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A LOW-INERTIA RECORDER FOR DIRECTIVE ANTENNA PATTERNS

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ABSTRACT

Automatic recording of antenna radiation patterns by equipment possessing mechanical inertia is limited in speed and subject to misuse when these patterns are sharp or contain nulls. To meet this problem a recorder has been developed according to a design which eliminates mechanical inertias. Received signal intensity is converted into time logarithmically and recording is accomplished by a spark from a uniformly translated paper. Point position then gives signal intensity logarithmically and paper position gives antenna orientation. The rectangular presentation provides eight inches for 40 decibels of antenna signal to a square law detector, and arbitrarily ten inches for the angular range employed, say 180°. The rise time corresponds to 400 inches per second writing speed, but the writing speed actually realizable depends upon the marking rate of the recorder and the density of points required. Thus the recorder is limited in continuity of presentation rather than in accuracy of presentation.

PROBLEM STATUS

This report concludes the work on the problem.

AUTHORIZATION

NRL Problem R09-46R
NR 509-460 (7-1-48)

A LOW-INERTIA RECORDER FOR DIRECTIVE ANTENNA PATTERNS

INTRODUCTION

The plotting of the diffraction pattern of microwave antennas by automatic recorders has become a standard technique. This is reasonable since it would be a very laborious process indeed to obtain manually a sufficient number of closely spaced data to duplicate the smooth accurate curves produced by a recorder.

The methods heretofore used for producing these automatic plots have been based upon either the recording current meters, such as Esterline Angus, or any of several types of follow-up servo system.[*] These schemes suffer in different degrees from mechanical inertial problems which limit the maximum writing speed at critical damping, i.e., the maximum speed the writing stylus may have at which neither overshooting or undershooting will occur. While the servo system is, in this regard, vastly superior to the recording current meters, it has an apparent upper limit of about 30 to 40 inches per second maximum displacement velocity in practical devices.[†] This is sufficient to give a rectangular plot spread over 10 inches along the ordinate which accurately pictures, with a reasonable abscissa velocity, most of the diffraction curves encountered in antenna work.

There are certain patterns, however, for which the conventional servos are not satisfactory, either because of the high rate of rise or because of the rapid change of rate. Those patterns having a central null in the main lobe impose particularly severe requirements in both respects. Similar difficulties are also encountered with the sharp patterns resulting from large apertures. In such cases it is entirely possible to obtain false though satisfactory-appearing patterns, if the abscissa velocity is chosen too high. To meet this situation the present recorder is based upon a design which eliminates all mechanical inertias. It is limited only by electrical inertias in its rise and fall time at critical damping.

The normal requirement for range of signal recording in directive antenna work is 40 decibels; however, the square-law detectors normally used in such work make it necessary that the recorder operate over an 80-decibel range.

The object of this report is to present a general descriptive summary of the recorder. All detailed description and the extensive analysis involved in novel features of the circuitry have been omitted.

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[*] *Symonds, R. J. "Microwave Antenna Pattern Recorder," BTL Report MM-44-170-55, Nov. 1944; LeCaine, H., and Katchky, M. "Automatic Antenna Pattern Recorder," National Research Council of Canada Report, Oct. 1946; Tyson, O.A., and Edwards, W.J.E., "A Portable Servo Recorder for Antenna Patterns," NRL Report R-3498, July 6, 1949.*

[†] *Gerwin, H.L. "Automatic Antenna Pattern Recorder," NRL Progress Report, July, 1949.*

GENERAL DESCRIPTION

The principles of operation are as follows: A disk, upon the periphery of which are located two diametrically-opposed sparking styli, rotates at constant speed and at a constant distance from a cylindrical paper holder. A pulsed marking spark is caused to occur in such a way that the position of a sparking stylus relative to the paper at the instant of spark is proportional to the logarithm of the received signal. The spark then controls the ordinate information transferred to the spark-sensitive paper.* The paper position along the abscissa is controlled by the motion of the cylindrical paper holder relative to the sparking disk and along the scanning axis. This motion is electrically produced by a synchro system and in the antenna application corresponds to the angular elevation or azimuth motion of an antenna mount.

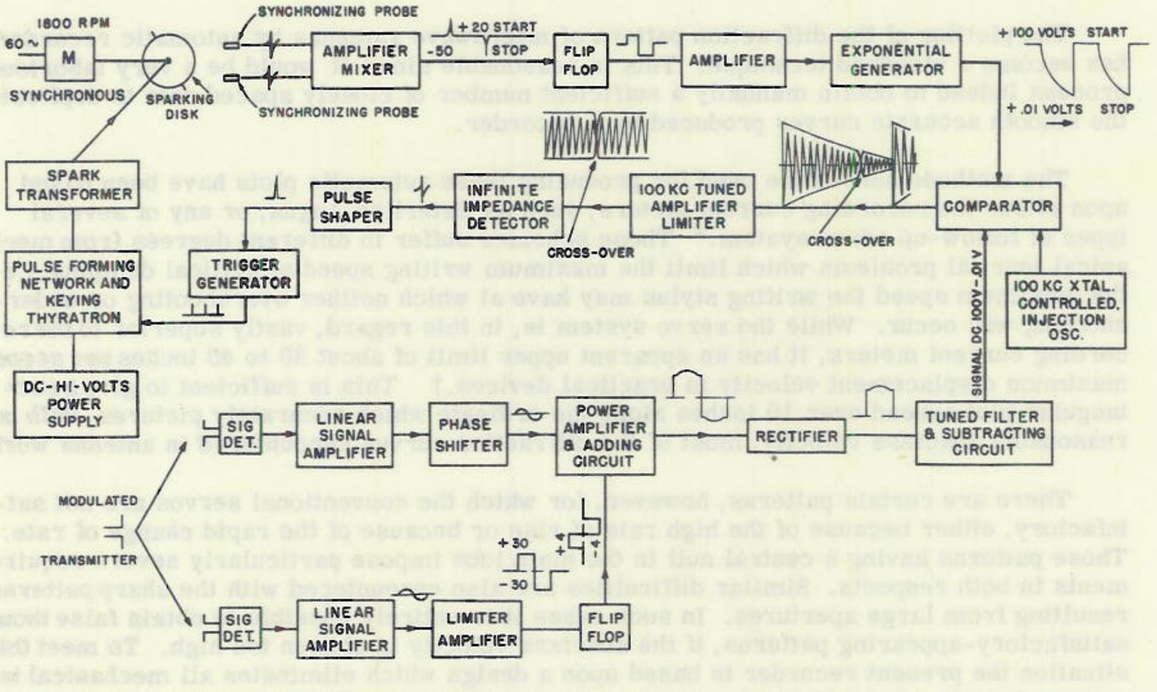

Figure 1 - Schematic diagram of low-inertia pattern recorder

Figure 1 is a block diagram of the arrangement of apparatus used to obtain this result. An exponential generator produces a precise exponential wave which is accurately synchronized to the sparking disk by two start-stop probes. This wave, whose duration is equal to the sweep of one stylus from border to border of the paper, is compared by a balanced modulator type of comparator with a d-c voltage which is proportional to the received signal strength. The comparator output is a 100-kc carrier having an exponentially shaped envelope with a zero and a phase reversal at coincidence of input amplitudes. The time of this coincidence is therefore delayed from the start of the exponential carrier envelope by an amount proportional to the logarithm of the received signal.

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* *Teledeltos paper, carbon paper, or any paper of uniform dielectric quality showing contrast at the puncture point.*

In order that the zero or crossover may be made to initiate accurately in time the marking spark over a 10,000 to 1 change in signal voltage, the region around the zero has to be greatly amplified to give a sharp null. This is done by following the comparator with a high-gain, limiter amplifier whose output is essentially constant except for the very sharp null. The zero pulse is then picked off by an infinite-impedance detector, passed through a pulse shaper and used to control a slave trigger generator. The clean trigger pulses are applied to the control grid of a thyratron which acts as a switch tube in a pulse-forming network having a pulse width of about 10μ sec. The stylus spark gap is matched to the pulse network by a one-to-two pulse transformer which normally delivers about 3000 volts before ionization and a somewhat lower voltage during the arc. Since the linearly-rectified audio frequency output must vary between 100 volts and 0.01 volt, a serious rectification problem is involved. This problem was solved by adding a constant d-c pedestal to each half of the symmetrical sine wave before the wave is introduced into a diode rectifier. Subsequently the undirectional output wave of the rectifier passes through a stripping circuit which removes the constant amplitude pedestal. The output of the stripping circuit is fed to the comparator through a tuned cascade filter having a short time constant but a very low ripple d.c.

The biasing pedestal is generated by a flip-flop which is driven by a fixed monitor antenna, linear signal amplifier and a limiter. The limiter serves to generate a reasonably constant-amplitude, steep-sided, keying wave that has a leading edge of constant phase relative to the generating sine wave and independent of the sine wave amplitude. The flip-flop amplitude is constant to ±.001 volt for long periods of time. A phase shifter is introduced between the linear signal amplifier in the test circuit in order to adjust the relative phase between the pedestal and the sine wave. This adjustment need not be changed after original set-up unless for some reason it becomes necessary to have a very large difference in cable lengths which connect the monitor detector and test antenna detector to the equipment.

The actual apparatus is pictured in Figure 2 and is seen to consist, in this laboratory model, of a rack cabinet of electronic gear and the mechanical scanner and thyratron spark generator mounted on a laboratory table. Figure 3 is a close-up of the recording head, and shows the paper holder partly concealed under the sparking disk. The holder is constrained to move on accurate rails and is propelled by a 36-1 geared synchro through a flexible cable. The sparking disk and synchronizing disk are mounted on a common shaft and are driven by an 1800-rpm synchronous motor. The three synchronizing probes consist of the two start-stop probes previously mentioned and one which feeds a synchronizing pulse to a monitor-scope sweep generator. This scope probe is located between the two limit probes and therefore initiates the sweep at the beginning of the third decade or at 40 decibels down so that the expanded region of the last two decades appears on the scope. The vertical deflection of the scope is a trace of the crossover or null pulse from the infinite-impedance detector. The two top meters on the front panel of the electronic gear indicate the monitor amplifier signal level to insure sufficient limiting, and the completeness of pedestal stripping.

The circuit diagrams are shown by deck number, according to the location in the electronic cabinet.

Deck #1 - The signal and monitor amplifiers (Plate 1) are designed to work either from crystal rectifiers or from bolometer detectors. This laboratory model is fixed-tuned to 1000 cycles with a 300-cycle passband. The voltage gain is 10^4 over a range of 80 decibels down from 100 volts.

Deck #2 - Contains the signal rectifier and pedestal generator (Plate 2). The 6X5 diode rectifier works into a highly-dissipative, low-impedance, tuned filter; hence the 6L6 amplifier. The pedestal is injected at the 6J5 driver plate. The stripper consists of a fixed d-c bucking voltage appearing in series with the output of the tuned filter. The exact stripping voltage is adjusted by a potentiometer which is located on Deck #3.

<u>Deck #3</u> - contains the monitor amplifier, 100-Kc injection generator and monitor scope (Plate 3). The monitor amplifier is an a-c amplifier and rectifier working into a 50-μ amp meter. The input is d.c. from the signal rectifier and is operable when the function selector is set at A. The d-c input is converted to a.c. by a vibrating reed converter.* The 100-Kc injection generator works from a 100-Kc quartz crystal and contains a phase-controlling network in the grids of the output tubes in order to secure carrier cancellation in the comparator.

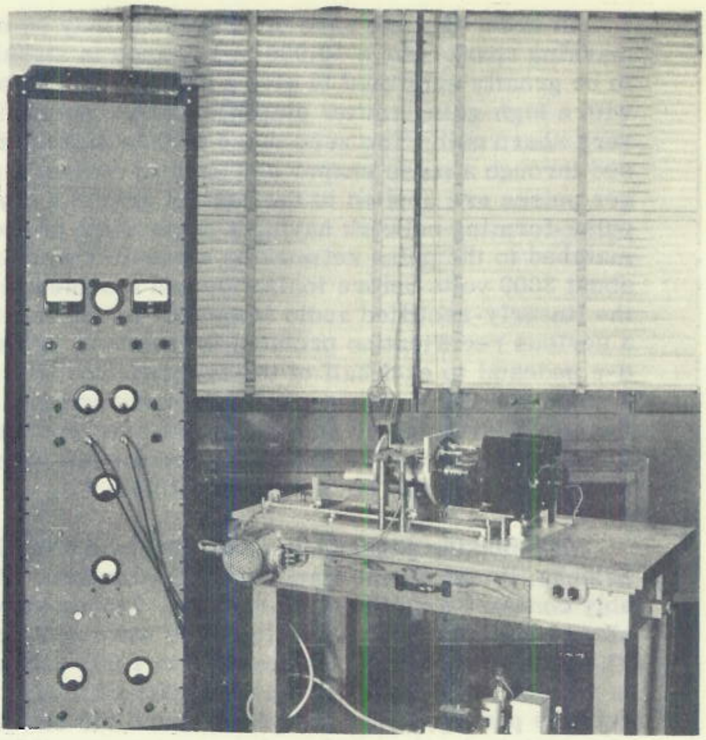

Figure 2 - Complete recorder

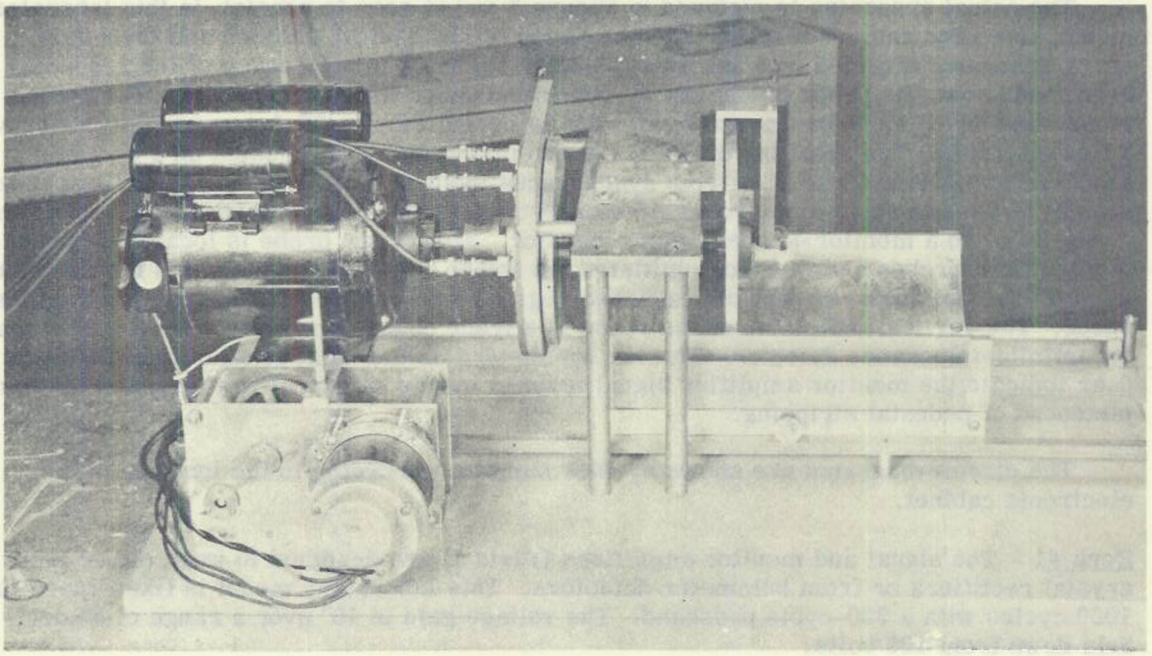

Figure 3 - Recording head

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* *Brown Instrument Company*

Deck #4 - contains the exponential generator, the signal comparator, the comparator amplifier, and trigger generator (Plate 4). The exponential generator, which is 1/2 6SN7 with an RC network of precise time constant in the cathode circuit, is driven by an amplified square wave from a polarized flip-flop comprised of two 6AK6'S. The flip-flop in turn is keyed through a 6SN7 mixer, by the polarized start-stop pulses furnished by the synchronizing probes and amplified by the 6SH7'S. The comparator is a form of balanced modulator consisting of two 1620 tubes. The two voltages to be compared are introduced in the control grid of one of the tubes while the corresponding grid of the other is held at a fixed potential. The comparator amplifier is a limiting amplifier consisting of four cascaded 6SH7'S. The crossover is picked off by an infinite-impedance demodulator consisting of 1/2 6SN7. The pulse is further shaped and amplified by 1/2 6SN7 and used to key a 2050 thyratron and pulse-forming network to produce a clean trigger for the spark generator.

Deck #5 - contains the scope sweep generator and a multiple bias supply for several points in the general circuitry (Plate 5). The sweep generator works from a synchronizing probe much in the fashion of the exponential generator except that a sawtooth wave is produced by a multivibrator and charging capacitor.

Deck #6 - contains the spark generator which functions in a manner similar to most soft tube radar modulators (Plate 6).

Deck #7 and Deck #8 - contain conventional regulated power supplies for the various plus voltages used throughout the general circuitry (Plate 7).

PERFORMANCE

The writing speed at critical damping of any recording device of this kind is best demonstrated by the equipment behavior when operating with a square wave input. Figure 4 is a reduced photographic reproduction of an actual plot of a square wave of 60-decibel amplitude. The rise and fall time of the input wave was of the order of one millisecond and the rise and fall time of the plot was of the order of 10 milliseconds with no appreciable over or under shooting. This corresponds to an equivalent writing speed, in a continuous plot recorder, of over 400 inches per second, which is at least ten times the writing speed of the best servo recorders.

It is to be noted, however, that the resolution is limited in the present machine to 60 marks per second. This results from the fact that two sparking styli are used with an 1800-rpm scanning motor giving 3600 marks per minute. The resolution could readily be increased by a factor of 3 or more by increasing the scanning speed and adding more sparking styli to the scanning disk. However, the resolution of 60 marks per second has been adequate for most antenna pattern problems thus far encountered. Figure 5 is an example of the plot obtained of an antenna pattern with a deep null.

The writing speed is limited by the density of points or definition in decibels required in the presentation. Since the 8-inch ordinate range of the chart corresponds to 40 decibels in terms of power received by the antenna, a definition of 1 decibel would correspond to 0.2 inch. With the present model this definition limits the writing speed to 12 inches or 60 decibels per second. In a future model where the resolution in marks per second could easily be quadrupled, the writing speed for a definition of 1 decibel would be 48 inches or 240 decibels per second.

Actually, the chief advantage the present model possesses, in contrast to servo-operated recorders, is its ability to avoid writing errors at rapid rate points of an antenna

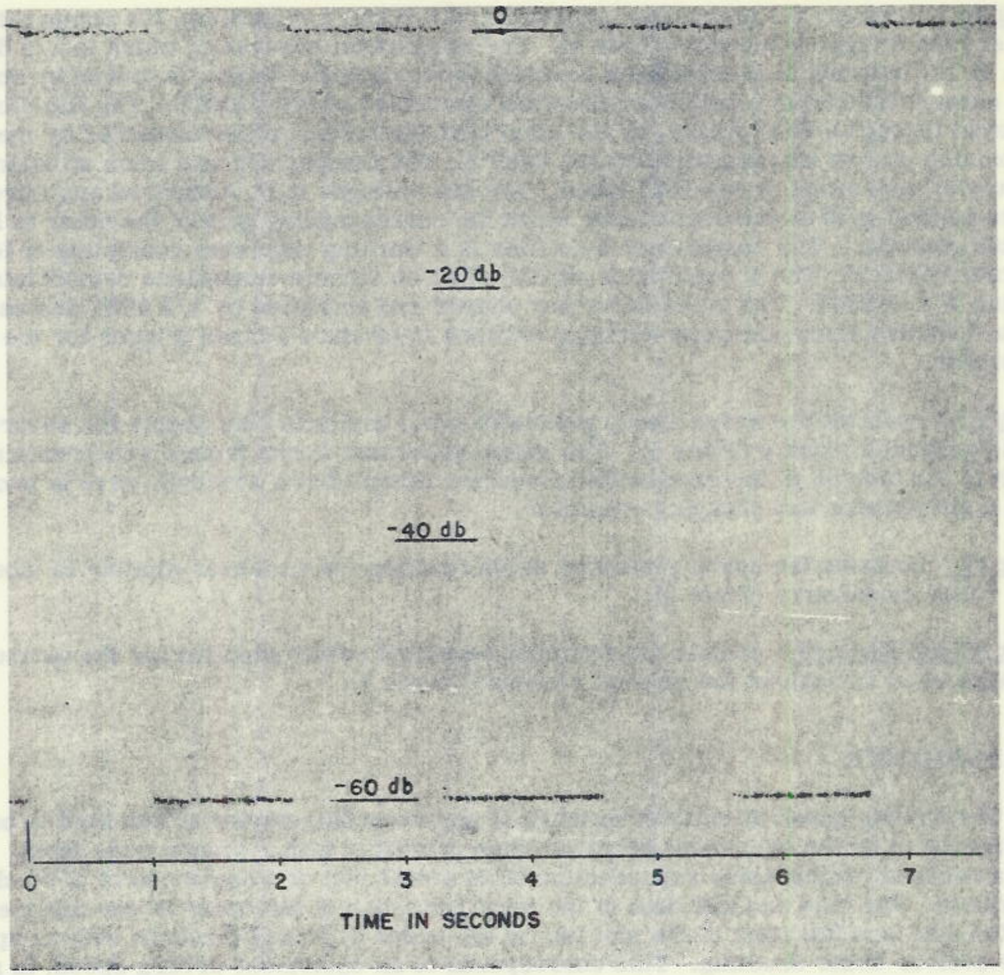

Figure 4 - Square wave, 60-db amplitude

pattern. At these very rapid rate points little or no information is plotted but the eye can usually supply the continuity such as in (Figure 4). Thus it may be said that in effect this recording system substitutes resolution limiting for the inertia limiting of the servo. This is a distinct advantage, however, since this effect appears as breaks in the continuity and is not subject to misinterpretation.

CONCLUSIONS

Experimentation with the present equipment indicates that the principle of operation is one that would yield, with proper engineering, a recorder which is free of the inertial problems of the electromechanical servo. Also, as pointed out previously, the system could operate with a minimum writing speed (definition to 1 db) considerably in excess of the fastest known electromechanical servo which has a comparable plotting length.

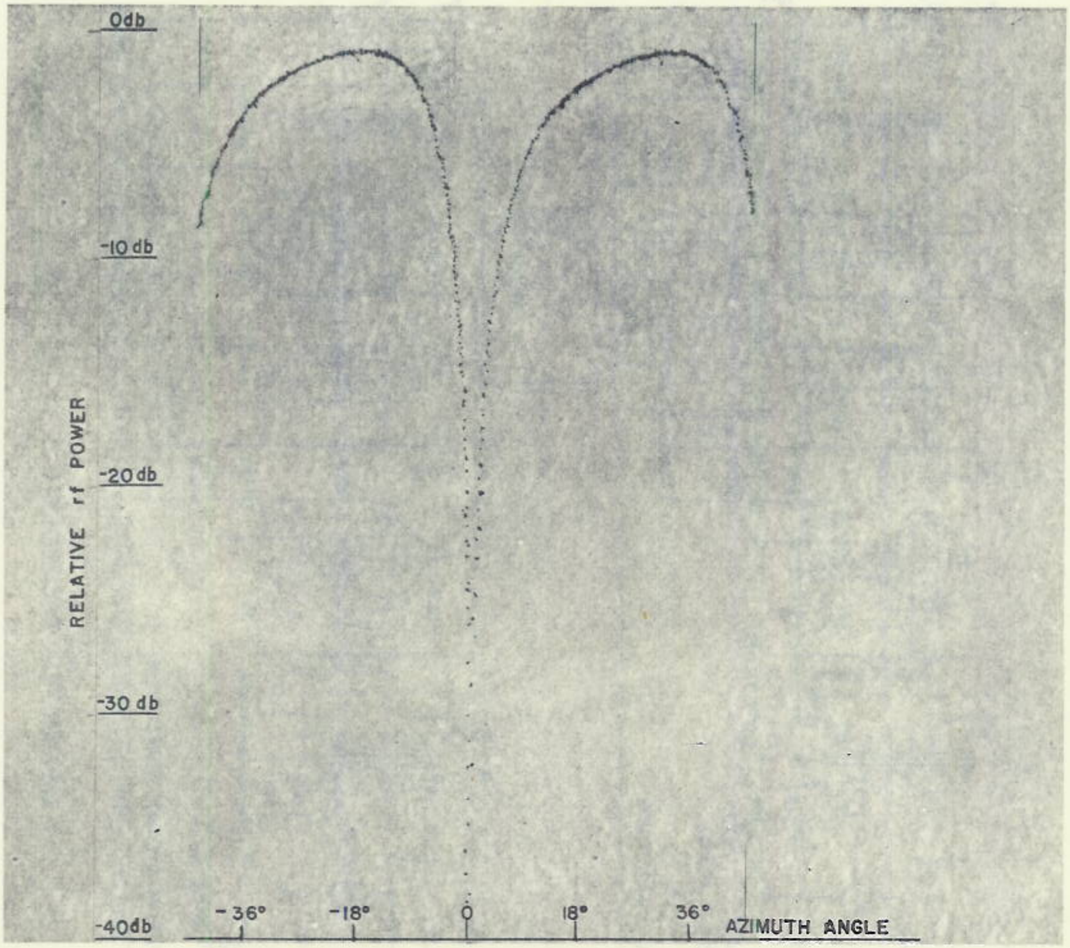

Figure 5 - Antenna pattern with deep null

ACKNOWLEDGMENT

Acknowledgment is made to Mr. F. W. Cleary for his able assistance in the working out of many of the details of the electronic circuitry. Also acknowledgment is made to Mr. W. J. E. Edwards for his many helpful suggestions and for his mechanical design of the recording head.

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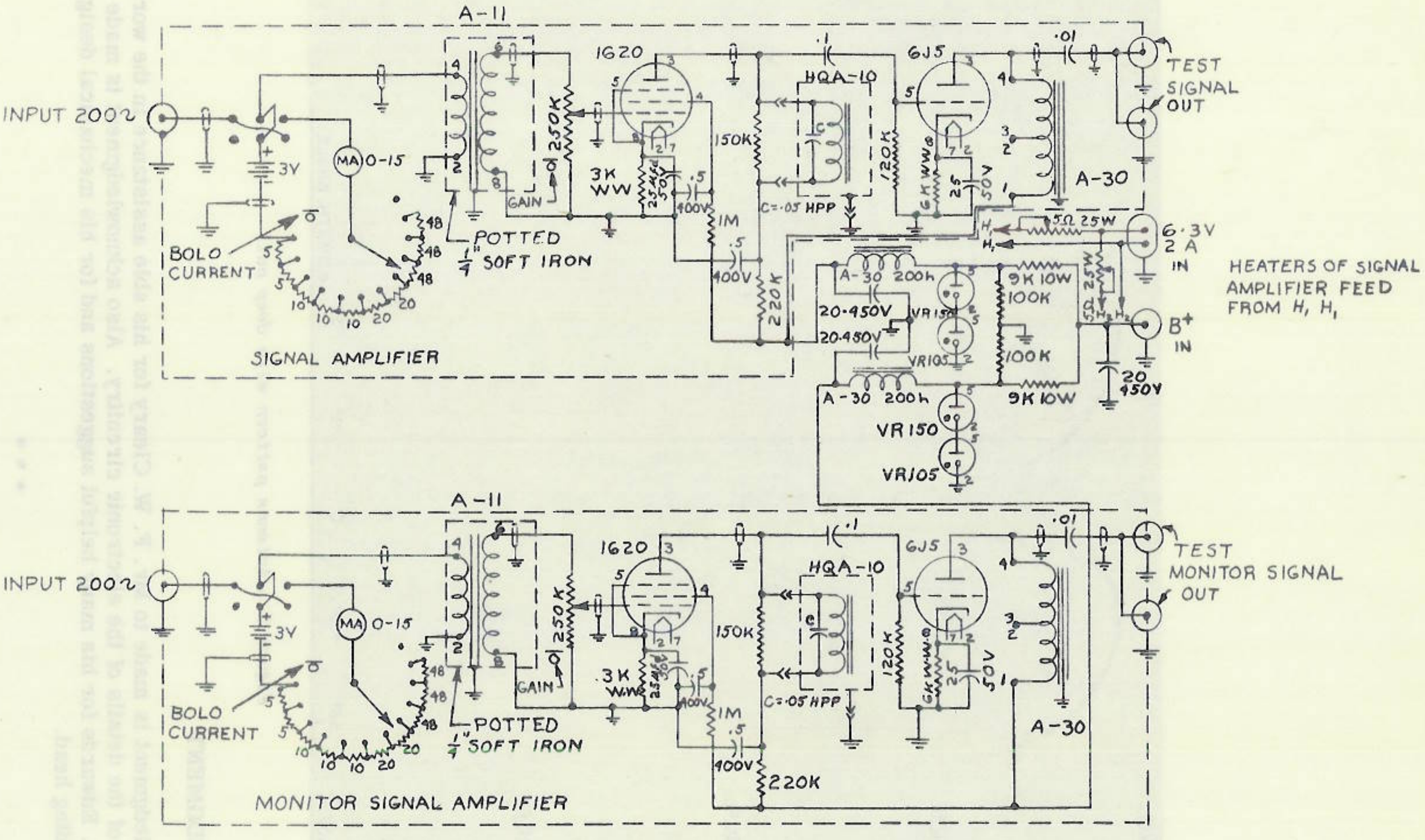
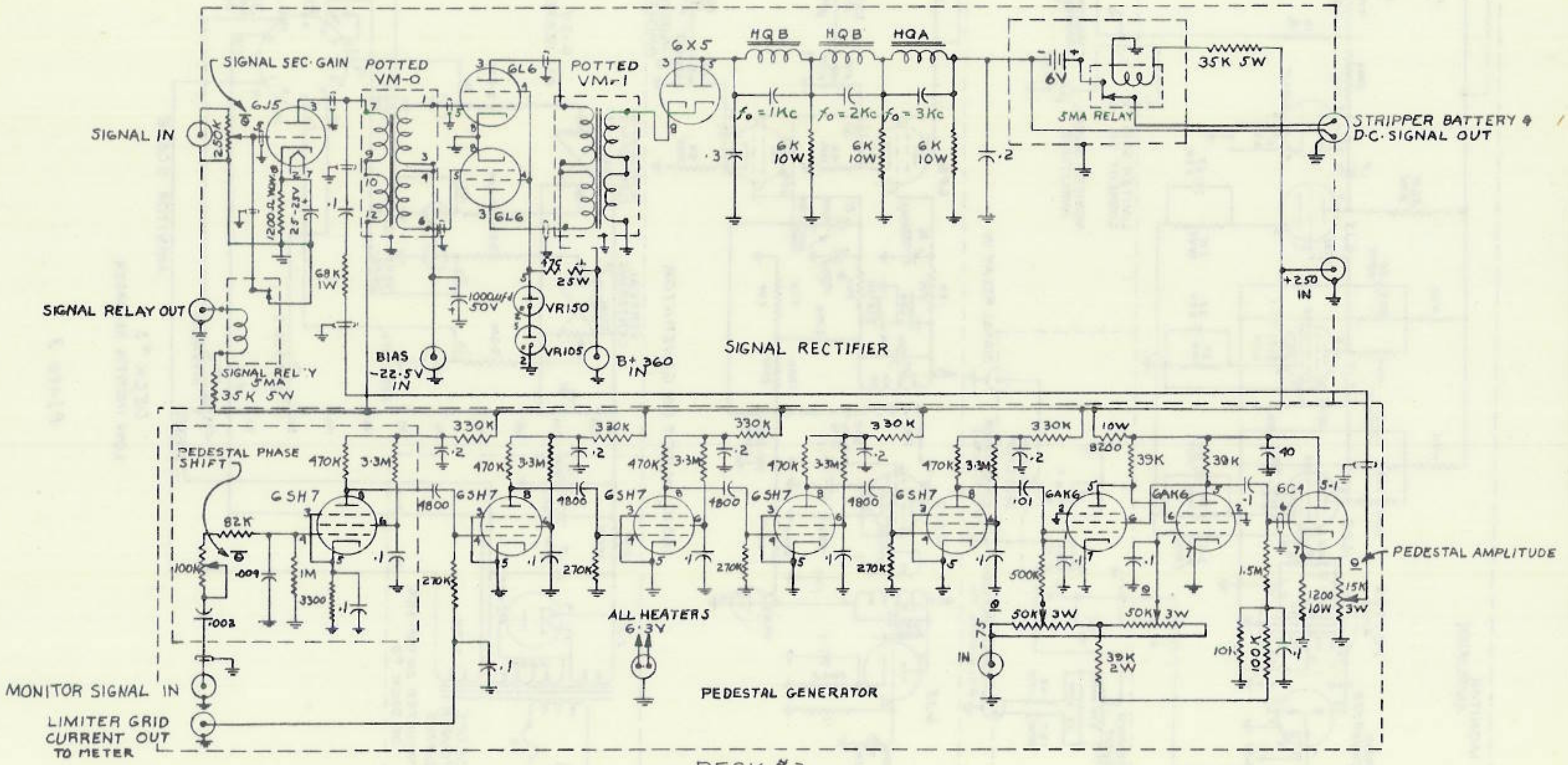


DECK #1
LOW INERTIA RECORDER

Plate 1



DECK #2
LOW INERTIA RECORDER

Plate 2

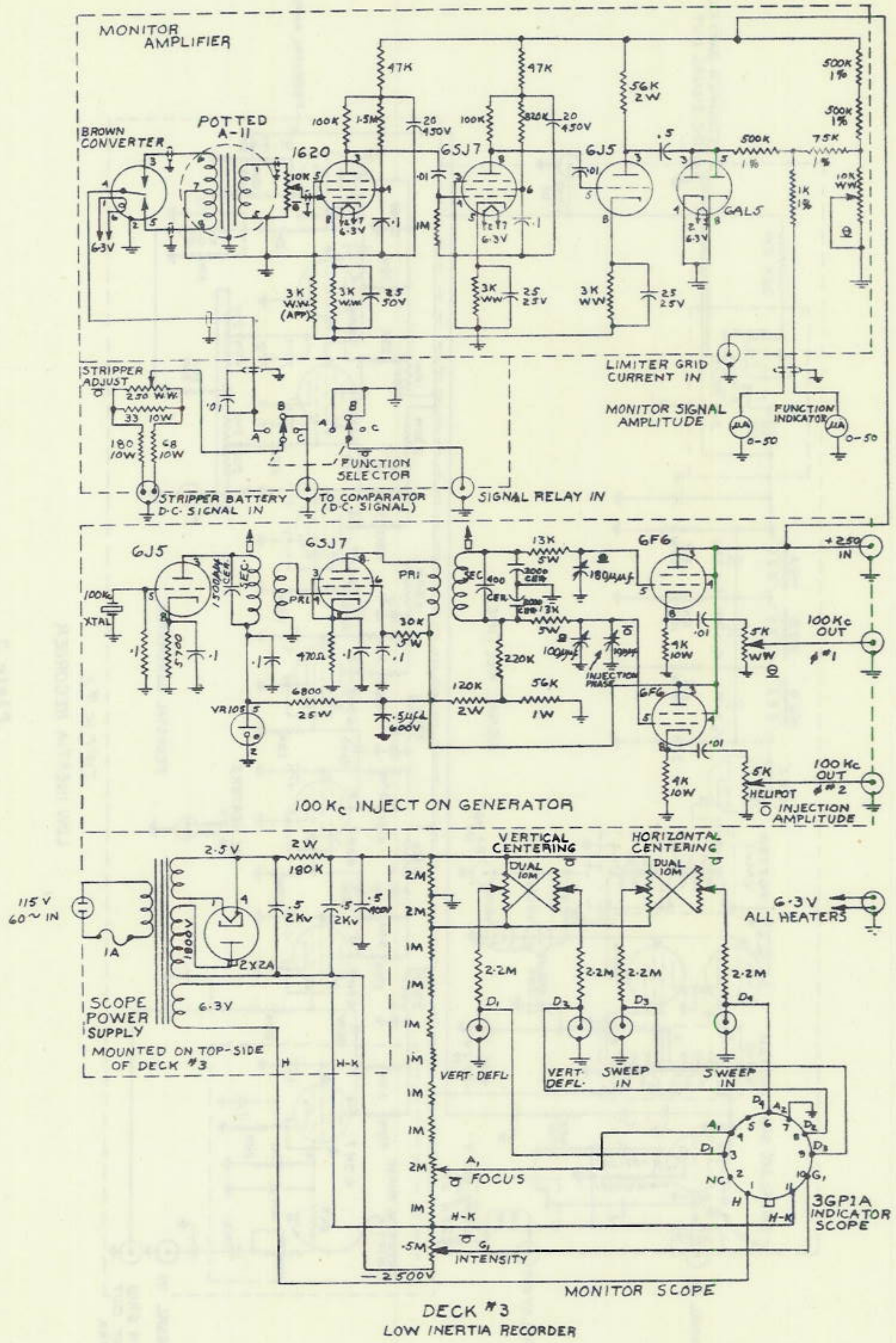
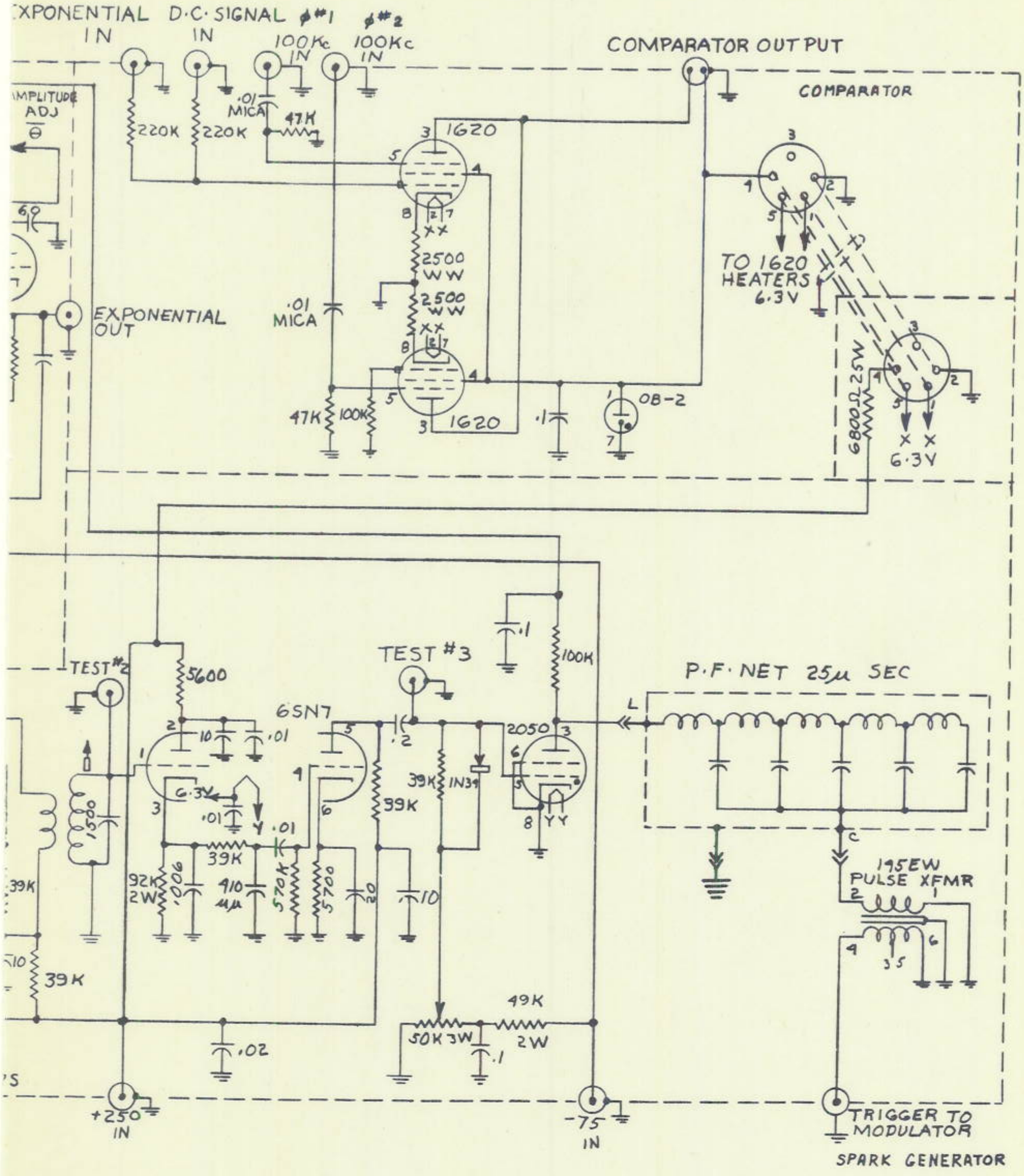

MONITOR AMPLIFIER
BROWN CONVERTER
POTTED A-11
1620
6SJ7
6J5
6AL5
47K
100K
1.5M
20 450V
820K
56K 2W
.5
500K 1%
75K 1%
10K WW
1K 1%
3K W.W. (APP)
3K W.W.
25 50V
3K WW
25 25V
6.3V
LIMITER GRID CURRENT IN
MONITOR SIGNAL AMPLITUDE
FUNCTION INDICATOR
0-50
STRIPPER ADJUST
250 W.W.
33 10W
180 10W
68 10W
FUNCTION SELECTOR
STRIPPER BATTERY D.C. SIGNAL IN
TO COMPARATOR (D.C. SIGNAL)
SIGNAL RELAY IN
6J5
6SJ7
6F6
100Kc XTAL
1500µµf
SEC
PRI
13K 5W
180µµf
2000 CER
400 CER
30K 5W
470Ω
220K
120K 2W
56K 1W
6800 25W
.5µfd 600V
VR105
INJECTION PHASE
+250 IN
100Kc OUT #1
5K WW
4K 10W
100Kc OUT #2
5K HELIPOT
INJECTION AMPLITUDE
100 Kc INJECTION GENERATOR
115V 60~ IN
1A
2.5V
2W 180K
.5 2Kv
2X2A
6.3V
SCOPE POWER SUPPLY
MOUNTED ON TOP-SIDE OF DECK #3
VERTICAL CENTERING
HORIZONTAL CENTERING
DUAL 10M
2M
1M
2.2M
D1
D2
D3
D4
VERT. DEFL.
SWEEP IN
6.3V ALL HEATERS
FOCUS
INTENSITY
H-K
G1
-2500V
3GP1A INDICATOR SCOPE
MONITOR SCOPE
DECK #3
LOW INERTIA RECORDER

Plate 3


XPONENTIAL IN
D·C· SIGNAL IN
φ#1 100Kc IN
φ#2 100Kc IN
COMPARATOR OUTPUT
COMPARATOR
MPLITUDE ADJ θ
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220K
.01 MICA
47K
1620
3
5
4
8
2
7
XX
2500 WW
2500 WW
6.0
EXPONENTIAL OUT
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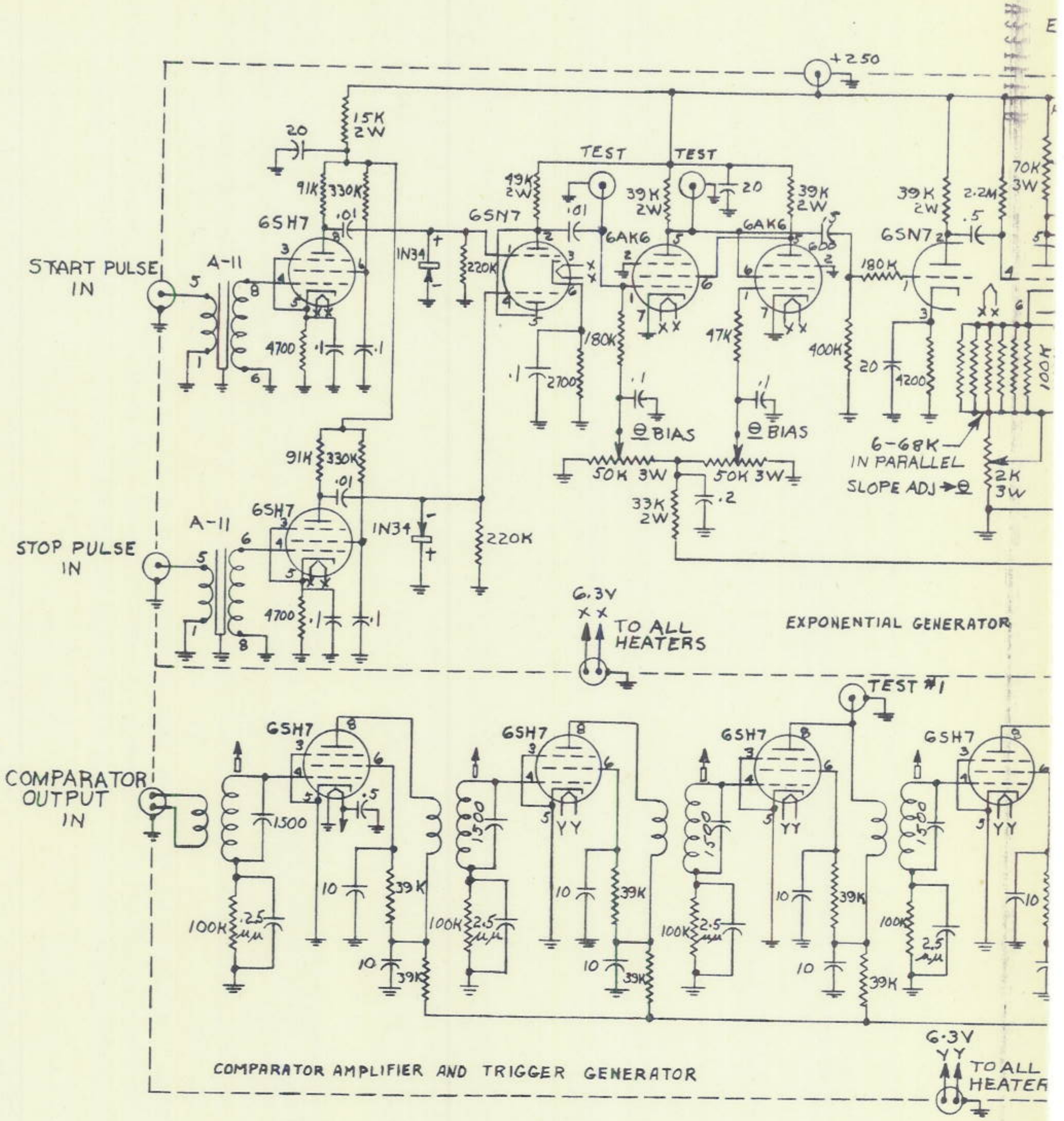
47K
100K
1620
.1
OB-2
1
7
TO 1620 HEATERS 6.3V
6800Ω 25W
X X 6·3V
TEST #2
5600
6SN7
10
.01
6.3V
.01
.01
39K
1500
92K 2W
.006
410 μμ
570K
5700
20
39K
TEST #3
.2
39K
1N34
2050
6
5
8 YY
10
.1
100K
P·F· NET 25μ SEC
L
C
195EW PULSE XFMR
1
2
4
3 5
6
39K
510
39K
.02
50K 3W
.1
49K 2W
+250 IN
-75 IN
TRIGGER TO MODULATOR
SPARK GENERATOR
S

R

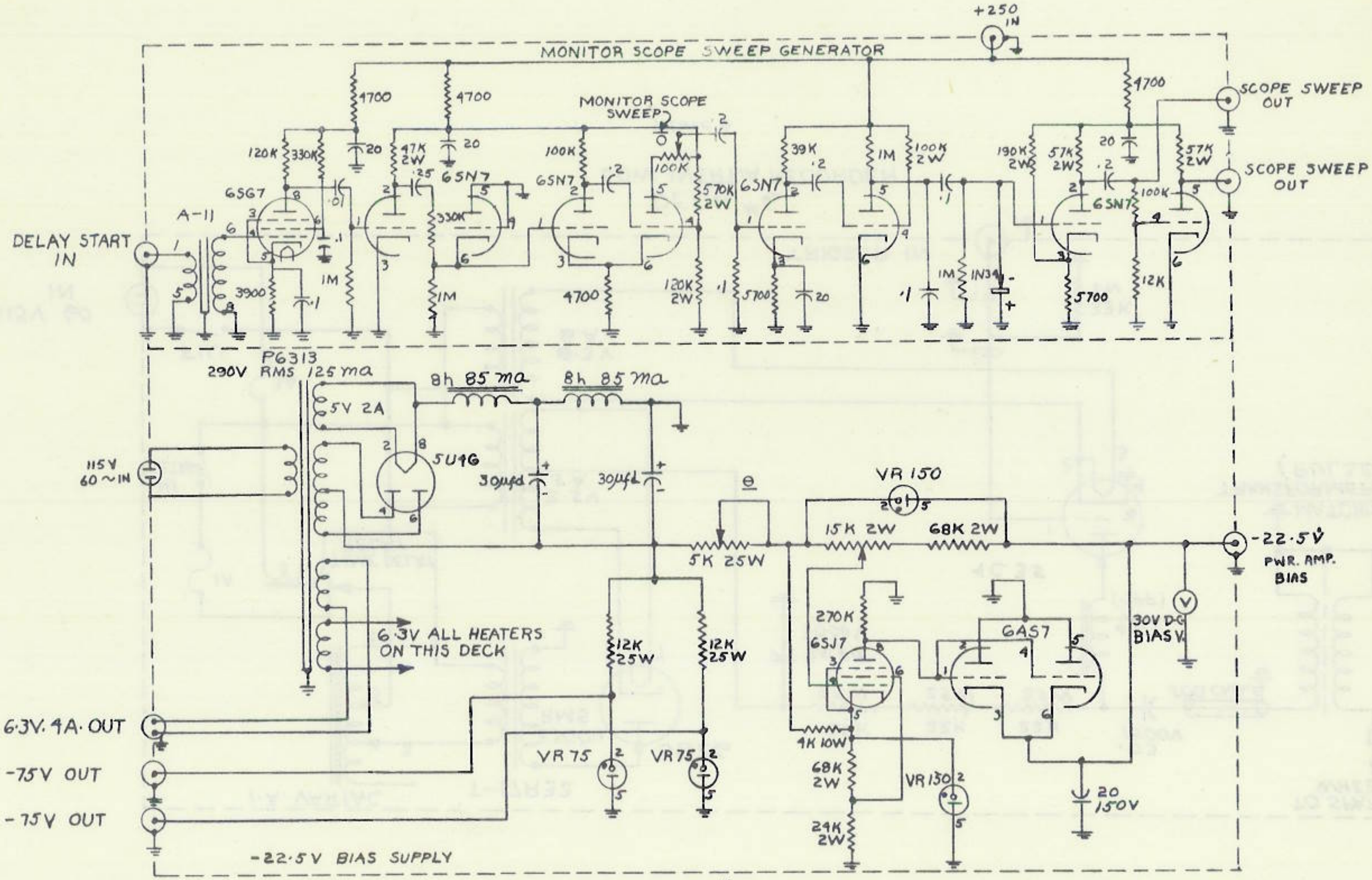
· 4



DECK #4

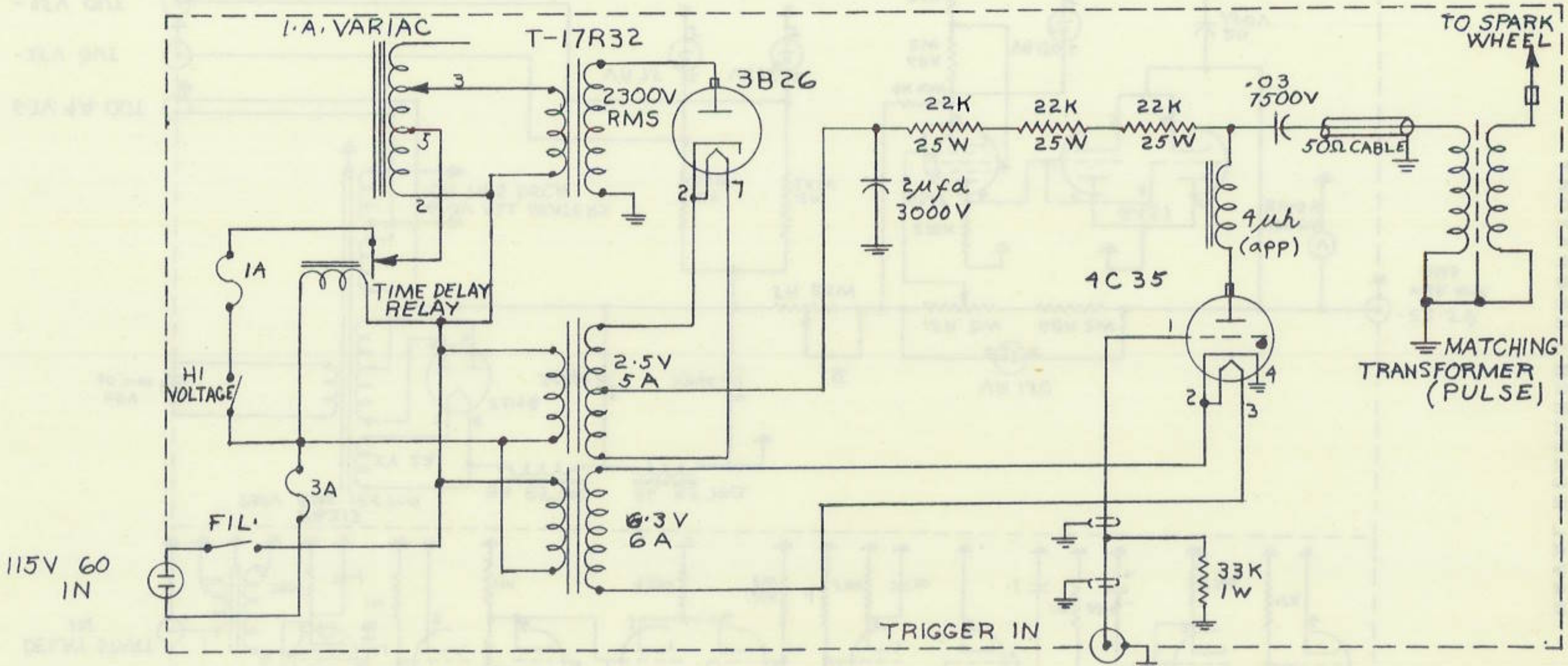
LOW INERTIA RECORDE

Plate



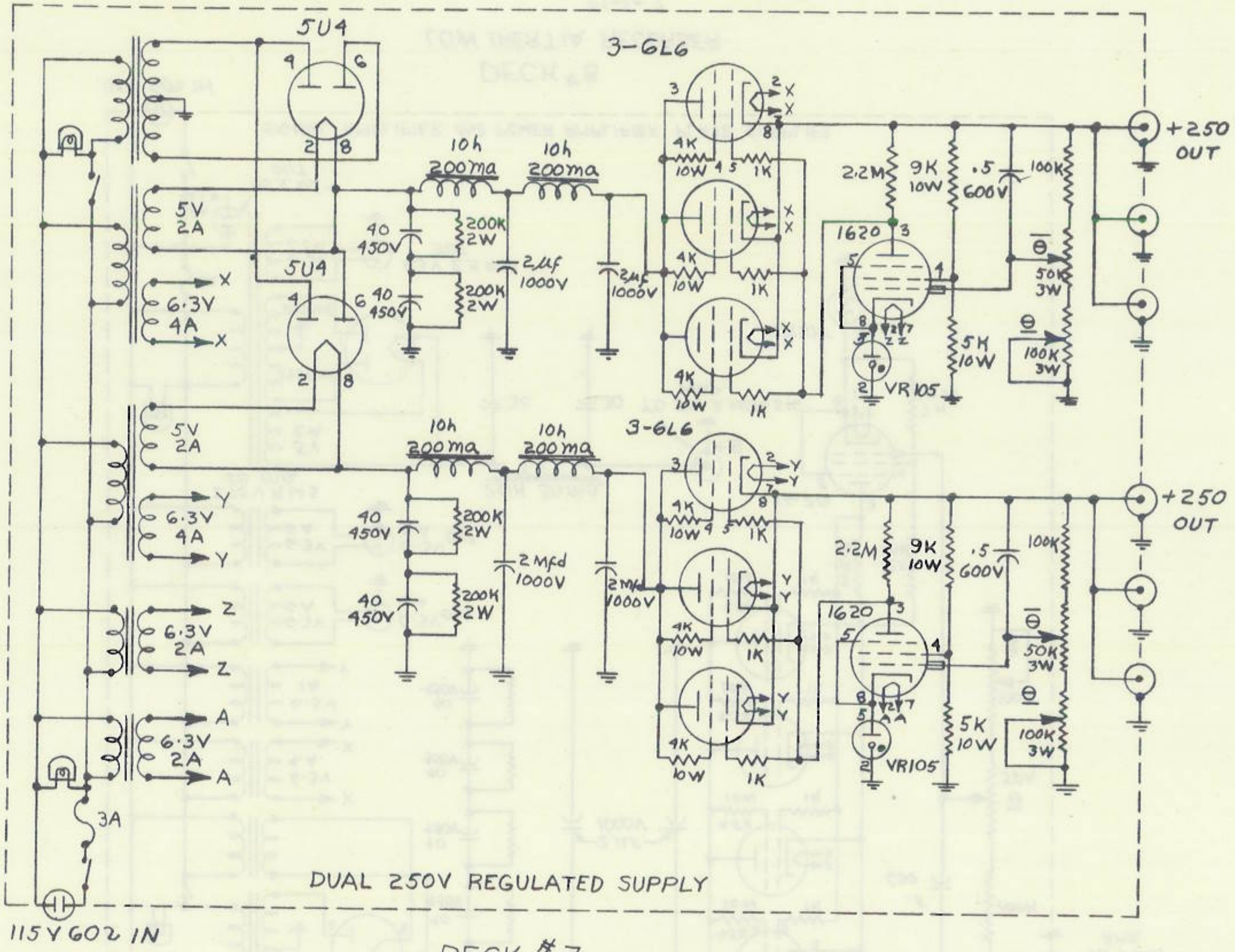
DECK #5
LOW INERTIA RECORDER

Plate 5



DECK #6
LOW INERTIA RECORDER

Plate 6



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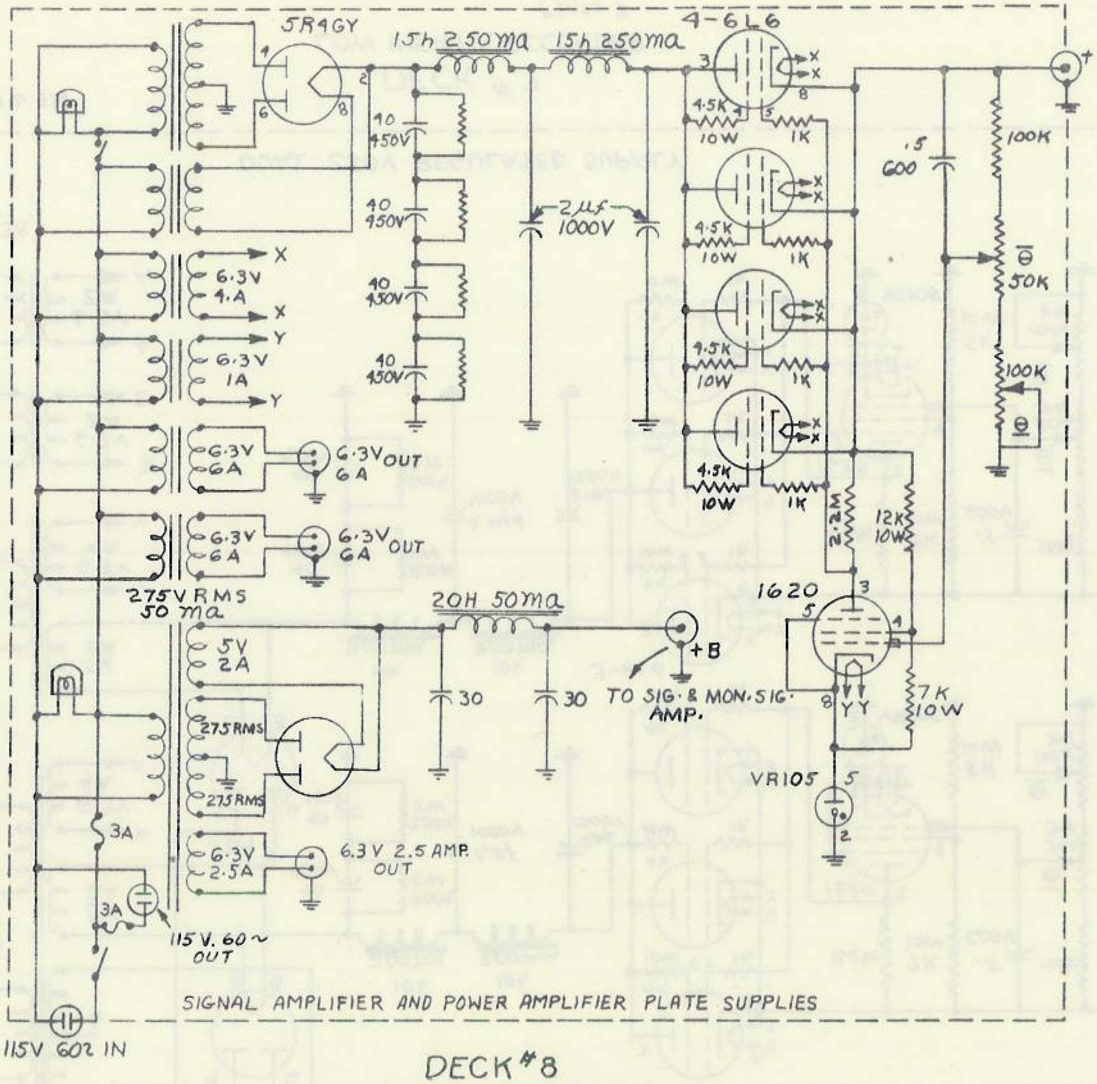
LOW INERTIA RECORDER

Plate 7



DECK #8
LOW INERTIA RECORDER
Plate 7

NAVY-DPPO PRNC. WASH. D.C.