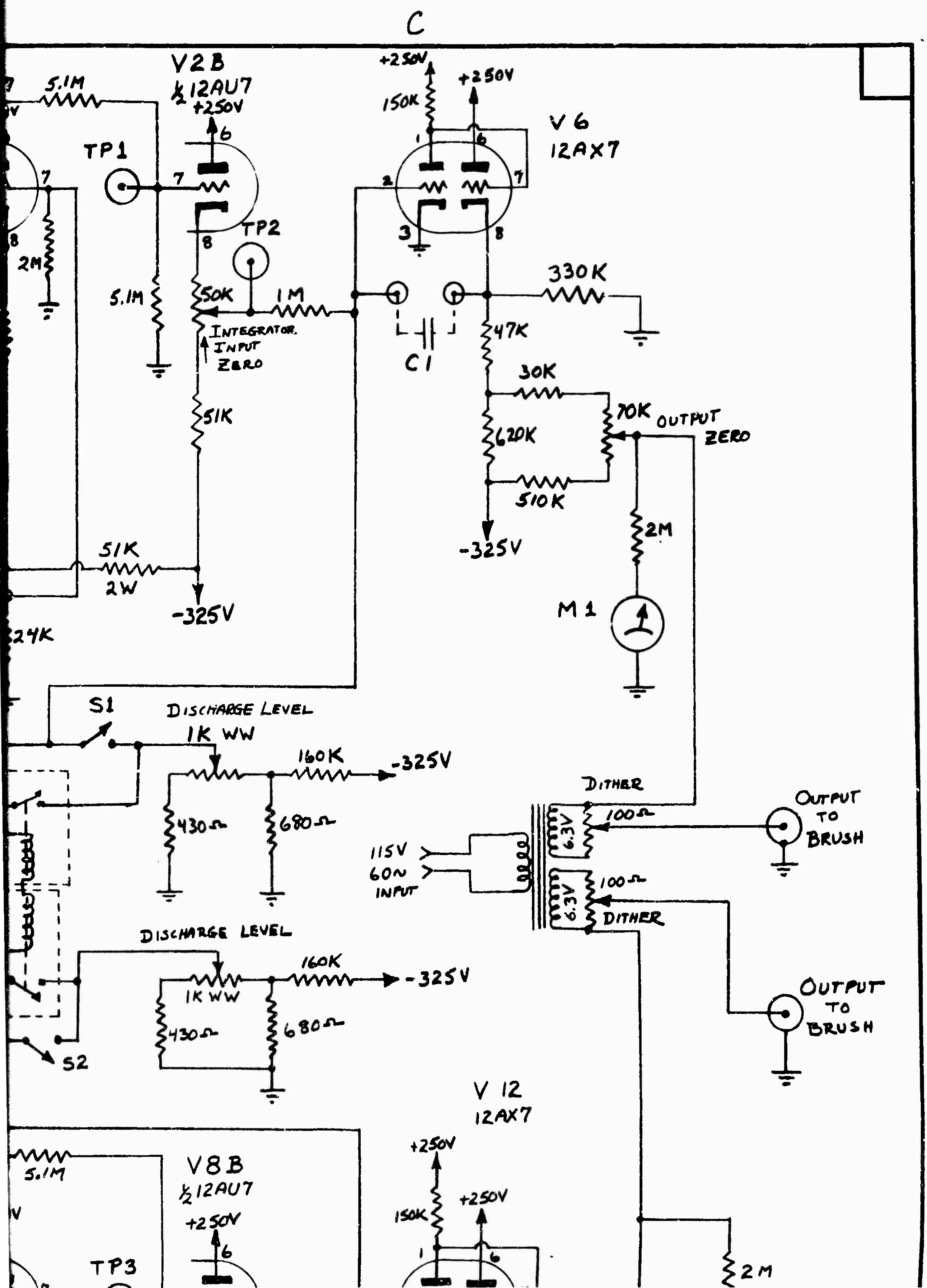
A

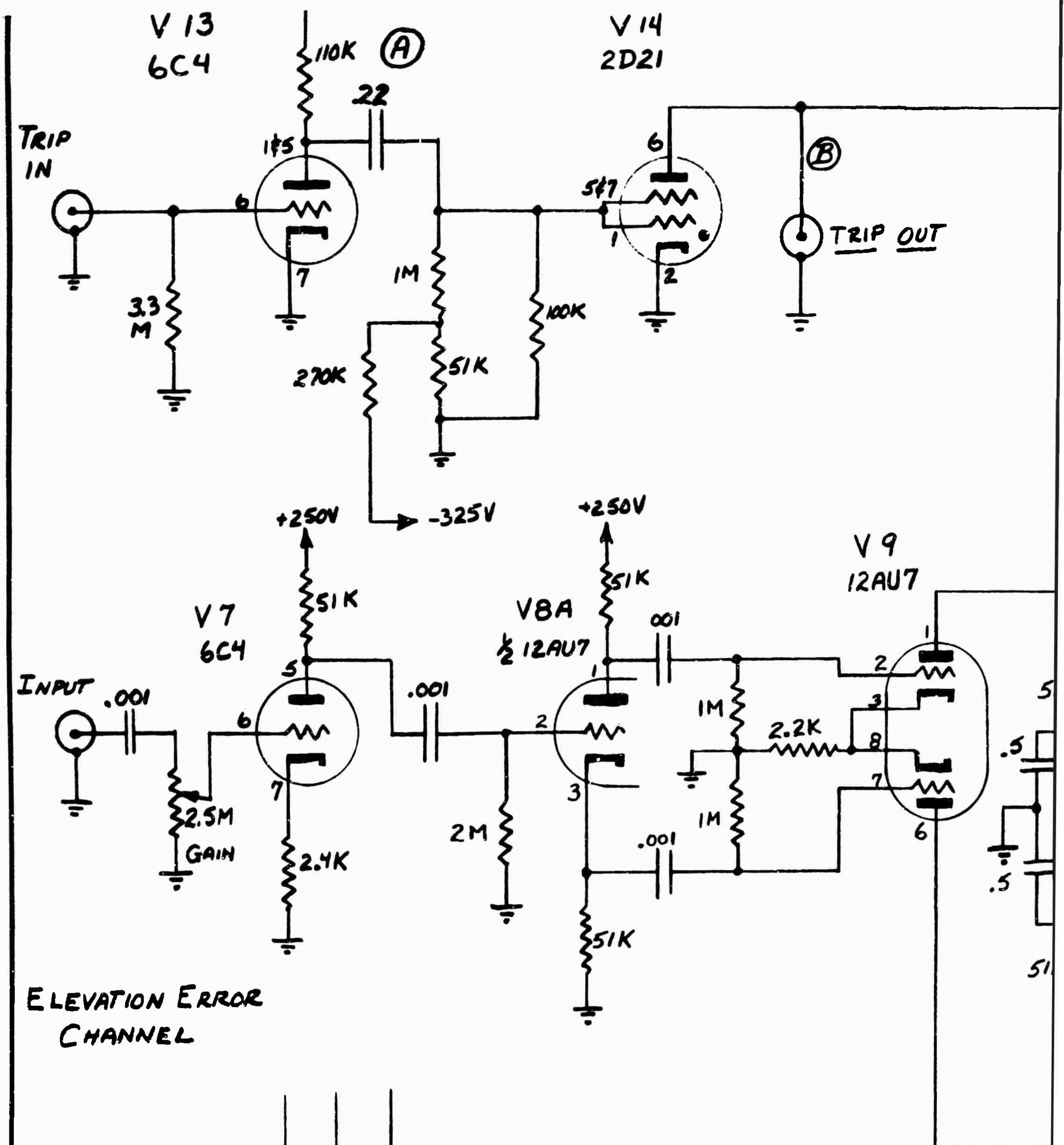

WAVE GAGE CHANNEL
INPUT
.001μf
2.5M
GAIN
V1
6C4
+250V
51K
2.4K
.001μf
2M
V2A
½ 12AU7
+250V
51K
.001
1M
2.2K
1M
.001
51K
V3
12AU7
.5
.5
TRIP IN
3.3 M
V13
6C4
+250
110K
Ⓐ
.22
1M
270K
51K
100K
-325V
V14
2D21
Ⓑ
TRIP OUT
+250V
51K
V7
+250V
51K
V8A
.001
V9
12AU7

P2

DO NOT SCALE



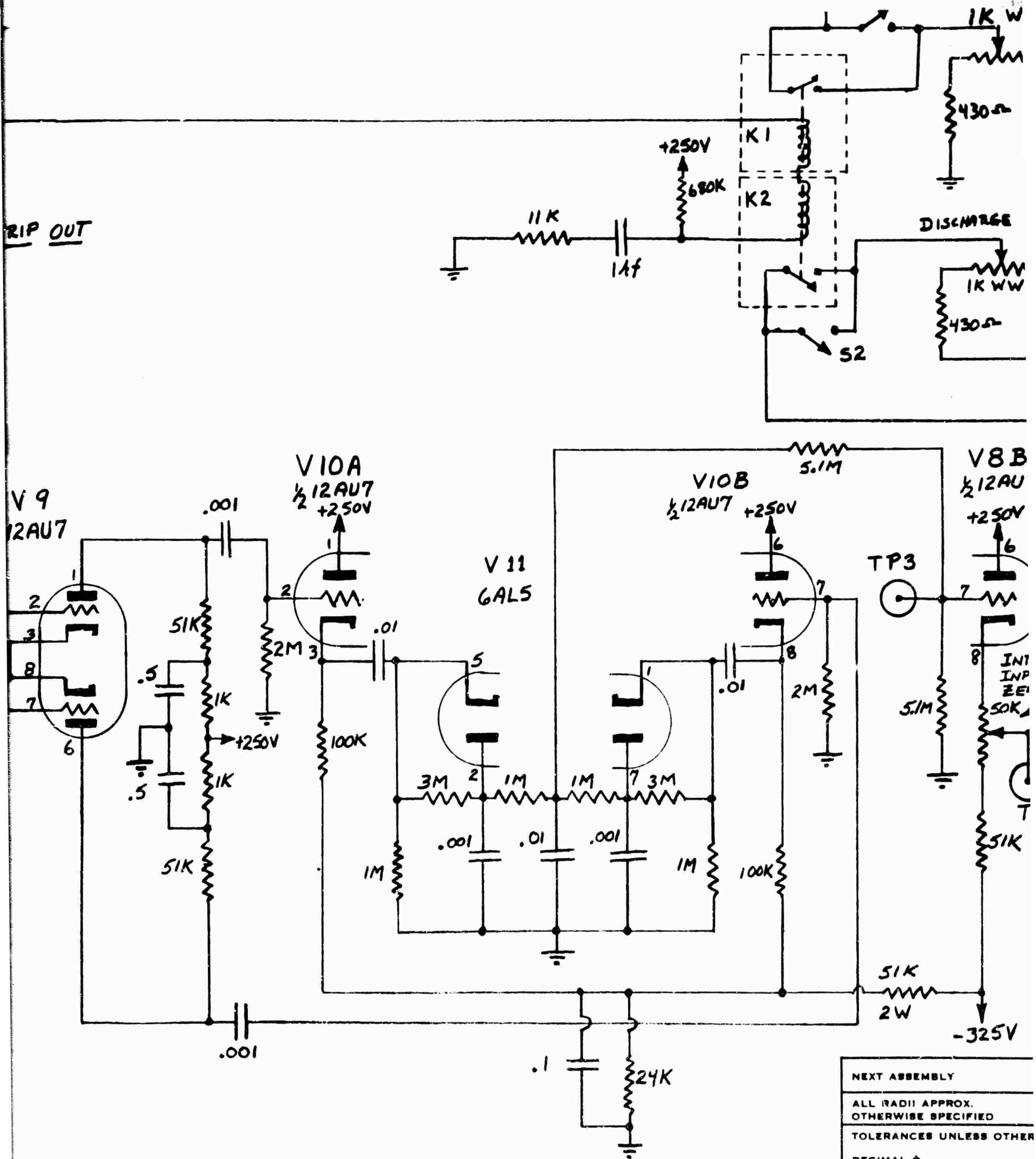

C
V2B
½ 12AU7
+250V
5.1M
TP1
2M
5.1M
TP2
50K
1M
INTEGRATOR INPUT ZERO
51K
51K
2W
-325V
24K
+250V
150K
+250V
V6
12AX7
330K
C1
47K
30K
70K
OUTPUT ZERO
620K
510K
-325V
2M
M1
S1
DISCHARGE LEVEL
1K WW
160K
-325V
430Ω
680Ω
DITHER
100Ω
6.3V
115V
60~
INPUT
100Ω
6.3V
DITHER
OUTPUT TO BRUSH
OUTPUT TO BRUSH
DISCHARGE LEVEL
1K WW
160K
-325V
430Ω
680Ω
S2
V12
12AX7
+250V
150K
+250V
5.1M
V8B
½ 12AU7
+250V
TP3
2M



(B) .01μf REMOVED	9-16-54	DPR
(A) .22 WAS .01	12-8-55	DPR
REVISION	DATE	By

"ALBANENE" No. 196L K&E CO., N.Y.

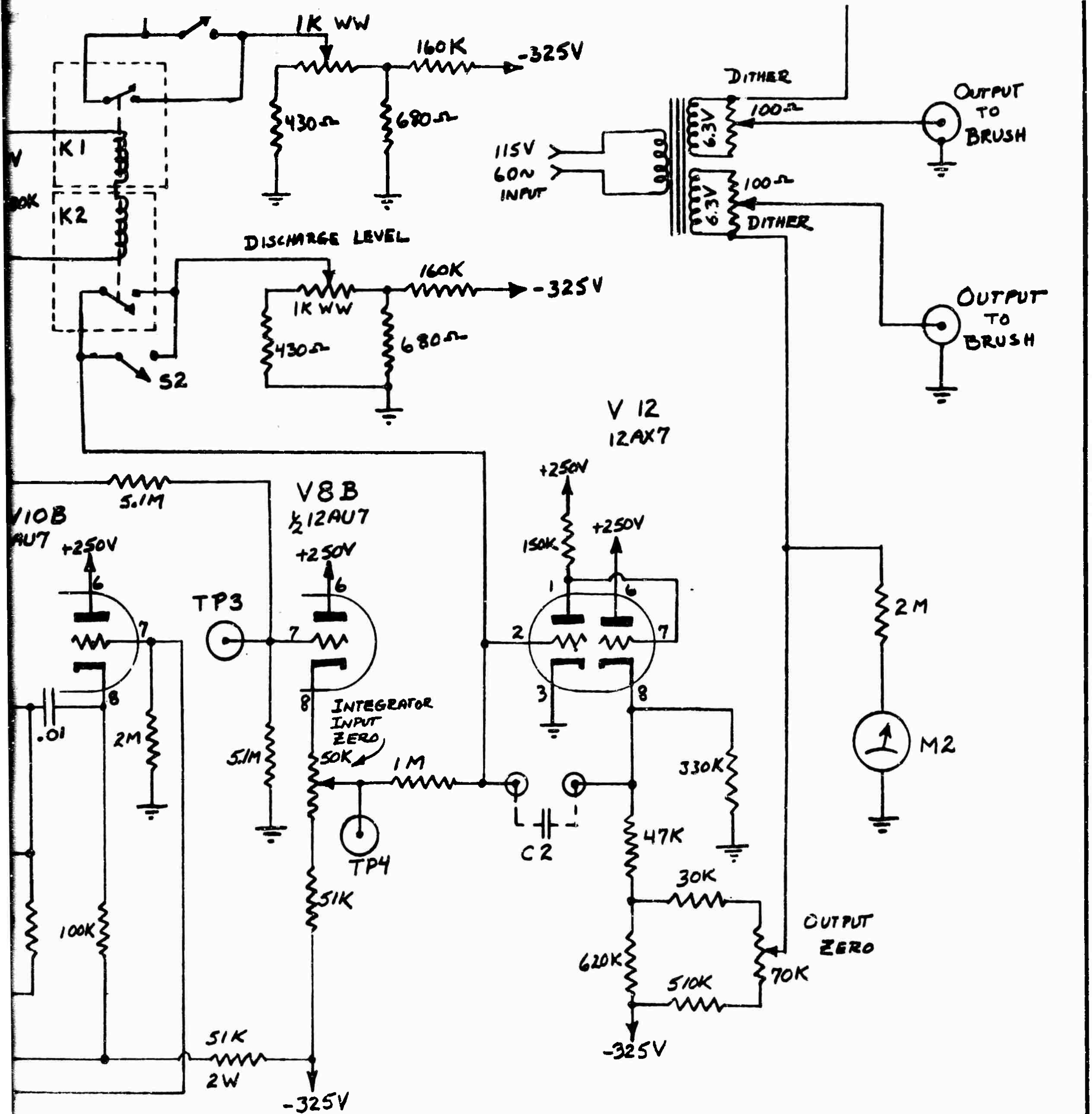
Fig. 7 SCHEMATIC OF SPECTRUM AMPLIFIER, I



NEXT ASSEMBLY
ALL RADII APPROX. OTHERWISE SPECIFIED
TOLERANCES UNLESS OTHER
DECIMAL ±
ANGULAR ±
BREAK SHARP EDGES-REMO
MATERIAL:

UM AMPLIFIER, DETECTOR, AND INTEGRATOR

E



NEXT ASSEMBLY	REV.	DATE	BY	DESCRIPTION	CH.

ALL RADII APPROX. UNLESS OTHERWISE SPECIFIED

TOLERANCES UNLESS OTHERWISE SPECIFIED

DECIMAL ±

ANGULAR ±

BREAK SHARP EDGES-REMOVE BURRS

MATERIAL:

DWN. D.F.Rogers	DATE 12-5-53	SCALE
CHKD. D.F.Rogers	APPVD. D.F.Rogers	GROUP BBG-1

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SILVER SPRING, MD.

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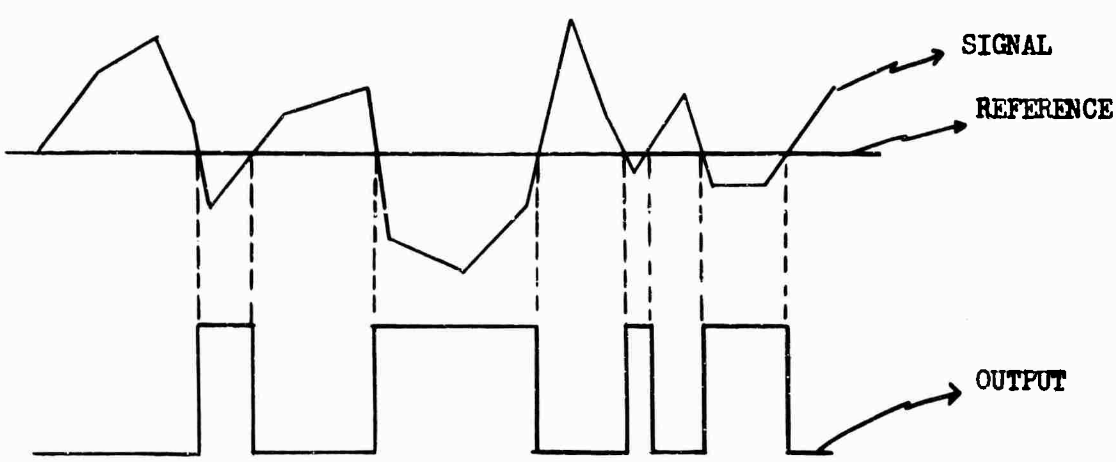
F

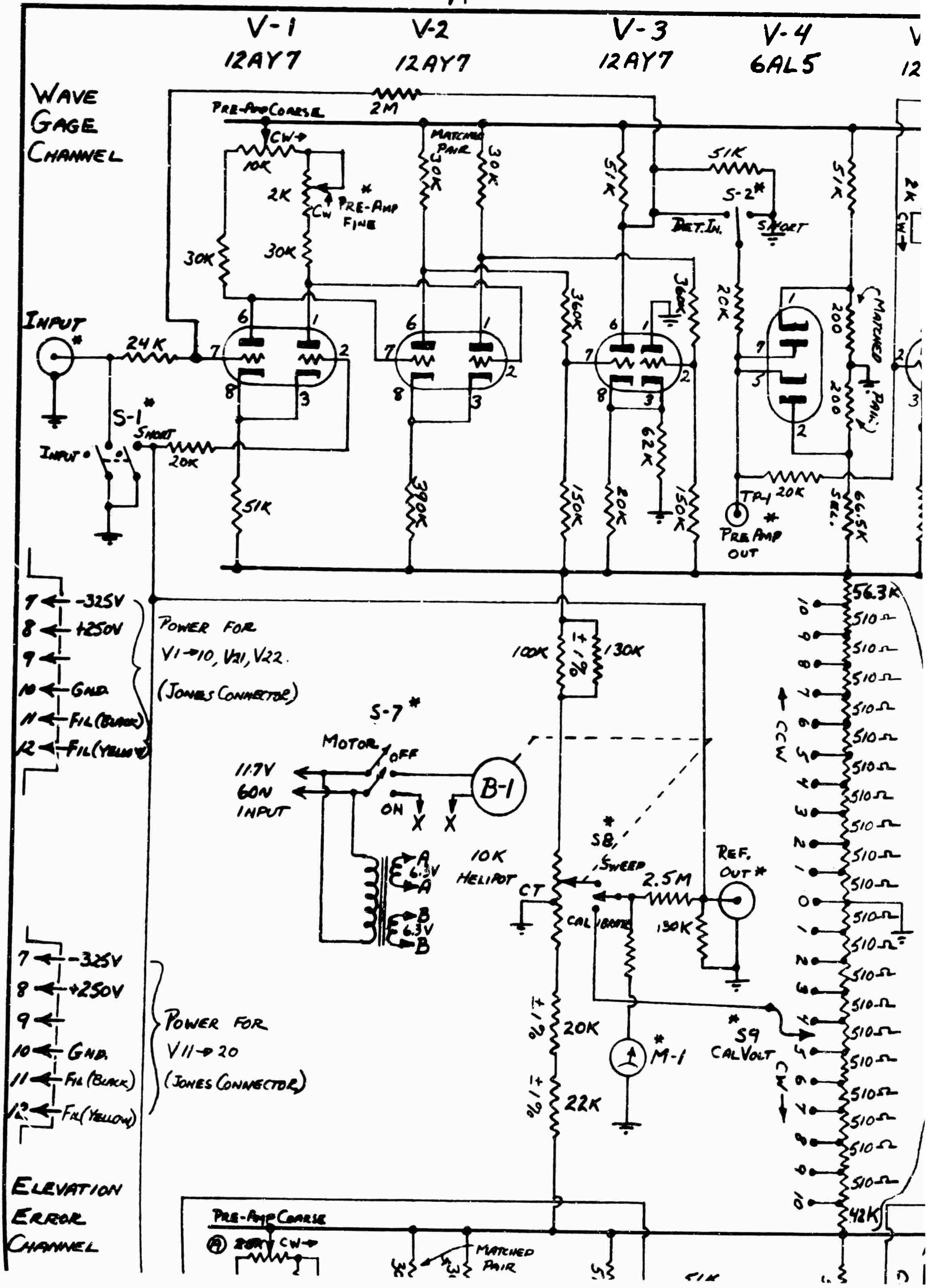
THEORY OF OPERATION - DISTRIBUTION ANALYZER

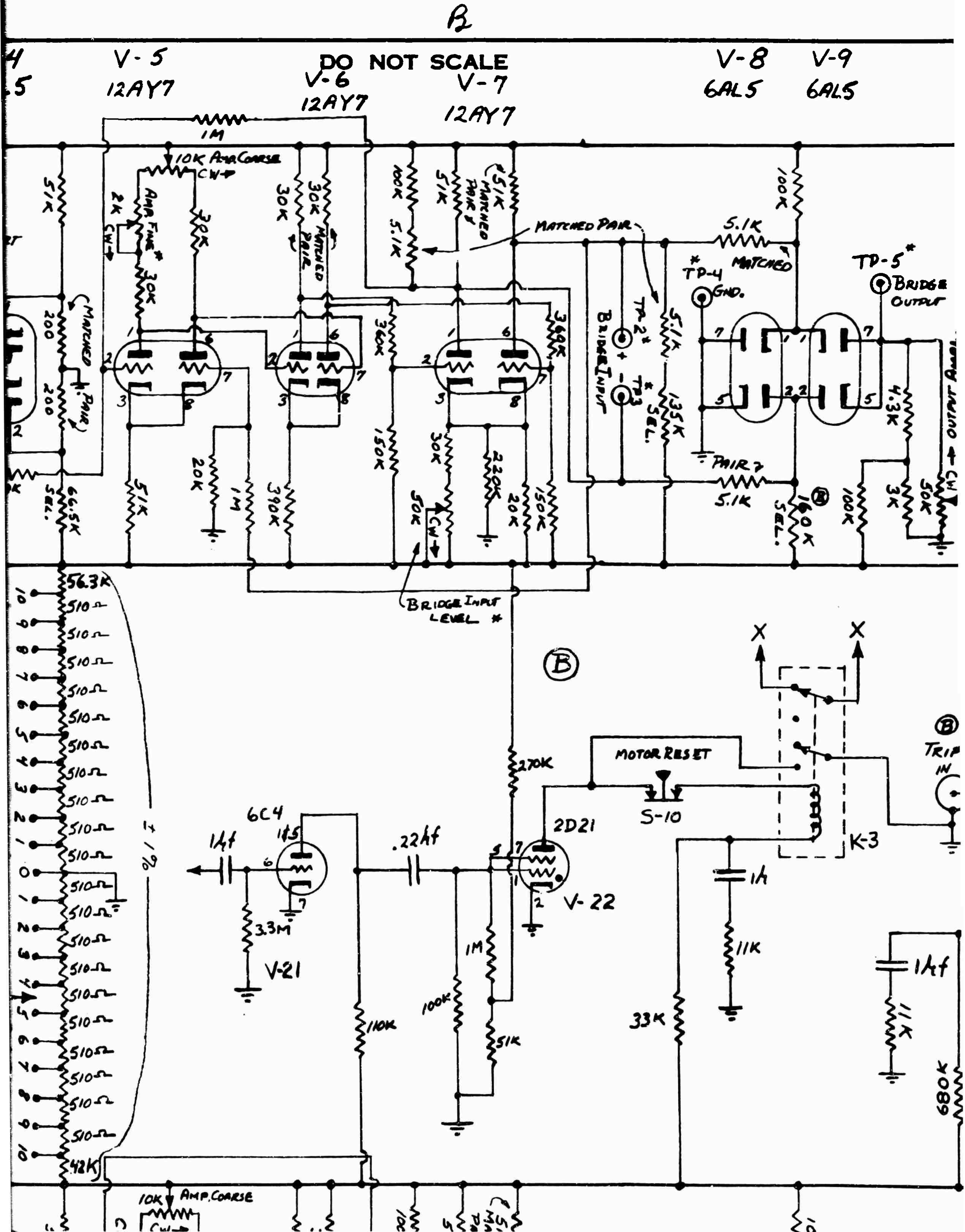
The amplitude distribution analyzer gets its input directly from the tape signal demodulators. In the first stage (V1 - Figure 8) the signal is compared with a reference voltage generated by a precision potentiometer and regulated power supplies. When the reference voltage is below -1.4 volts (the minimum voltage out of the demodulator) no signal is generated. However, when the reference voltage is varied from -1.4 up to +1.4 volts (the maximum from the demodulator) the data signal will go below the reference signal for periods of time dependent on the amplitude and shape of the data signal. During the times when the data signal is below the reference level an output will be obtained. This output is greatly amplified and clipped so that the final output is a function which jumps from zero to maximum or vice versa every time the input signal crosses the reference. (See sketch below.) The time spent at this maximum value will thus be a measure of the percentage of time during which the signal is below the reference level.



If this irregular period (constant amplitude) voltage is integrated over one cycle of the tape loop, the integrated output is a measure of the percentage of time during which the data signal is below the reference level. The rate of change of the reference level is slow compared to the tape cycle so that the change in reference voltage during one cycle of the tape loop is negligible. V1 (Figure 8) is the comparator while V2 through V9 do the amplifying and clipping. V10 is an integrator identical to the one used in the spectrum analyzer. The trip relays are operated from the trip circuit of the spectrum analyzer chassis. Two channels are available for simultaneous analysis of two tape channels. V11 through V20 are the second channel. V21 - V22 are used to stop the drive motor on the precision potentiometer after one complete cycle of the reference voltage. Alignment procedures for this chassis are contained in Appendix III. Examples of amplitude distribution curves are shown in Figures 17 and 18.

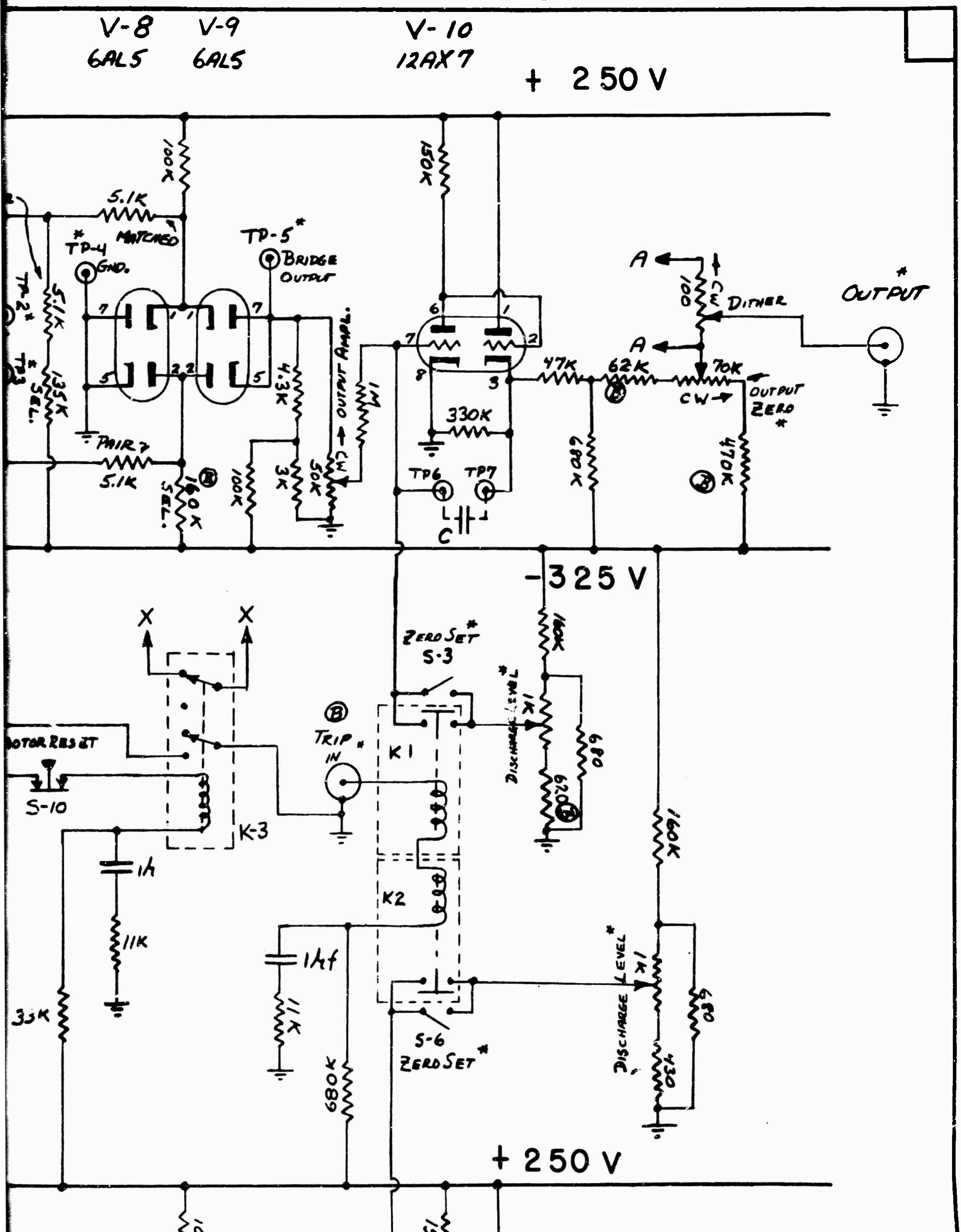
A


V-1
12AY7
V-2
12AY7
V-3
12AY7
V-4
6AL5
WAVE GAGE CHANNEL
PRE-AMP COARSE
2M
CW
10K
2K
PRE-AMP FINE
30K
30K
MATCHED PAIR
30K
30K
51K
51K
S-2*
DET. IN.
SHORT
20K
51K
200
200
MATCHED PAIR
INPUT*
24K
S-1*
SHORT
INPUT
20K
51K
390K
360K
360K
62K
150K
20K
150K
TP-1
20K
PRE AMP OUT
SEL.
66.5K
56.3K
7 -325V
8 +250V
9
10 GND.
11 FIL (BLACK)
12 FIL (YELLOW)
POWER FOR V1→10, V21, V22.
(JONES CONNECTOR)
100K
±1%
130K
S-7*
MOTOR
OFF
ON
117V 60N INPUT
B-1
X
X
A
6.3V
A
B
6.3V
B
10K HELIPOT
CT
SB, SWEEP
CAL. IBRATE
2.5M
REF. OUT*
130K
CCW
CW
510Ω
±1%
20K
±1%
22K
M-1*
S9 CAL VOLT
42K
7 -325V
8 +250V
9
10 GND.
11 FIL (BLACK)
12 FIL (YELLOW)
POWER FOR V11→20
(JONES CONNECTOR)
ELEVATION ERROR CHANNEL
PRE-AMP COARSE
MATCHED PAIR

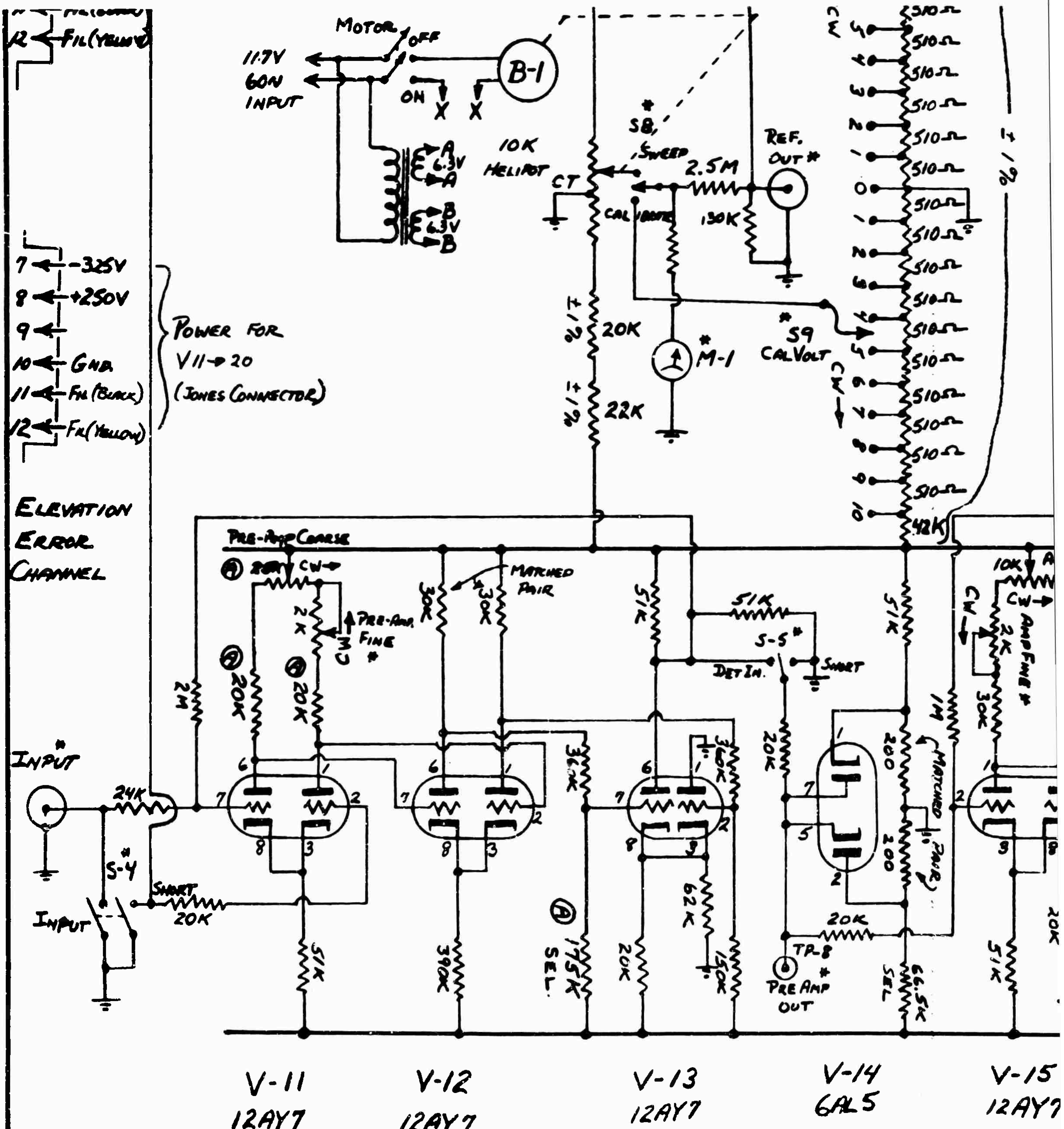


B
DO NOT SCALE
V-5
12AY7
V-6
12AY7
V-7
12AY7
V-8
6AL5
V-9
6AL5
1M
10K AMP COARSE
CW
2K
AMP FINE *
30K
51K
200
MATCHED PAIR
SEL.
66.5K
MATCHED PAIR
360K
150K
20K
390K
100K
5.1K
MATCHED PAIR
36.0K
50K
220K
BRIDGE INPUT LEVEL *
TP-2 *
TP-3 *
BRIDGE INPUT
TP-4 *
GND.
TP-5 *
BRIDGE OUTPUT
MATCHED
PAIR
135K
100K
SEL.
4.3K
3K
OUTPUT AMPL.
56.3K
510Ω
±1%
42K
6C4
1μf
3.3M
V-21
.22μf
110K
270K
1M
100K
51K
2D21
V-22
MOTOR RESET
S-10
K-3
1μ
11K
33K
1μf
680K
TRIP IN
10K AMP. COARSE

C



V-8
6AL5
V-9
6AL5
V-10
12AX7
+ 250 V
100K
5.1K
MATCHED
150K
TP-4*
GND.
TP-5*
BRIDGE OUTPUT
TP-2*
TP3*
SEL.
5.1K
135K
A
100
CW
DITHER
OUTPUT*
A
47K
62K
70K
CW
OUTPUT ZERO*
OUTPUT AMPL.
CW
1M
4.3K
330K
PAIR
5.1K
160K
SEL.
100K
3K
50K
TP6
TP7
C
680K
470K
-325 V
X
X
ZERO SET*
S-3
160K
TRIP IN*
K1
DISCHARGE LEVEL*
1K
680
620
MOTOR RESET
S-10
K-3
1μ
11K
K2
1μf
11K
160K
DISCHARGE LEVEL*
1K
680
430
33K
S-6
ZERO SET*
680K
+ 250 V



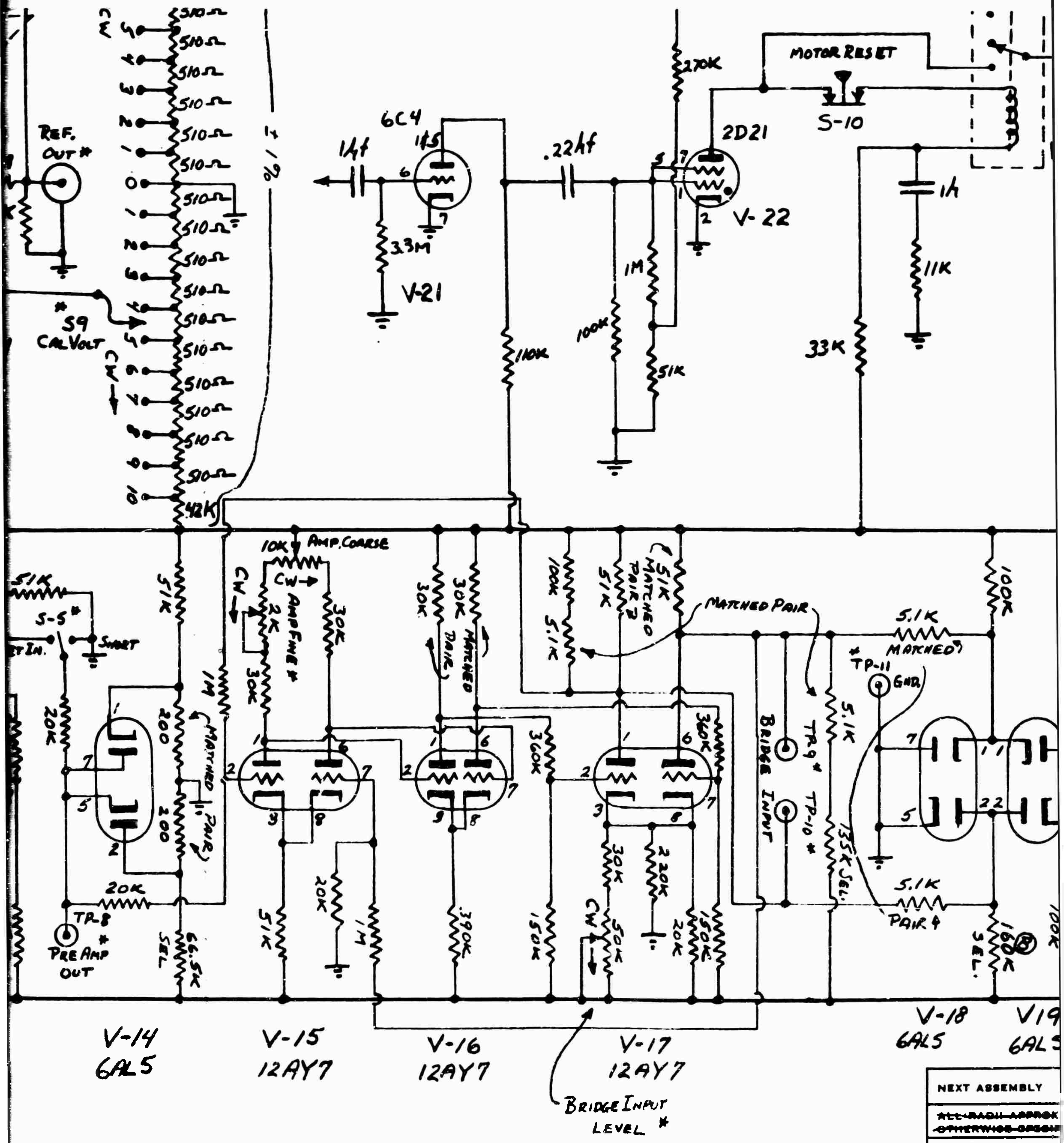
(B) REVISED & REDRAWN 3-16-54 DAK

REV. (A) 2-19-54 DAK
VALUES CHANGED TO PERMIT BALANCE

Fig. 8 SCHEMATIC OF AMPLITUDE DISTRIBUTIO

"ALBANENE" No. 100L K&E CO., N.Y.

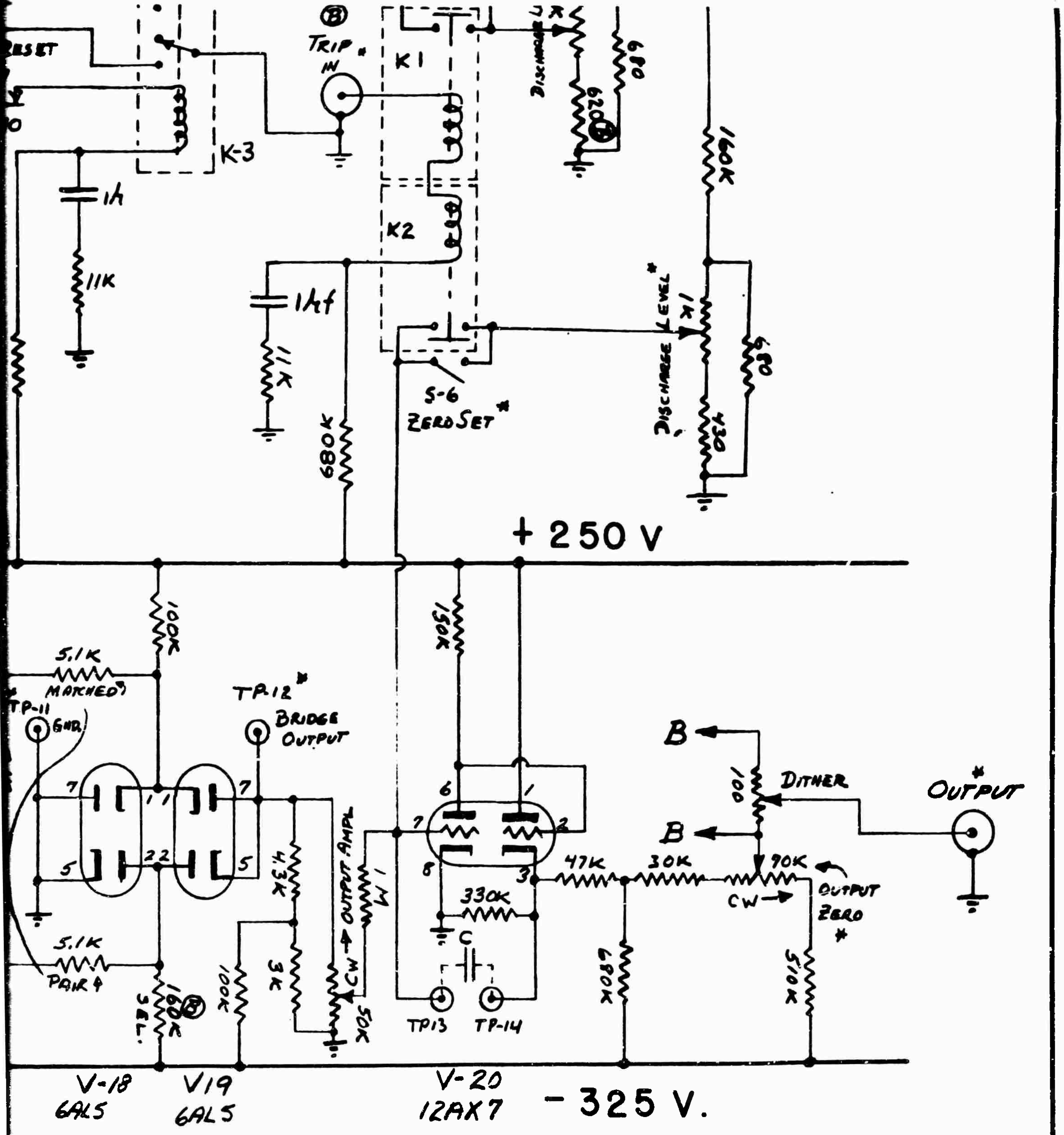
D



C OF AMPLITUDE DISTRIBUTION ANALYZER

NEXT ASSEMBLY
~~ALL RADII APPROX OTHERWISE SPECIF~~
~~TOLERANCES UNLE~~
~~DECIMAL ±~~
~~ANGULAR ±~~
~~BREAK SHARP EDG~~
~~MATERIAL:~~

E



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TESTS - GENERAL

Many tests have been performed on these units to investigate their accuracy. The more important of these are listed in the following table and described in detail in the following paragraphs.

A. Spectrum Analyzer

1. Low frequency response of harmonic analyzer
2. Effect of harmonic analyzer balance on spectra
3. Dynamic amplitude range of the harmonic analyzer
4. Frequency calibration
5. Amplitude linearity and frequency response of the amplifier and detector
6. Amplitude linearity of the integrator
7. Amplitude linearity of the recorder
8. Accuracy of the integration
9. Effect of the splice on the spectra
10. Spectra of known wave shapes
11. Effect of analyzer bandwidth on spectra

B. Amplitude Distribution Analyzer

1. Integrator checks - same as 6, 7, and 8 for the spectrum analyzer
2. Frequency response
3. Amplitude distribution of known wave forms
4. Effect of the splice on the amplitude distribution plots

SPECTRUM ANALYZER TESTS

The low frequency response of the harmonic analyzers was checked by feeding constant amplitude sine waves to the unit and observing the output as a function of frequency. The input amplitude was monitored on a d-c oscilloscope. It was found that the response dropped about 6 percent at 10 cycles. Based on these measurements the unit can be operated at 10 cycles by correcting the readings. (Bandwidth also affects the low frequency readings. This effect is discussed later.)

The harmonic analyzer relies on a balanced modulator to cancel out the oscillator frequency. Tests were run to ascertain the degree to which the residual unbalance of the modulator affects the readings. Runs were made with the recorder gain turned up to 10 times the normal gain. The results (Figure 9) indicate that the maximum components due to unbalance are about 5 percent. The inputs to the harmonic analyzer were shorted during these tests to eliminate other effects. The residual unbalance can be minimized by carefully following the alignment procedures. In any event this unbalance affects only the low frequencies. The filter rejection effectively eliminates any oscillator voltage at the higher frequencies. Bandwidth settings affect this phenomenon also and will be discussed later.

The meter on the harmonic analyzer was designed to read components of a steady input signal. Since the inputs here are noisy in character (having large spikes of short duration in some cases), oscilloscope monitoring was found necessary in order to determine whether or not the spikes were saturating the circuits. The peak signals which can be used without overdriving have been recorded and each run must be examined on the oscilloscope to make sure this value is not exceeded.

The frequency scales of the harmonic analyzers are nonlinear requiring that a frequency scale be placed on the Brush recorder. This is done by recording the spectrum of a known-frequency square wave. Its harmonics give precise frequency points. From this recording a frequency scale was made up which can be put on the Brush recorder paper by hand. Synchronous motors are used throughout so that the frequency calibration is constant and does not have to be repeated.

The frequency response of the amplifier and detector is sufficient to pass the 20 kc signal and its sidebands which come from the harmonic analyzers. They have been designed so that they may be used with the General Radio harmonic analyzer which operates at 50 kc. Considerable care was taken in the design of these circuits to insure good amplitude linearity. The amplifier-detector combination is linear within 2 percent from 10 percent to 100 percent full scale readings. The integrator introduces no additional overall nonlinearity. Actually its nonlinearity is in the opposite direction and somewhat compensates for the amplifier and detector. The combination has a linearity near one percent from 10 percent to 100 percent of maximum readings. Due to the extremely slow speed at which the Brush recorders are operated (0.25 mm/sec) the pen friction causes nonlinearity of the recorded signals particularly at small amplitudes. A 60-cycle dither voltage has been introduced in series with the signal to the recorders to reduce this effect. The overall linearity curve is shown in Figure 10.

The accuracy of the integrator has been checked by feeding a d-c voltage directly into the integrator and observing the output voltage on a Brush recorder. Over the range of amplitudes used the output voltage should rise at a constant rate (volts per second). The ratio of actual to theoretical value at the point of maximum deviation in the operating range was 1.07.

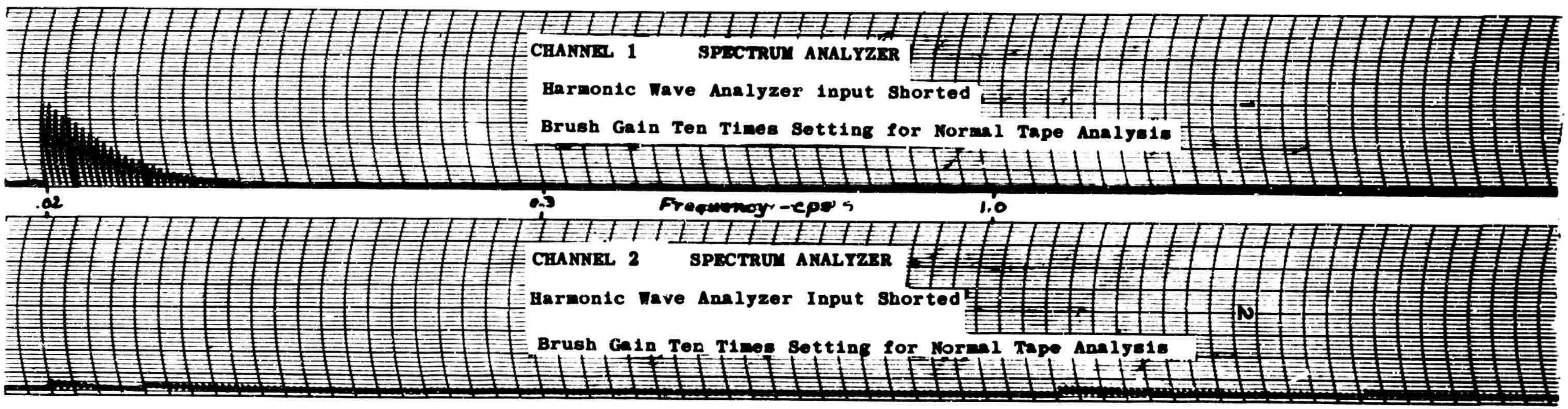

Fig. 9 UNBALANCE EFFECTS

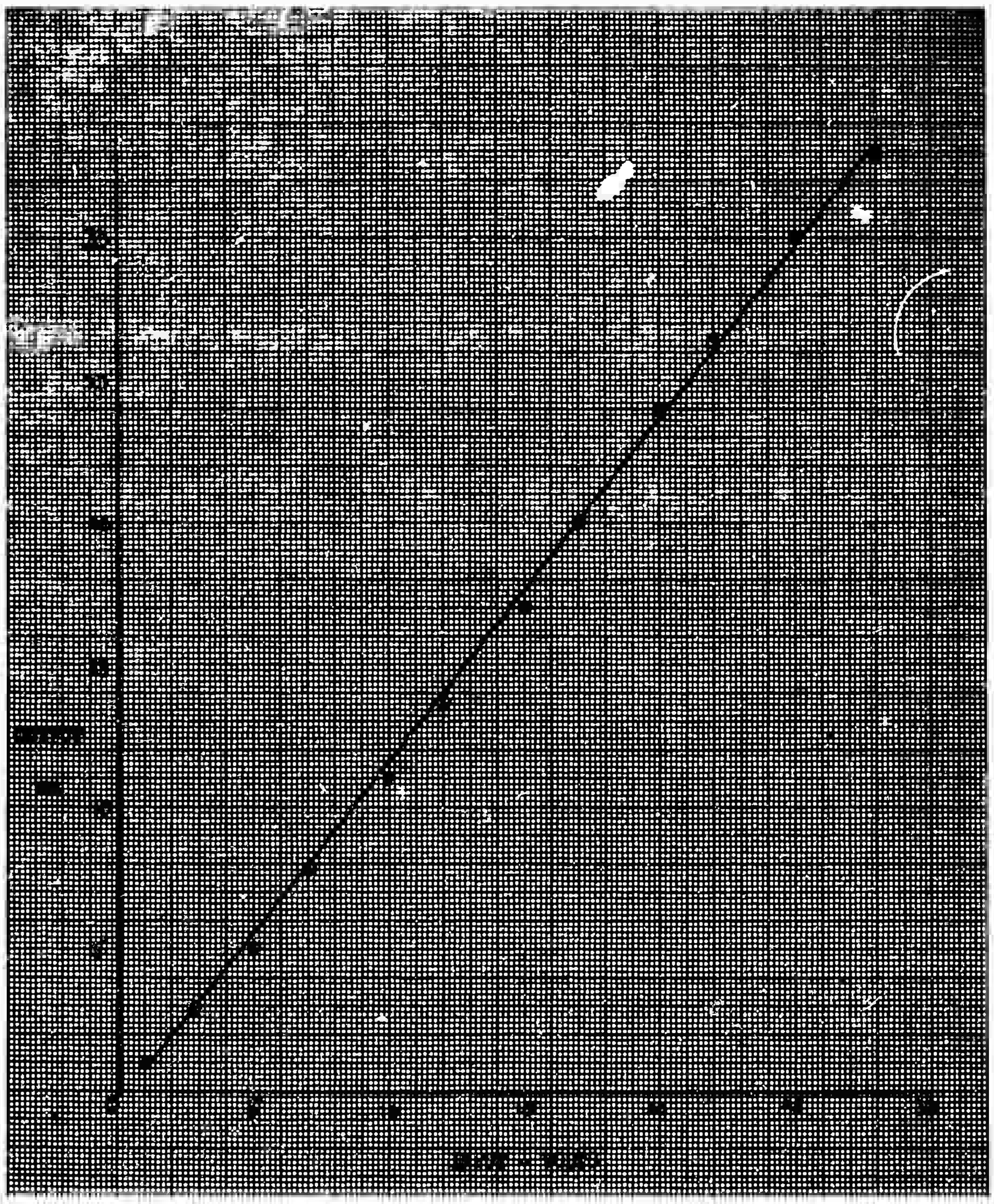

Fig. 10 AMPLITUDE LINEARITY OF SPECTRUM CIRCUITS

It has been demonstrated that a certain amount of splice energy is contributing to the output of the integrators. Unfortunately, the spectrum of the splice energy cannot be investigated with any degree of accuracy because energy of the same order of magnitude exists due to residual unbalance of the modulator circuits which was discussed earlier. These effects are maximum at the lower frequencies where they appear to have a magnitude of about 5 percent of the maximum signal level. (Careful balancing of the modulators prior to each run is required to maintain the level at 5 percent or below.) At the higher frequencies (above about 0.1 cps real time) this effect is less than half of the low frequency value.

The spectra of several known wave shapes have been observed in order to demonstrate that the equipment is operating properly. One of these is shown in Figure 11. The agreement with the theoretical spectrum is good. It should be noted that the lack of detail in the spectrum is due to the wide bandwidth used. Narrower bandwidths result in more detail but in the case of finite samples the accuracy is reduced.*

Reference has been made to the variable bandwidth of the harmonic analyzers. Since these units operate on the heterodyne principle the filter always operates at the same center frequency (20 kc). The bandwidth of this filter can be varied by two front panel controls. No discussion of the effect of bandwidth on the accuracy of the spectra obtained from finite samples will be attempted here.* However, this bandwidth affects the accuracy even assuming the finite sample effects are negligible. The accuracy of the harmonic analyzer depends upon the rejection of the oscillator frequency and upper sideband frequency of the modulator. If any of these components are present in the output they are measured as part of the output by the detector and integrator. The oscillator frequency is primarily rejected by the balanced modulator and secondarily by the rejection of the filter. The upper sideband is rejected solely by the filter. The worst condition is at the lowest frequency. With the harmonic analyzer dial set at 20 cps, the oscillator frequency is 20,020 cps and the upper sideband is 20,040 cps. The filter must be narrow enough to reject effectively 20,040 cps and pass 20,000 cps. Since Hewlett-Packard prescribes certain frequency limits for the various bandwidths, considerable analysis was carried out to ascertain the low frequency limits for this particular application. This analysis shows that the error in the amplitude of any frequency component down to 20 cps (0.04 cps real time) is less than 10 percent with the widest bandwidth available. The more stringent limitation imposed by Hewlett-Packard is dictated by the requirement that the harmonic analyzer measure harmonics which are one percent of the fundamental with some degree of accuracy. The spectrum analyzer described here requires that components be measured accurately down to about 10 percent of the maximum component observed. Figure 12 shows the result of a test designed to investigate the low frequency response experimentally. Sine waves were fed to the spectrum analyzer from a signal generator. Spectra were recorded at 10, 15, 30, and 60 cps (0.02, 0.03, 0.06, and 0.12 cps real time). The amplitude of the sine waves was held constant. This test substantiated the analysis which had been done previously.

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*APL/JHU CF-2040, Errors in Power Spectra Due to Finite Sample, by L. M. Spetner, June 30, 1953.

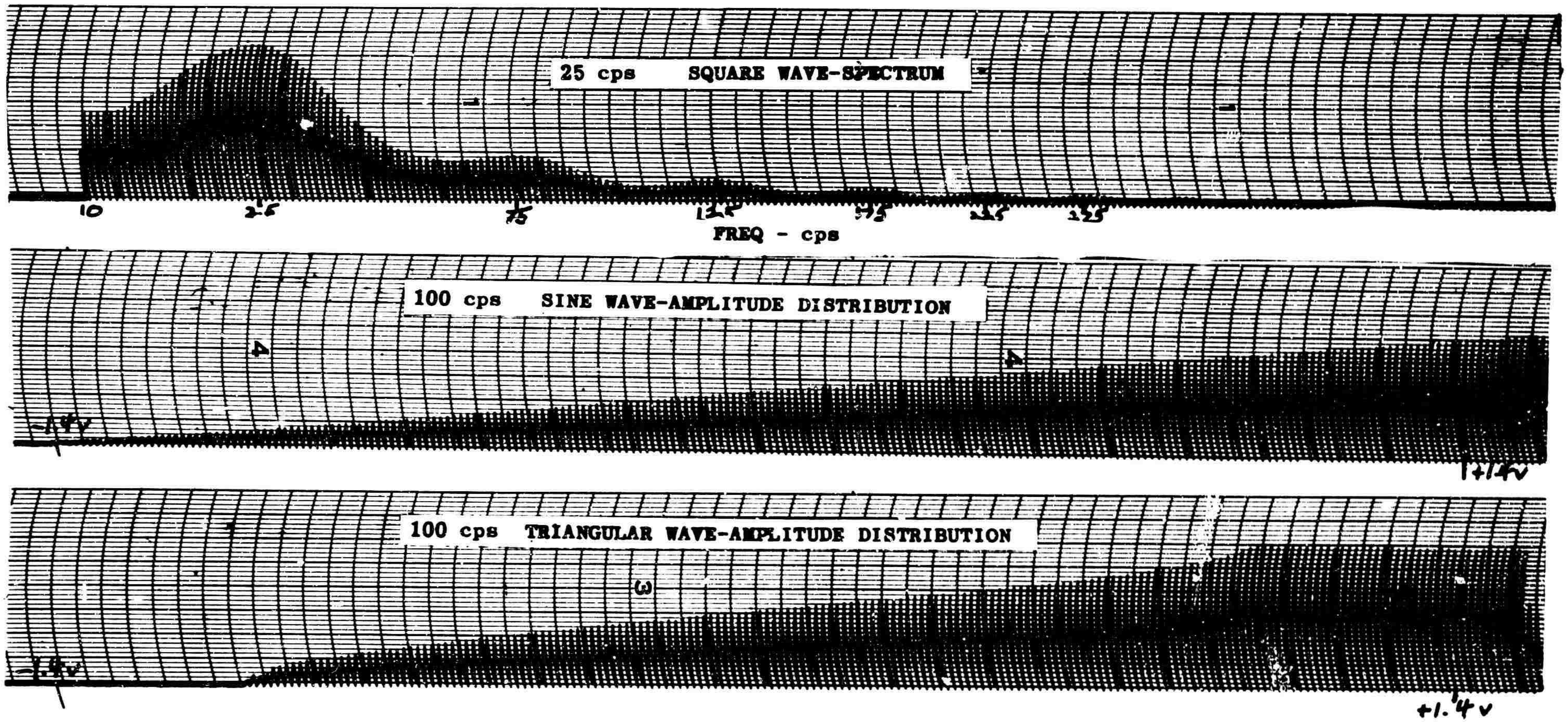
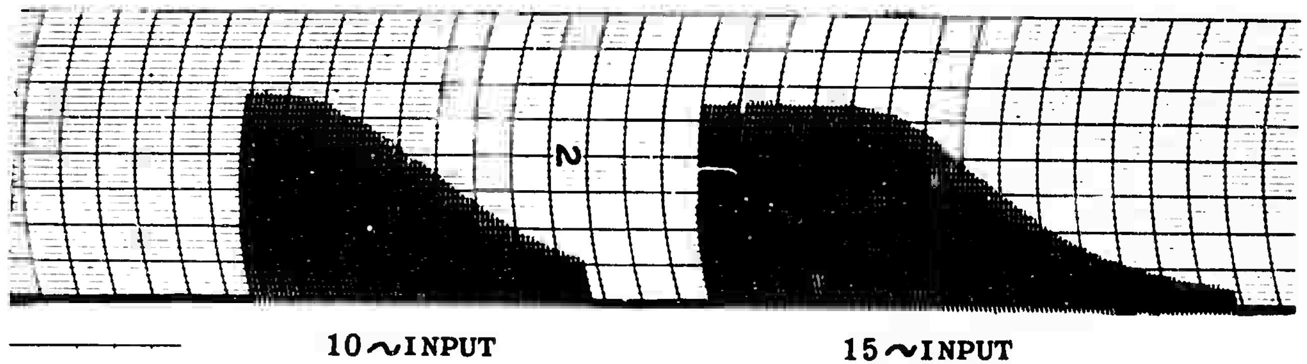


Fig. 11 SPECTRA AND AMPLITUDE DISTRIBUTION CURVES OF KNOWN SIGNALS



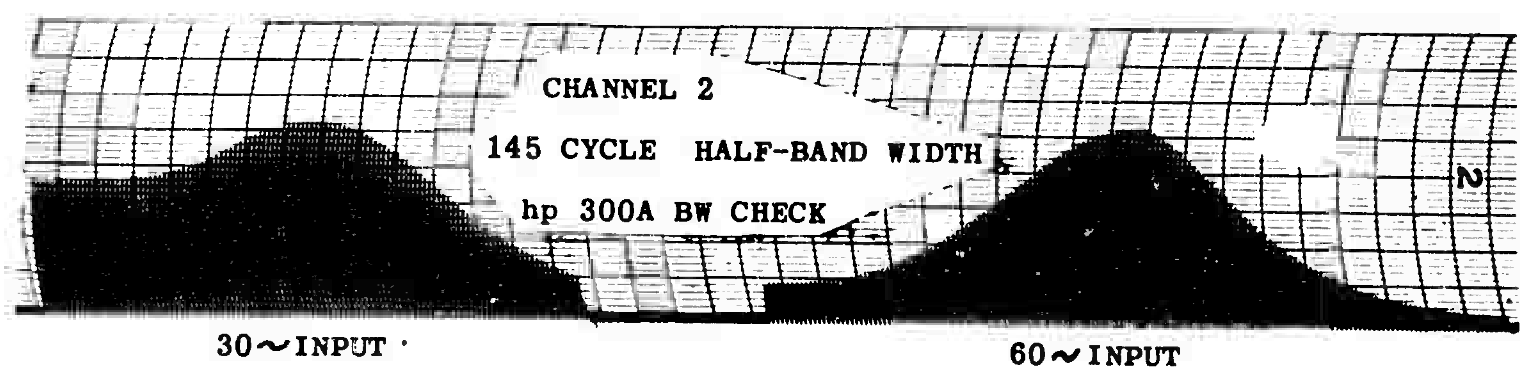


Fig. 12 UPPER SIDEBAND EFFECT

AMPLITUDE DISTRIBUTION ANALYZER TESTS

The integrator and recorder linearity tests previously described are equally applicable here since identical circuitry was used.

Due to the tape speed-up of 512 times used here, the frequency response of the amplitude distribution analyzer is important. The upper limit of the frequencies obtained at the input to the analyzer is the 5000 cycle limit of the demodulators. An attempt was made to make the distribution analyzer operate up to this value. The results of tests with sine waves of 20 and 2000 cycles are shown in Figure 13. Further tests have shown that the distribution analyzer is usable to 5000 cps. The important components in the data analyzed to date have not exceeded 2000 cycles. The amplitude distribution of a sine wave from a signal generator is compared to the theoretical in Figure 14; the agreement is excellent. The theoretical distribution curve of a triangular wave is a straight line. The curve for an actual triangular wave is shown in Figure 15. These curves are replotted in order to eliminate the effect of the curvilinear coordinates of the Brush paper.

In order to demonstrate the effect of the splice on these curves the amplitude distribution curve was obtained for a sine wave directly into the analyzer and another curve was obtained with the sine wave recorded and re-recorded in the normal fashion. These curves are shown in Figure 16.

TYPICAL RESULTS

Examples of the actual curves obtained with typical input data are shown in Figures 17 and 18.

LIMITATIONS

The present use of this equipment does not utilize all of the potentialities of the equipment. Therefore a brief discussion of the limiting factors in the use of this equipment will be presented.

1. Data

The data must be presented to the equipment on magnetic tape. Data in other forms must be converted to signals which can be recorded on tape. The recorder will accept signals of 1 volt rms maximum (1.4 v dc plus or minus) from dc to 500 cycles. A crude curve follower is now being used with this equipment. It will convert Brush recordings (as wide as 6-channel Brush paper) or other plotted data to electrical signals appropriate for recording on tape.

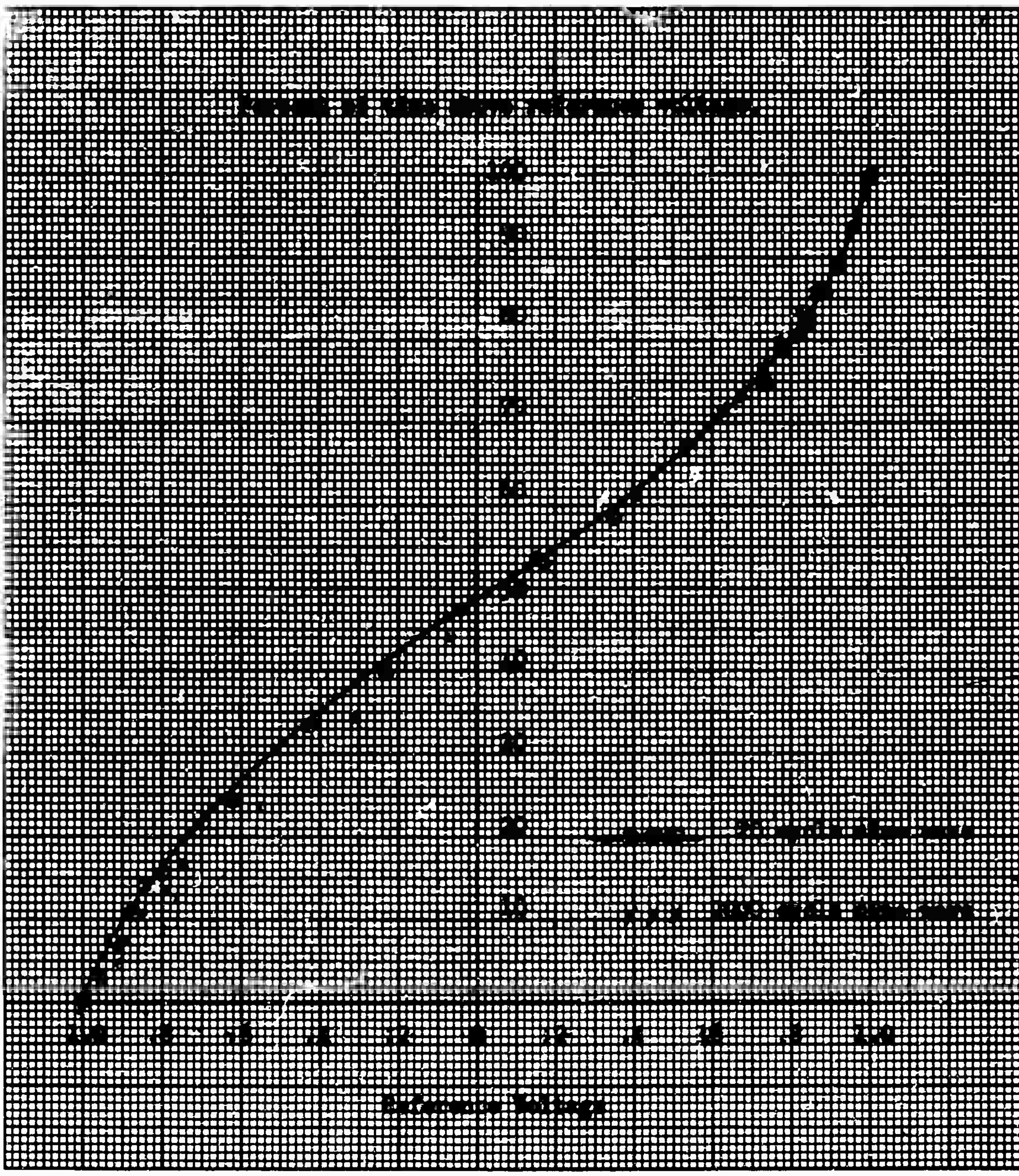


Fig. 13 FREQUENCY RESPONSE OF AMPLITUDE DISTRIBUTION ANALYZER

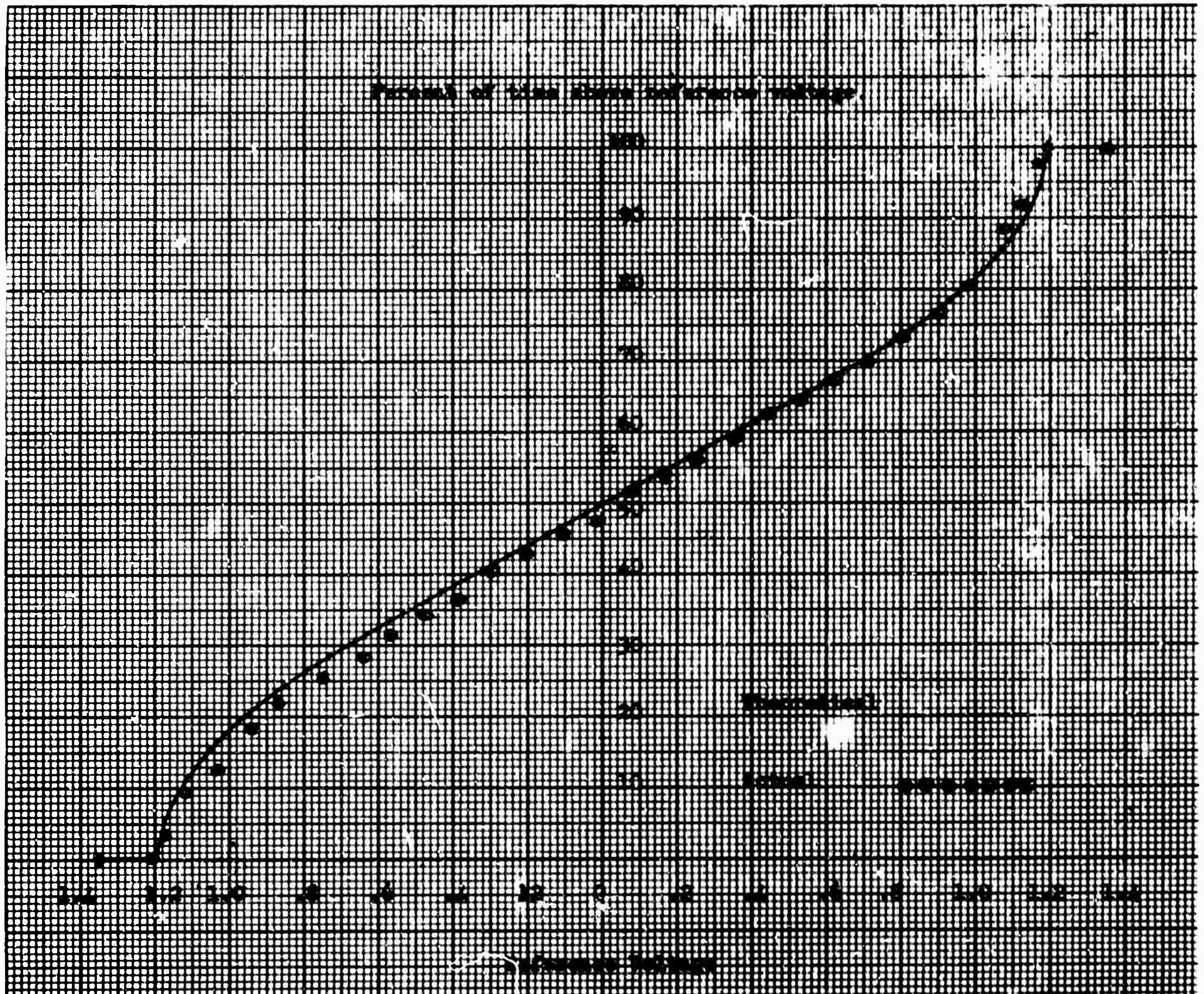


Fig. 14 ACTUAL vs THEORETICAL AMPLITUDE DISTRIBUTION (SINE WAVE)

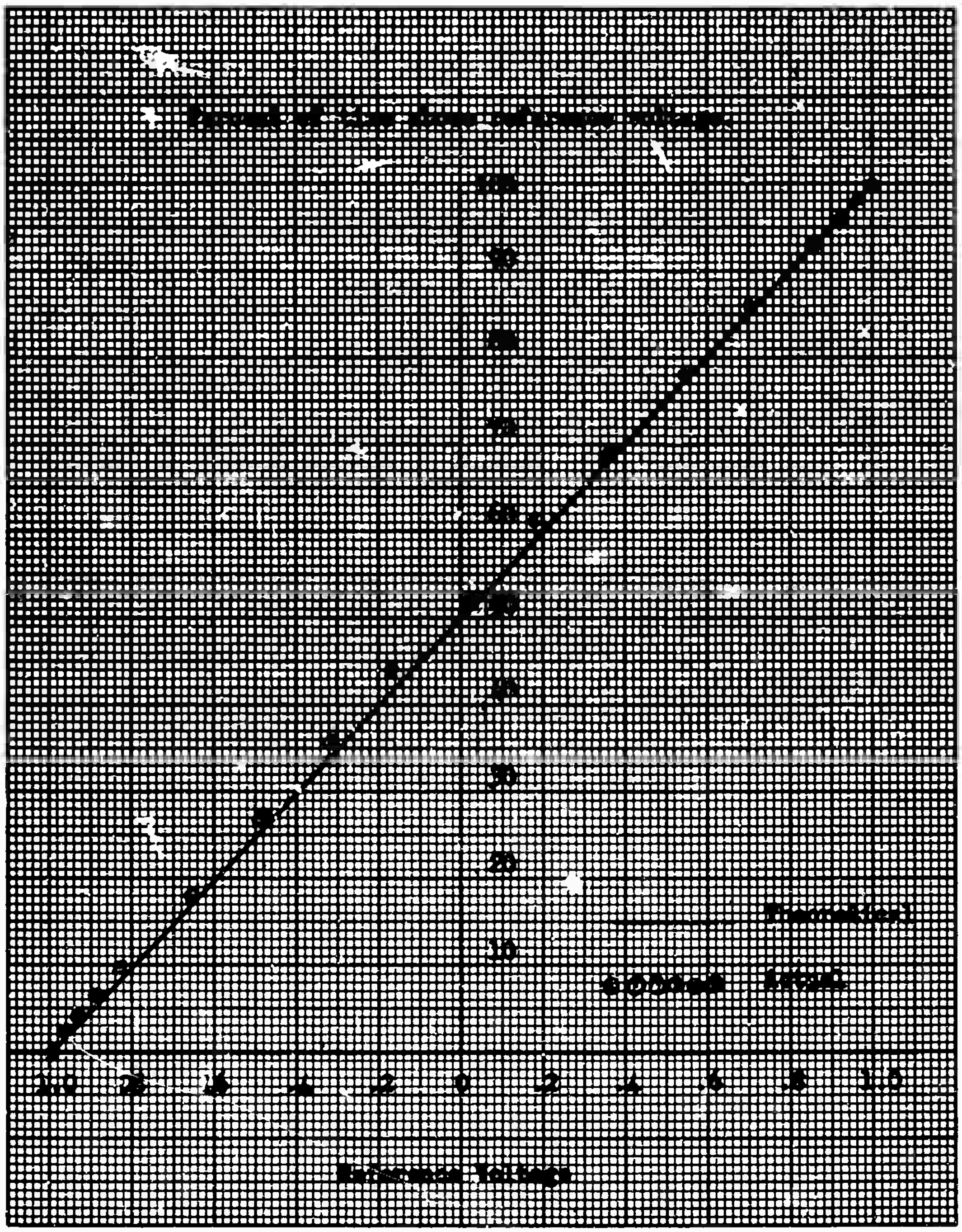


Fig. 15 ACTUAL vs THEORETICAL AMPLITUDE DISTRIBUTION (TRIANGULAR)

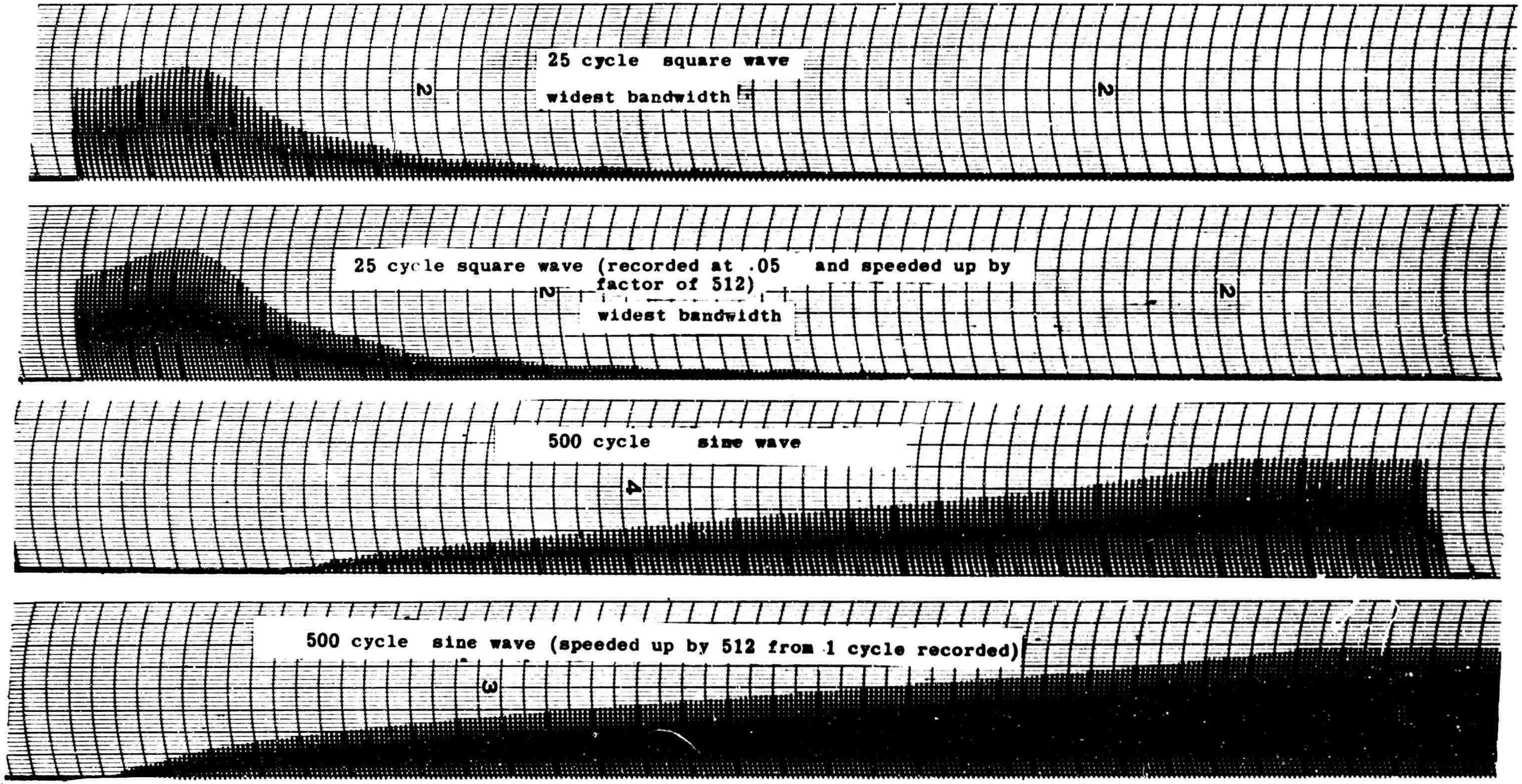


Fig. 16 SPECTRA AND AMPLITUDE DISTRIBUTION CURVES WITH AND WITHOUT SPLICE

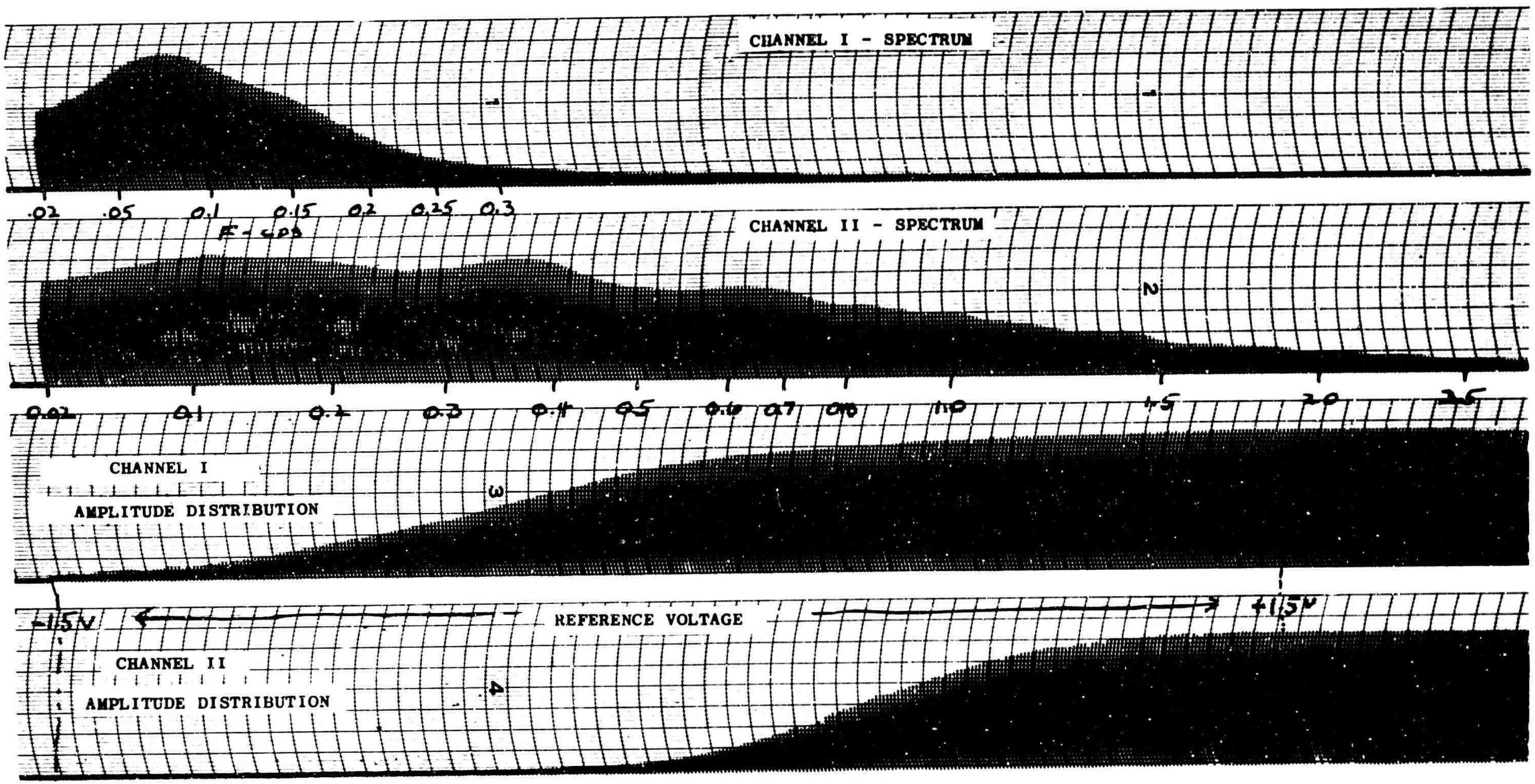


Fig. 17 TYPICAL OUTPUT CURVE

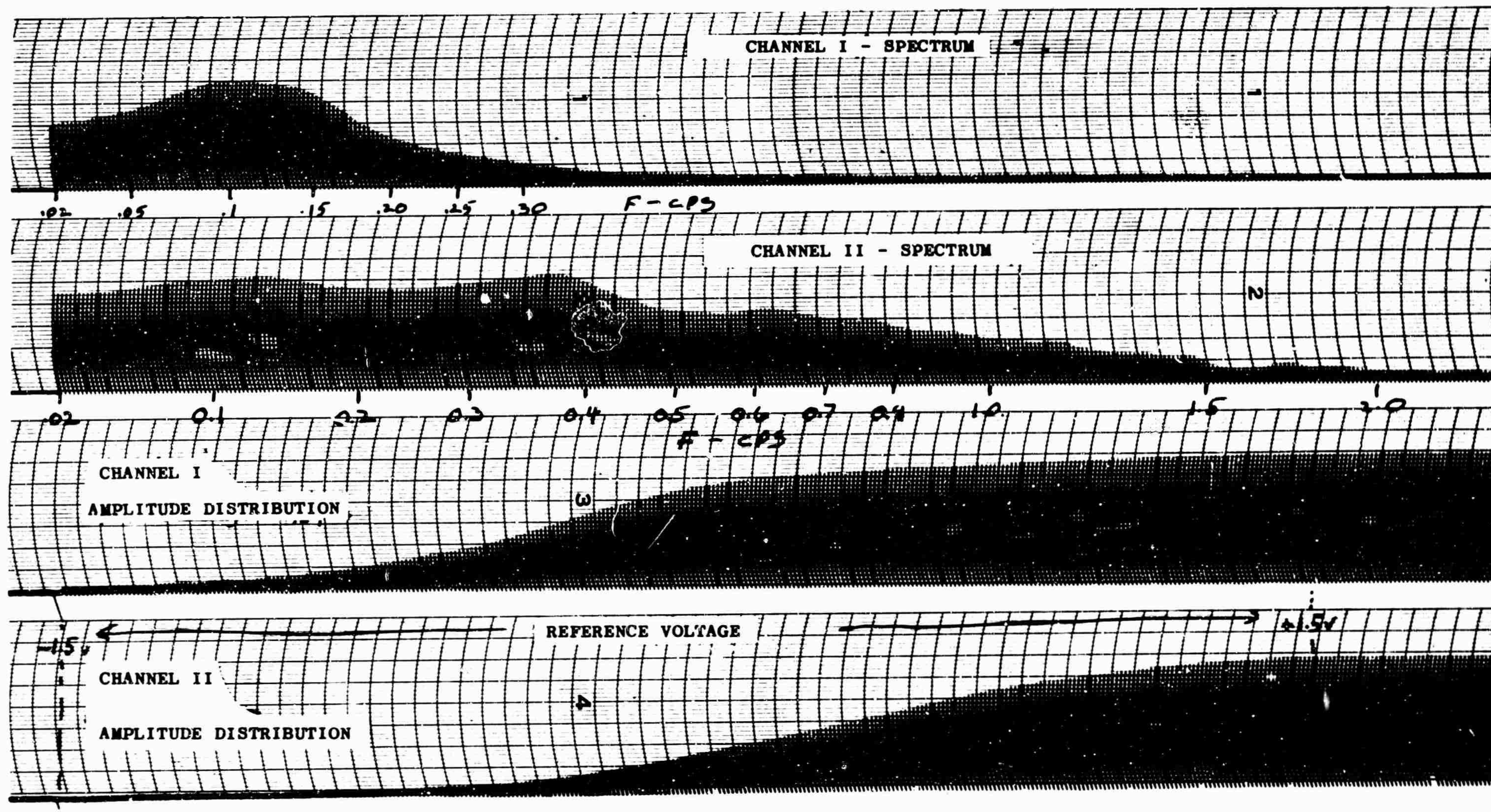


Fig. 18 TYPICAL OUTPUT CURVE

2. Speed-up

Speed-up ratios are dependent upon the frequencies of interest in the spectra. The basic ratios available are 1:1, 2:1, 8:1 and 16:1. By re-recording, many combinations are available. Ratios as high as 1024:1 have been used successfully.

3. Frequency

The recorders will operate from dc to 500 cycles. The fast playback has a 5000 cycle limit. Therefore the initial data must lie in the range of 0 to 500 cps. The maximum frequency of interest must not exceed 5000 cps after speed-up. These limits apply also to the distribution analyzer. The harmonic analyzers impose an additional limitation on the spectrum analysis. The harmonic analyzer has a nominal low frequency limit of 20 cycles (this is a function of bandwidth). Therefore the lowest frequency of interest after speed-up must not be less than 20 cps. (This can be reduced to 10 cps if less accuracy can be accepted.)

DBS:jt

APPENDIX I

OPERATION OF THE TAPE EQUIPMENT

The following general operating procedures are used:

1. To reduce temperature effects the equipment is left on 24 hours a day during periods when the equipment is being used daily.

2. The recording center frequency and signal level set are adjusted daily with the EPUT meter. A special test box is provided which furnishes d-c voltages for shifting the carrier to frequencies equivalent to peak modulation (40 percent deviation).

3. The demodulators are checked daily for center frequency and level set using voltages of the proper frequency from a Hewlett-Packard Audio Signal Generator calibrated from the EPUT meter. The center frequencies used are dependent upon the tape speeds and speed-up ratios being used.

4. When closing tape loops considerable care must be taken to reduce the energy produced by the splice. Two things are done to accomplish this. First the splice is made as neatly as possible by butting the tape ends accurately and holding the splice with very thin scotch tape. Secondly, additional tension is used on the playback loop by attaching rubber bands to the tension pulley at the top of the playback unit.

5. The trip mechanism used (either photocell or a signal on a third tape channel) must be adjusted to trip consistently.

APPENDIX II

OPERATION OF THE SPECTRUM ANALYZER

1. The harmonic analyzers must be carefully calibrated according to the instructions contained inside the cover of the calibrating controls. A balance of less than 2.5 millivolts on the meter is considered adequate. Prior to the start of each run the frequency dial must be set to 10 cps. This should be done by running the motors from a lower value up to 10 cps dial reading in order to eliminate compliance effects in the motor coupling.

2. The amplifier, detector, and integrator chassis must be adjusted according to the following instructions:

    a. Observe the voltage at the INTEGRATOR INPUT (TP-2) with a VTVM. Set INTEGRATOR INPUT ZERO for zero volts dc on the 10 volt range with no signal input.

    b. Observe the voltage at the OUTPUT on a VTVM (10 volt scale). Adjust DISCHARGE LEVEL for integrator balance (i.e., no deflection on the meter when the trip operates and set OUTPUT ZERO for zero volts dc at the OUTPUT.

    c. Adjust GAIN so that the maximum signal observed on the OUTPUT METER is between 30 and 33 volts at the peak of the swing.

    d. Adjust DITHER (on the rear of the chassis) for about 1/2 mm deflection on the recorder with no signal input.

3. These adjustments must be made on both channels prior to each run.

4. Connect inputs and trip signal for normal operation.

APPENDIX III

OPERATION OF THE AMPLITUDE DISTRIBUTION ANALYZER

1. The amplitude distribution chassis must be adjusted according to the following instructions:

   a. Start with the switches on both channels in the following positions:

      SHORT INPUT - INPUT
      SHORT DETECTOR INPUT- INPUT
      OUTPUT ZERO SET - OUTPUT

   b. Throw the SHORT INPUT switch to the SHORT position and adjust AMPLIFIER FINE control for zero at PREAMP OUT jack using the 2.5 volt dc scale of the Simpson meter. If required, the PREAMP COARSE control (on chassis) may be used. Return the switch to the INPUT position.

   c. Throw the SHORT DETECTOR INPUT switch to the SHORT position. Adjust the AMPLIFIER FINE control for zero volts between the BRIDGE INPUT jacks on the 2.5 volts dc scale of the Simpson. If required the AMPLIFIER COARSE control (on chassis) may be used. Adjust the BRIDGE INPUT LEVEL control for zero between either BRIDGE INPUT jack and ground. Repeat the settings until both readings are zero. Return the switch to the INPUT position.

   d. Throw the SWEEP CAL switch to the CAL position. The reference voltage should be -1.4 volts. Short the INPUT to ground. Adjust the DISCHARGE LEVEL for integrator balance (no deflection when the trip operates) by observing the OUTPUT voltage on the 10 volt dc scale of a VTVM. Adjust the OUTPUT ZERO control for zero volts on the 10 volt dc scale of the VTVM at the Output. Return the switch to the SWEEP position.

   e. Set the DITHER control (on rear of chassis) for about 1/2 mm deflection on the recorder.

   f. Repeat the above for the other channel.

   g. Remove all input shorts. Turn on the SWEEP MOTOR and run until the meter reads -1.4 volts. Connect the inputs to the output of the demodulators and connect the trip input to the tape trip circuit.

2. These adjustments should be repeated prior to each run.

Initial distribution of this document has been made in accordance with the Guidance List published in APL/JHU TG-8-11, dated November 1953.

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