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COUPLING BETWEEN HIGH-FREQUENCY SLEEVE ANTENNAS FOR TASK FLEET FLAGSHIP CLC-1

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CONTENTS

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ABSTRACT

Four of the broadband high-frequency transmitting antennas for Task Fleet Flagship CLC-1 will be located in a relatively small area on the aft portion of the main deck. The effect of this comparatively close spacing will alter the input impedance from that predicted on the basis of a single antenna.

An experimental investigation using scale-model techniques was made to determine the magnitude of such effects. Coupling between the several antennas and the ship's superstructure was shown to exist but the effect is sufficiently small to permit satisfactory operation over a three-to-one frequency band.

PROBLEM STATUS

This is an interim report on one phase of the problem; work on the problem is continuing.

AUTHORIZATION

NRL Problem R09-01
RDB Projects NR 509-010 and NE 091-035

Manuscript submitted September 2, 1952

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COUPLING BETWEEN HIGH-FREQUENCY SLEEVE ANTENNAS FOR TASK FLEET FLAGSHIP CLC-1

INTRODUCTION

Task Fleet Flagship CLC-1 is being equipped with broadband h-f antennas of the cylindrical sleeve type,[1] the general features of which are illustrated in Figure 1. The vessel carries a total complement of ten h-f sleeve antennas, five for transmission and five for reception. The receiving antennas are located on the forward deck area and are not within the scope of this report. The transmitting antennas cover frequency ranges of 9 to 26 Mc (two antennas), 6 to 18 Mc, 4 to 12 Mc, and 2 to 6 Mc.

The 2 to 6 Mc antenna uses the ship's stack for the sleeve section of the antenna and is located midship. The relative locations of the four remaining antennas are shown in Figure 2. Each antenna will be equipped with a four-unit multicoupler and thus the five antennas will provide for the simultaneous operation of twenty transmitters. Although the four aft antennas were located as far as possible from significant elements of the ship's superstructure in order to minimize coupling and distortion, complete freedom from these effects could not be achieved. The spacing between the four antennas themselves was made as great as possible but here also the space restrictions which prevail make it impossible to reduce the coupling to a negligible value.

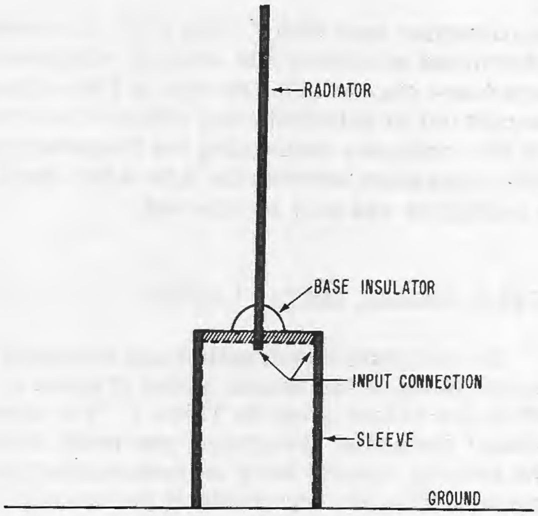

Figure 1 - Diagram showing construction of cylindrical-sleeve-type antenna

The interaction between the various antennas and between the antennas and the superstructure will produce a definite effect upon the radiation patterns in the horizontal plane. Pattern measurements, which will be discussed in a separate report, reveal these influences but show also that a reasonably good omnidirectional pattern still exists. The influence of coupling will also change the input impedance from that determined with the individual antennas mounted on an infinite ground screen. Under some circumstances this effect might not be serious, but the antenna installation on the CLC-1 demands that the impedance fall within certain limits and that SWR of not less than 0.3 be assured to permit effective

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1 Walters, A. W., "Sleeve Antenna Considerations for Task Fleet Flagship (CLC-1)," NRL Report 3494 (Confidential), July 1949

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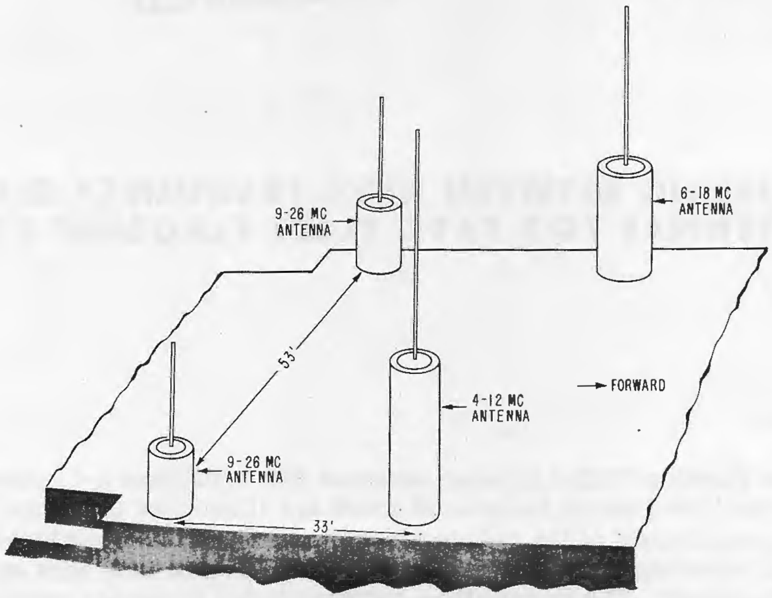

Figure 2 - Diagram of CLC-1 installation of sleeve antennas

multicoupler operation.[2] The CLC-1 antennas were designed, in accordance with previously determined standards,[3] to achieve minimum physical size consistent with providing the desired impedance characteristics over a 3-to-1 frequency band. The study herein reported was carried out to determine the effect of intercoupling upon the impedance characteristics of the four antennas embracing the frequency range of 4 to 26 Mc. Due to the comparatively wide separation between the 2 to 6 Mc stack antenna and the four after antennas, intercoupling is negligible and may be ignored.

SCALE-MODEL INSTALLATION

To facilitate construction and mounting of the model, only the after portion of the vessel was included in the scaled model (Figure 3). A scaling factor of 70 to 1 was employed to obtain the values given in Table 1. The abbreviated structure, however, included all significant elements. Provision was made to mount all four antennas, collectively or individually. The antenna mounts were so constructed that a slotted line could easily be connected to the antennas from the underside of the model. The model was mounted on a vertical ground screen in a position that permitted all necessary impedance measuring equipment to be located in back of the ground screen.

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[2] White, L. R., "Theoretical Notes on a Method of Common Antenna Working in the High-Frequency Band" NRL Report 3760 (Confidential), November 1950

[3] Walters, A. W., and Huffman, L. C., "Experimentally Determined Characteristics of Cylindrical Sleeve Antennas" NRL Report 3354 (Restricted), September 13, 1948.

TABLE 1
Scaled Dimensions and Frequency Ranges
Covered in Scale-Model Installation

Antenna Frequency Range (Mc)	Scaled Frequency Range (Mc)	Scaled Dimensions			
		Sleeve Diameter (in.)	Sleeve Length (in.)	Radiator Diameter (in.)	Radiator Length (in.)
9 to 26	630 to 1820	1.0	1.53	0.036	2.74
6 to 18	420 to 1260	1.5	2.3	0.054	4.13
4 to 12	280 to 840	1.29	3.77	0.08	5.83

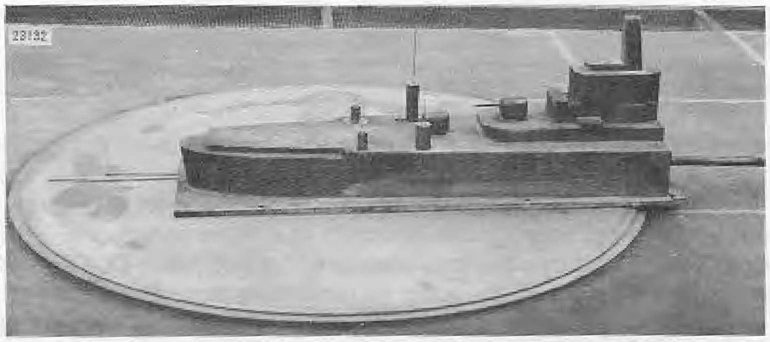

Figure 3 - CLC-1 model range for impedance measurements

EXPERIMENTAL METHOD

The change in the input impedance of one antenna caused by coupling to other nearby antennas is dependent upon the terminating impedance of the parasitic antennas. For any given frequency the input impedance of one antenna may have an infinite number of values for an infinite number of terminating conditions for the other antennas. The multicouplers and transmission lines for the CLC-1 installation will present a wide range of impedances as terminations for the antennas. An investigation of all possible terminations is impracticable; therefore, a compromise method was applied. This method employed a series of measurements of the impedance of each of the four antennas for limited conditions of terminations of the other antennas. Then by an analysis of the results it is possible to predict the endpoints or limits of impedance variation of any one antenna for all operationally occurring terminations of the other antennas. The measurements were made under the following four conditions:

First: The model antenna to be measured mounted on the ground screen with no other objects within coupling distance.

Second: The antenna to be measured mounted on the ship model with no other antennas in place.

Third: The antenna to be measured mounted on the ship model with the other antennas in place and each of these terminated in 50-ohm resistance.

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Fourth: The antenna to be measured mounted on the ship model with the other antennas in place, and with two of the parasitic antennas terminated in 50-ohm resistance, and the third terminated in a short-circuited line stretcher. Since there were three parasitic antennas, this fourth condition had three variations, i.e., the line stretcher connected to each of the parasitic antennas in turn with 50-ohm loads being used on the remaining two parasitic antennas. In addition, the line stretcher was moved in steps through a range of one-half wavelength for each antenna to which it was connected.

The impedance measurements were made with a General Radio slotted line in conjunction with several standard signal generators and receivers. A standard method of measurement was employed: the shift of the minimum current point, from its location with the slotted line short circuited, to its location with the slotted line terminated by the antenna, was determined. These data, in conjunction with a measurement of the standing-wave ratio produced on the line by the antenna, were converted to input impedance values.

RESULTS

First Three Conditions of Measurement

These measurements were made with each antenna alone on the ground screen, each antenna alone on the ship model, and the measured antenna on the ship model with the other three in place and terminated in 50-ohm resistance. As shown in Figure A1,* the 4 to 12 Mc antenna exhibits no marked coupling effect to the superstructure. However, a noticeable coupling effect to the other antennas appeared at 700 Mc. The 6 to 18 Mc antenna (Figure A2) shows some effect of coupling to the ship's superstructure at the high end of the frequency band. There is also coupling to the other antennas at 700 Mc. In Figures A3 and A4, both 9 to 26 Mc antennas show only slight effects of coupling to the ship's superstructure or to the other antennas.

To determine accurately the detrimental effects of this coupling on the performance of the antenna system, it is necessary to compute the SWR relative to a 50-ohm transmission line for each of the antennas. Therefore, the impedance-matching transformer theoretically designed for each antenna must be included in the computations.

The impedance-matching transformers for each of the antennas are of similar design. The transformers include a series coil located at the base of the upper radiator section and a special impedance transmission line of proper electrical length connected between the series coil and the RG-17/U transmission line. The parameters of the transformers for each antenna are given in Table 2.

TABLE 2
Parameters of the Impedance-Matching Transformers

Antenna	Series Coil	Transmission Line
4 to 12 Mc	.03 μh	88Ω line, 0.103λ at 250 Mc
6 to 18 Mc	.013μh	102Ω line, 0.08λ at 400 Mc
9 to 26 Mc	.028μh	102Ω line, 0.08λ at 600 Mc

* Figures A1 through A11 are in Appendix A.

[redacted]

The insulator capacity between the sleeve and radiator sections of the scale-model antennas was kept at a minimum so that the impedance could be compared directly with the original design data which were taken with a smaller scaling factor. In the practical design of the full-scale antennas, this insulator capacity would be more than the scaling factor times the capacity of the insulator on the model antenna. Therefore, since this insulator capacity is in parallel with the antenna impedance and thus affects the input impedance of the antenna, the scale-model antenna impedance data were corrected so as to correspond to a true scale model. The corrected data were used to compute the SWR on a 50-ohm line through the designed impedance transformer (Figures 4 through 7).

Except for one region, a SWR greater than 0.3 was calculated for all antennas under the three measuring conditions. The one exception was in the 6 to 18 Mc antenna (Figure 5) where the SWR was 0.19 at 700 Mc. This effect is caused by coupling to another antenna. Either the 4 to 12 Mc or the 9 to 26 Mc antenna could be the source of this coupling effect. For this small portion of the frequency range a SWR of less than 0.3 is not considered a serious limitation. By a compromise in frequency selection or in the operation of the multicoupler this difficulty could be minimized.

Fourth Condition of Measurement

The fourth condition under which the impedance of the antennas was measured consisted of having two of the parasitic antennas terminated in 50-ohm resistance with the third parasitic antenna terminated in a short-circuited line stretcher. The line stretcher was then moved through a range so that the line length varied at least one-half wavelength for each condition. These terminations were then rotated so that the line stretcher appeared as a termination for each parasitic antenna in turn.

Measurements obtained under these conditions presented a large quantity of data. The important information to be obtained from the data is the maximum variation in antenna impedance for the different line length settings. Therefore, the data were analyzed to obtain the upper and lower limits of variation in the antenna impedance. The summation of data was made by recording separately the minimum and maximum values for both the antenna resistance and reactance at each frequency. The minimum and maximum resistance points did not necessarily occur at the same line length setting as did the corresponding reactance points. The result of this analysis was to obtain a combination of resistance and reactance that represents the upper and lower limits of the greatest variation of impedance (Figures A5 through A11). It should be noted that, for these measurements, data were not obtained for termination of the second 9 to 26 Mc antenna. This omission is permissible since the results from the first three measuring conditions did not show any significant additional coupling from the second 9 to 26 Mc antenna that was not also present for the other.

The significance of the impedance variation plotted in Figures A5 through A11 cannot be easily evaluated until the data have been converted to the SWR with respect to a 50-ohm transmission line. As in the problem of presenting the impedance data, it is necessary to analyze the possible variation of SWR to determine the upper and lower limits. From the four combinations of maximum and minimum resistance and reactance values a maximum and minimum value of SWR was obtained.

This simplified method of analysis gives a minimum value of SWR which in general will be less than the actual for the worst condition in practice. On the other hand some intermediate value of impedance may give a SWR greater than the maximum value calculated above. The SWR for these impedance values was computed in the same manner as that used for these computations for the first three conditions of measurement.

In Figures 8 through 14, the computed SWR on a 50-ohm line is plotted as a function of the frequency. The SWR for the 4 to 12 Mc and 9 to 26 Mc antennas was always greater than

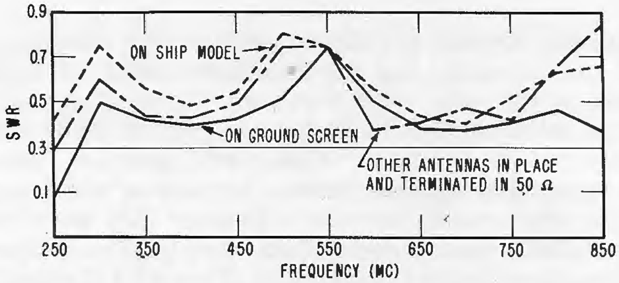

Figure 4 - SWR on 50-ohm transmission line for 4 to 12 Mc antenna including the impedance matching transformer

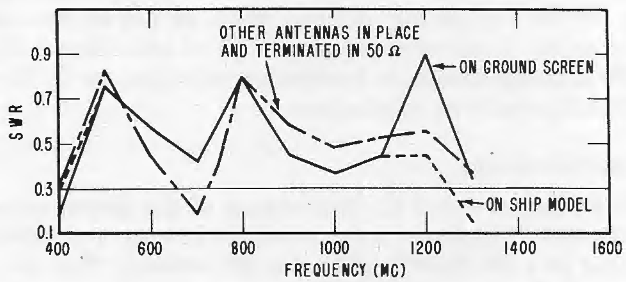

Figure 5 - SWR on 50-ohm transmission line for 6 to 18 Mc antenna including the impedance matching transformer

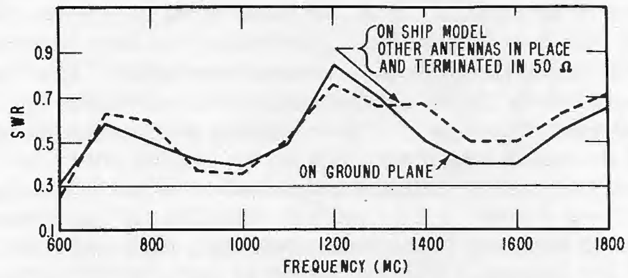

Figure 6 - SWR on 50-ohm transmission line including the impedance matching transformer for the 9 to 26 Mc antenna adjacent to the 6 to 18 Mc antenna

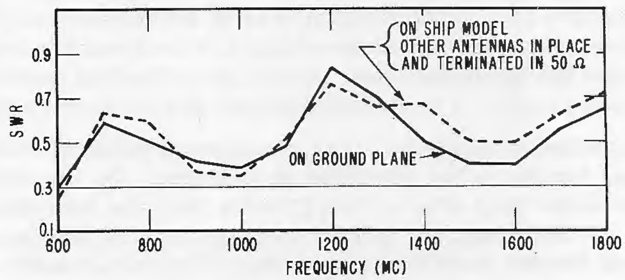

Figure 7 - SWR on 50-ohm transmission line including the impedance matching transformer for the 9 to 26 Mc antenna adjacent to the 4 to 12 Mc antenna

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0.3 for all frequencies. The 6 to 18 Mc antenna with the 4 to 12 Mc antenna terminated in a variable impedance and, with both 9 to 26 Mc antennas terminated in 50 ohms (Figure 10), showed a SWR greater than 0.3 except at 700 Mc. At this frequency the SWR varied between 0.24 and 0.17. A comparison of Figures 10 and 5 shows that this low value of SWR at 700 Mc is due to coupling to the 9 to 26 Mc or the 4 to 12 Mc antenna.

In Figure 11, the SWR for the 6 to 18 Mc antenna is given as a function of the frequency for 4 to 12 Mc antenna terminated in 50 ohms and the other 9 to 26 Mc antenna terminated in a variable impedance. The SWR is less than 0.3 at 700 Mc and between 1200 and 1300 Mc and the minimum value of SWR is less than 0.3 at 850 Mc. A comparison of Figures 5, 10, and 11 shows that the low value of SWR at 850 Mc and between 1200 and 1300 Mc is due to the coupling to the 9 to 26 Mc antenna. The low value of SWR at 700 Mc is again caused by coupling to the 4 to 12 Mc or 9 to 26 Mc antenna. The frequencies for which the full-scale antenna may have a SWR less than 0.3 are 10 Mc, 12.1 Mc, and between 17.1 and 18 Mc.

The SWR for the 6 to 18 Mc antenna, Figure 11, at 850 Mc and between 1200 and 1300 Mc can vary through a large range of values depending on the termination impedance of the parasitic antennas. The minimum value of SWR is less than 0.3 at these frequencies. The maximum value of SWR, however, is greater than 0.3 by a large margin. This means that by selecting the proper impedance for the termination of the parasitic 9 to 26 Mc antenna, a SWR greater than 0.3 can be maintained at 850 Mc and between 1200 and 1300 Mc for the 6 to 18 Mc antenna. The equivalent load impedance terminating the 9 to 26 Mc antenna can be varied through a large range by small changes in the length of the 50-ohm line between the multicoupler and the antenna. This is evident from the fact that a half wavelength of RG-17/U at 12.1 Mc is 6.3 feet. Thus all four antennas, namely, the 4 to 12 Mc, the 6 to 18 Mc, and the two 9 to 26 Mc antennas, will present a SWR greater than 0.3 at all frequencies except for the 6 to 18 Mc antenna at 700 Mc.

CONCLUSIONS

The four broadband antennas designed for installation on the after deck of the Task Fleet Flagship, CLC-1, have been the subject of a study to determine the effects of intercoupling upon the impedance characteristics of the antennas.

(1) The broadband characteristics of the 4 to 12 Mc transmitting antenna were not appreciably affected by intercoupling and a SWR greater than 0.3 could be maintained over the entire frequency band.

(2) The impedance characteristics of the 9 to 26 Mc antennas were not appreciably impaired by the intercoupling which prevailed and a SWR greater than 0.3 could be maintained over the band of 9 to 26 Mc.

(3) The broadband characteristics of the 6 to 18 Mc antenna are such that a SWR of 0.3 or greater is maintained throughout most of the frequency range. Over narrow bands of frequency, at 10 Mc, 12.1 Mc and between 17.2 and 18 Mc, the SWR may fall below the desired value of 0.3. The 10-Mc point can be improved by adjusting the length of the transmission line feeding the 4 to 12 Mc antenna. A SWR of 0.24 which will not seriously limit performance, can be obtained in this manner, and the SWR will not be less than this value regardless of the line lengths associated with the 9 to 26 Mc antennas. The deficiencies existing at 12.1 Mc and between 17.1 and 18 Mc can be corrected by selecting the proper lengths of transmission line for the 9 to 26 Mc antennas. (The line lengths referred to are those between the antennas and their associated multicouplers.)

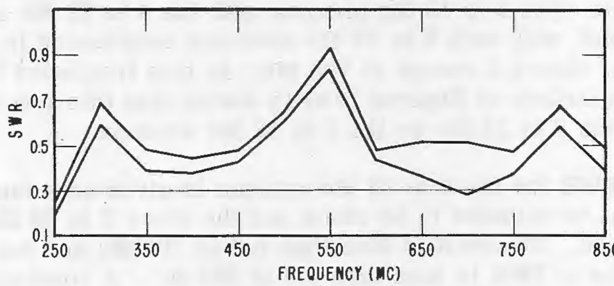

Figure 8 - Range of SWR for 4 to 12 Mc antenna with 6 to 18 Mc antenna terminated in a varied impedance and both 9 to 26 Mc antennas terminated in 50 ohms.

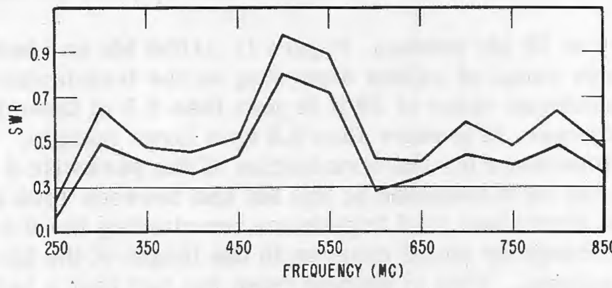

Figure 9 - Range of SWR for 4 to 12 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 6 to 18 Mc and 9 to 26 Mc antennas terminated in 50 ohms

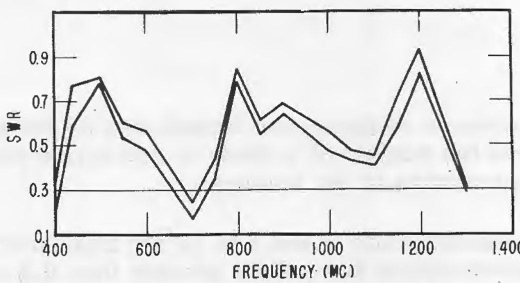

Figure 10 - Range of SWR for 6 to 18 Mc antenna with 4 to 12 Mc antenna terminated in a varied impedance and both 9 to 26 Mc antennas terminated in 50 ohms

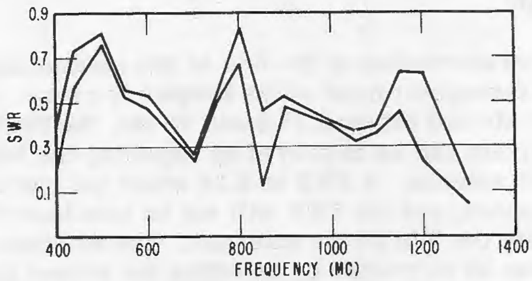

Figure 11 - Range of SWR for 6 to 18 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 9 to 26 Mc antennas terminated in 50 ohms

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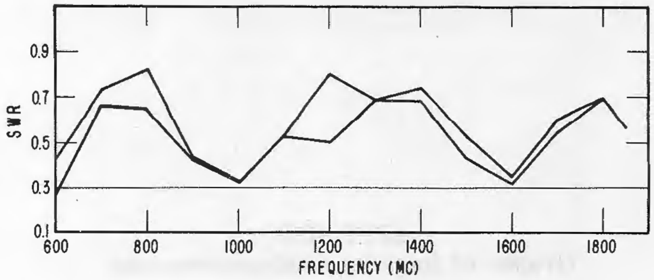

Figure 12 - Range of SWR for 9 to 26 Mc antenna with 4 to 12 Mc antenna terminated in a varied impedance and with 6 to 18 Mc and 9 to 26 Mc antennas terminated in 50 ohms

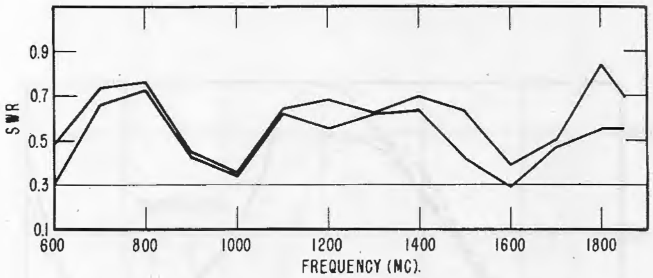

Figure 13 - Range of SWR for 9 to 26 Mc antenna with 6 to 18 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 9 to 26 Mc antennas terminated in 50 ohms

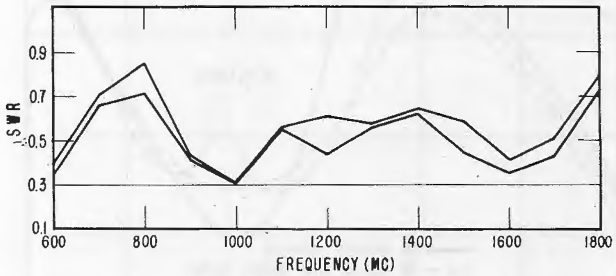

Figure 14 - Range of SWR for 9 to 26 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 6 to 18 Mc antennas terminated in 50 ohms

(4) The performance factors herein described do not take into account probable distorting effects relative to antenna patterns.

(5) The data presented apply specifically to the four antennas located on the after deck of the CLC-1 and do not constitute a generalized analysis of intercoupling between sleeve antennas.

(6) It is concluded that it is possible to achieve efficient multicoupler operation with the system of antennas described.

(7) The method of analysis employed permits the presentation of extensive data in simplified form.

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APPENDIX
Graphs of Impedance Measurements

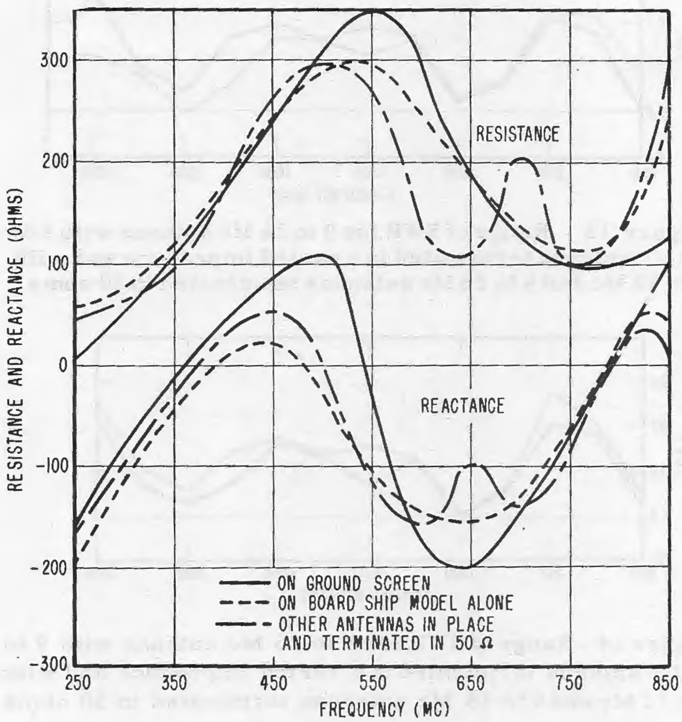

Figure A1 - Impedance of 4 to 12 Mc antenna showing the effect of coupling to the ship's superstructure and to the sleeve antennas

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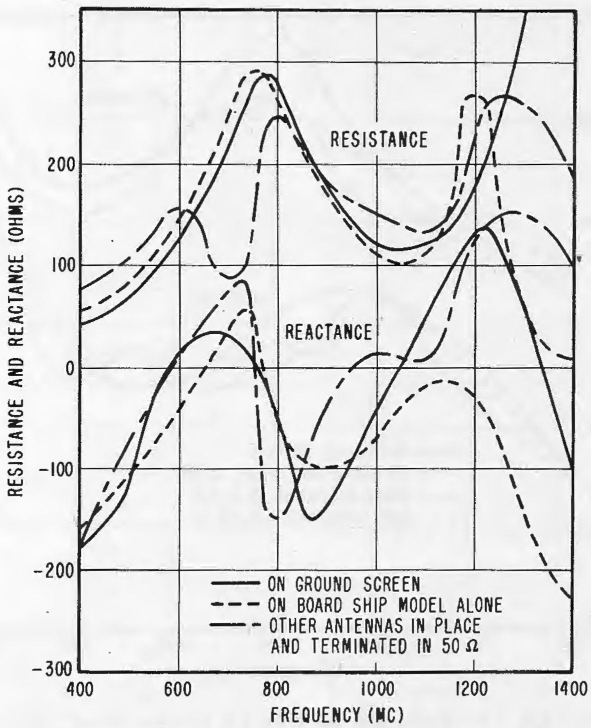

Figure A2 - Impedance of 6 to 18 Mc antenna showing the effect of coupling to the ship's superstructure and to the sleeve antennas

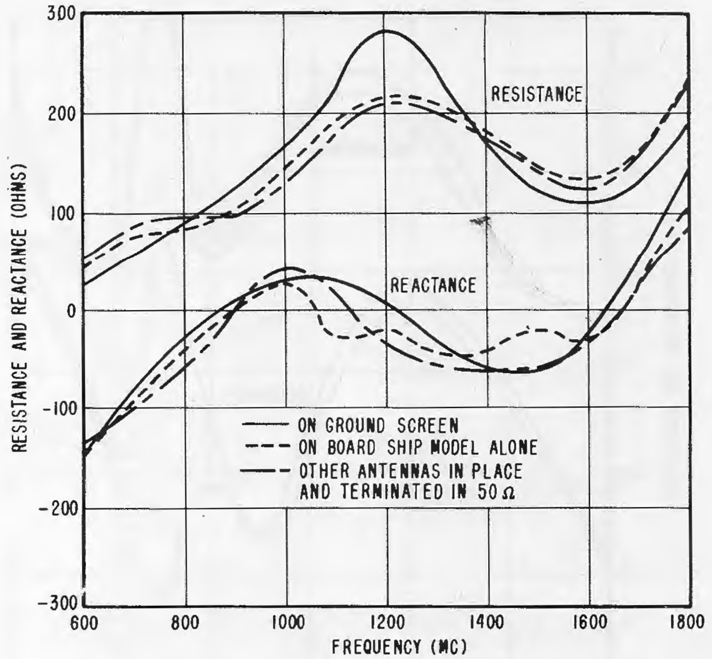

Figure A3 - Impedance of 9 to 26 Mc antenna adjacent to 6 to 18 Mc antenna showing the effect of coupling to the ship's superstructure and to the sleeve antennas

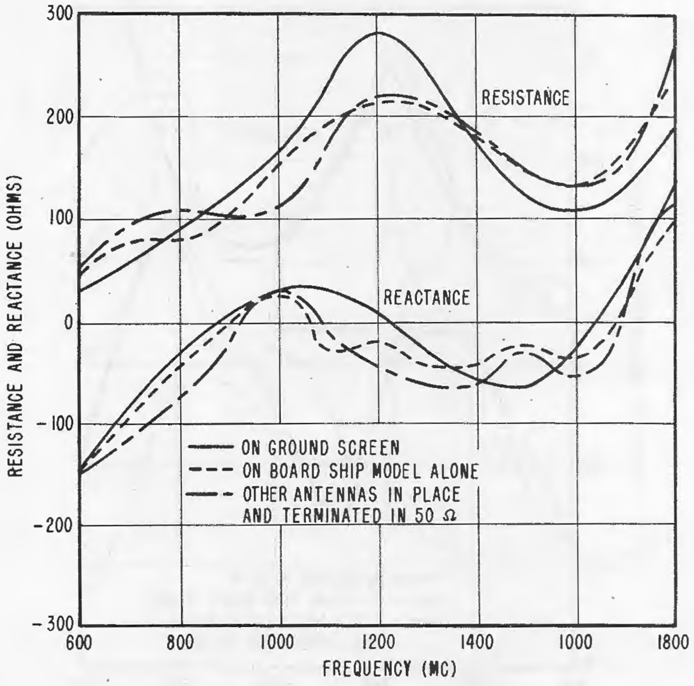

Figure A4 - Impedance of 9 to 26 Mc antenna adjacent to 4 to 12 Mc antenna showing the effect of coupling to the ship's superstructure and to the sleeve antennas

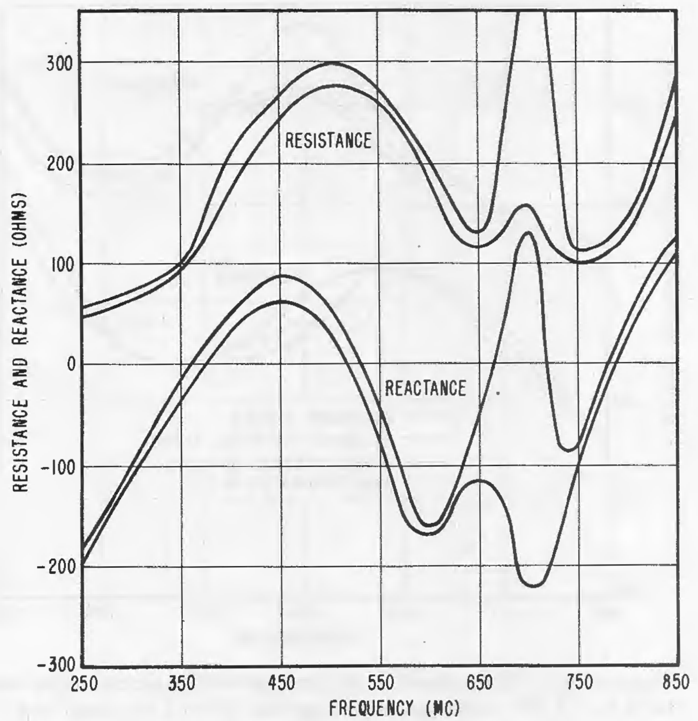

Figure A5 - Range of impedance variation for 4 to 12 Mc antenna with 6 to 18 Mc antenna terminated in a varied impedance and with both 9 to 26 Mc antennas terminated in 50 ohms

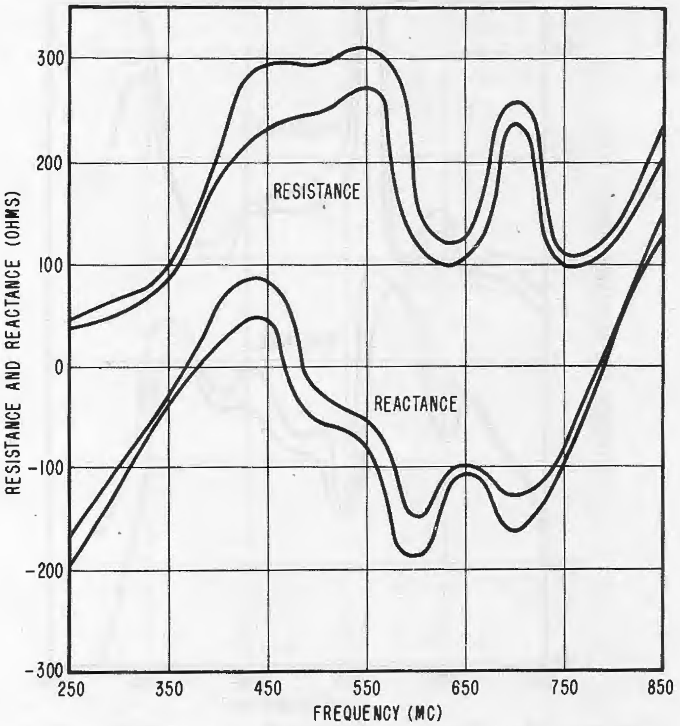

Figure A6 - Range of impedance variation for 4 to 12 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 6 to 18 Mc and 9 to 26 Mc antennas terminated in 50 ohms

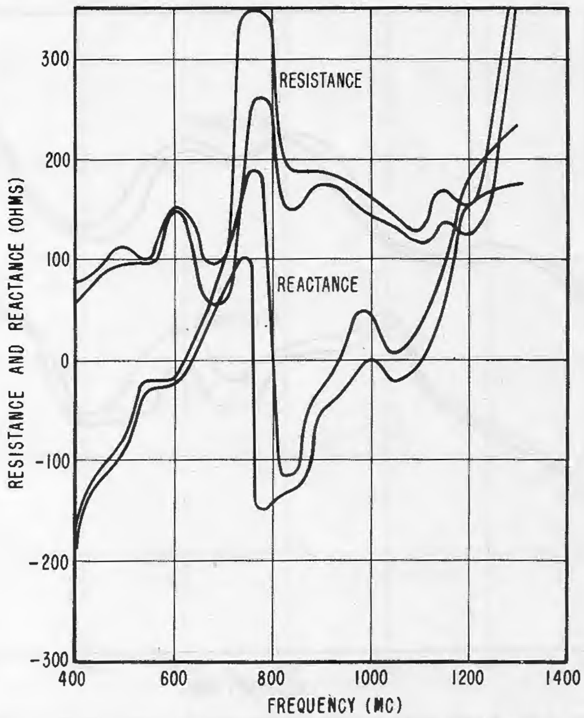

Figure A7 - Range of impedance variation for 6 to 18 Mc antenna with 4 to 12 Mc antenna terminated in a varied impedance and with both 9 to 26 Mc antennas terminated in 50 ohms

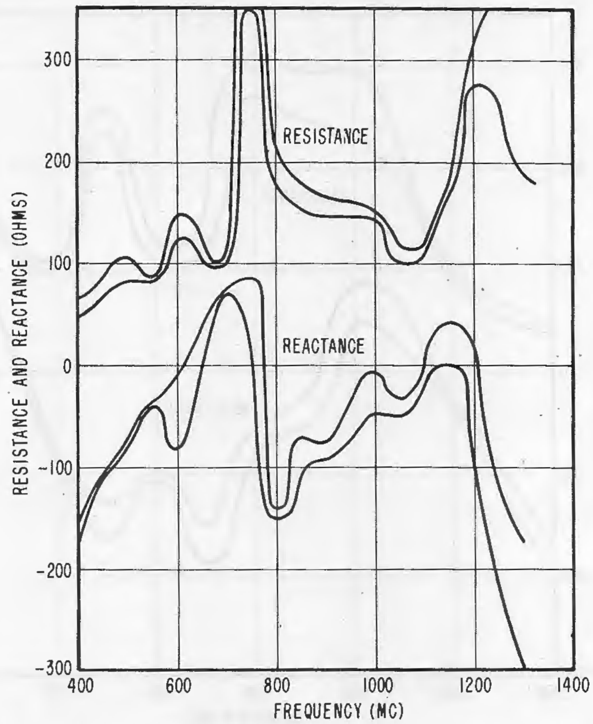

Figure A8 - Range of impedance variation for 6 to 18 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 9 to 26 Mc antennas terminated in 50 ohms

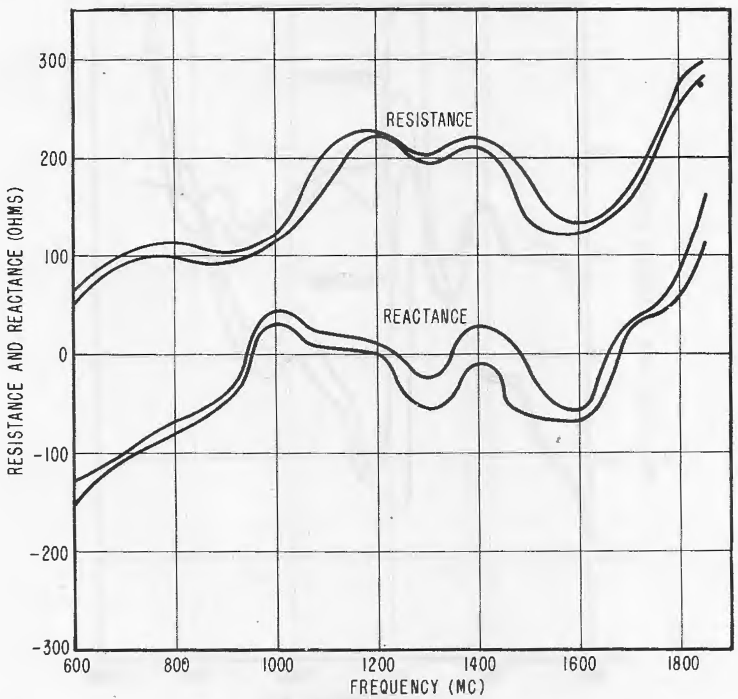

Figure A9 - Range of impedance variation for 9 to 26 Mc antenna with 4 to 12 Mc antenna terminated in a varied impedance and with 6 to 18 Mc and 9 to 26 Mc antennas terminated in 50 ohms

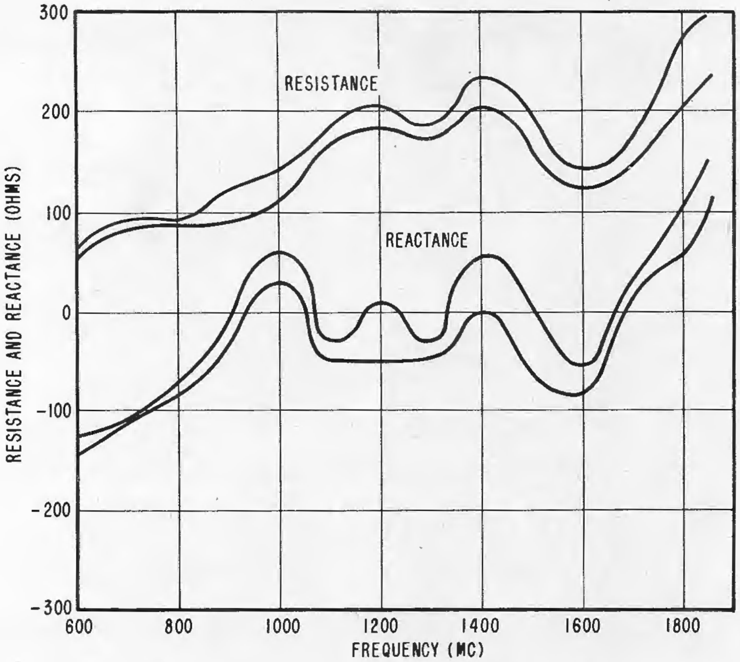

Figure A10 - Range of impedance variation for 9 to 26 Mc antenna with 6 to 18 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 9 to 26 Mc antennas terminated in 50 ohms

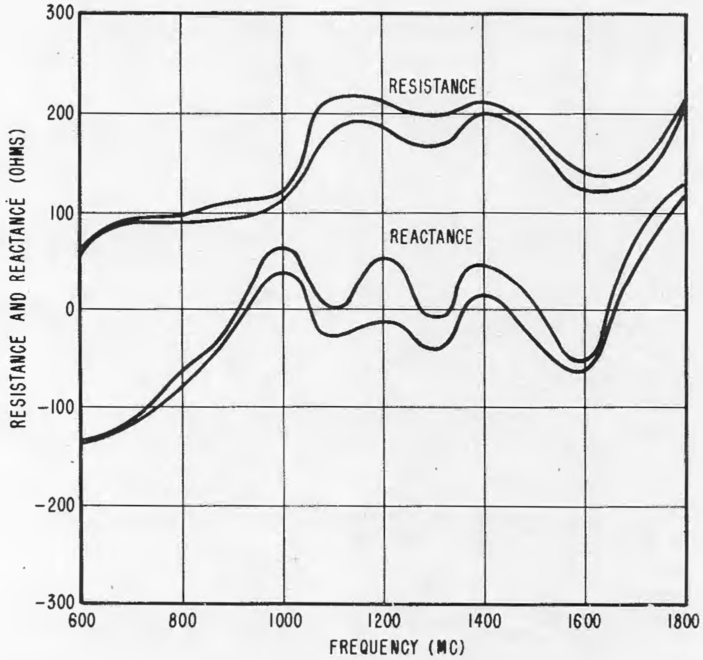

Figure A11 - Range of impedance variation for 9 to 26 Mc antenna with 9 to 26 Mc antenna terminated in a varied impedance and with 4 to 12 Mc and 6 to 18 Mc antennas terminated in 50 ohms

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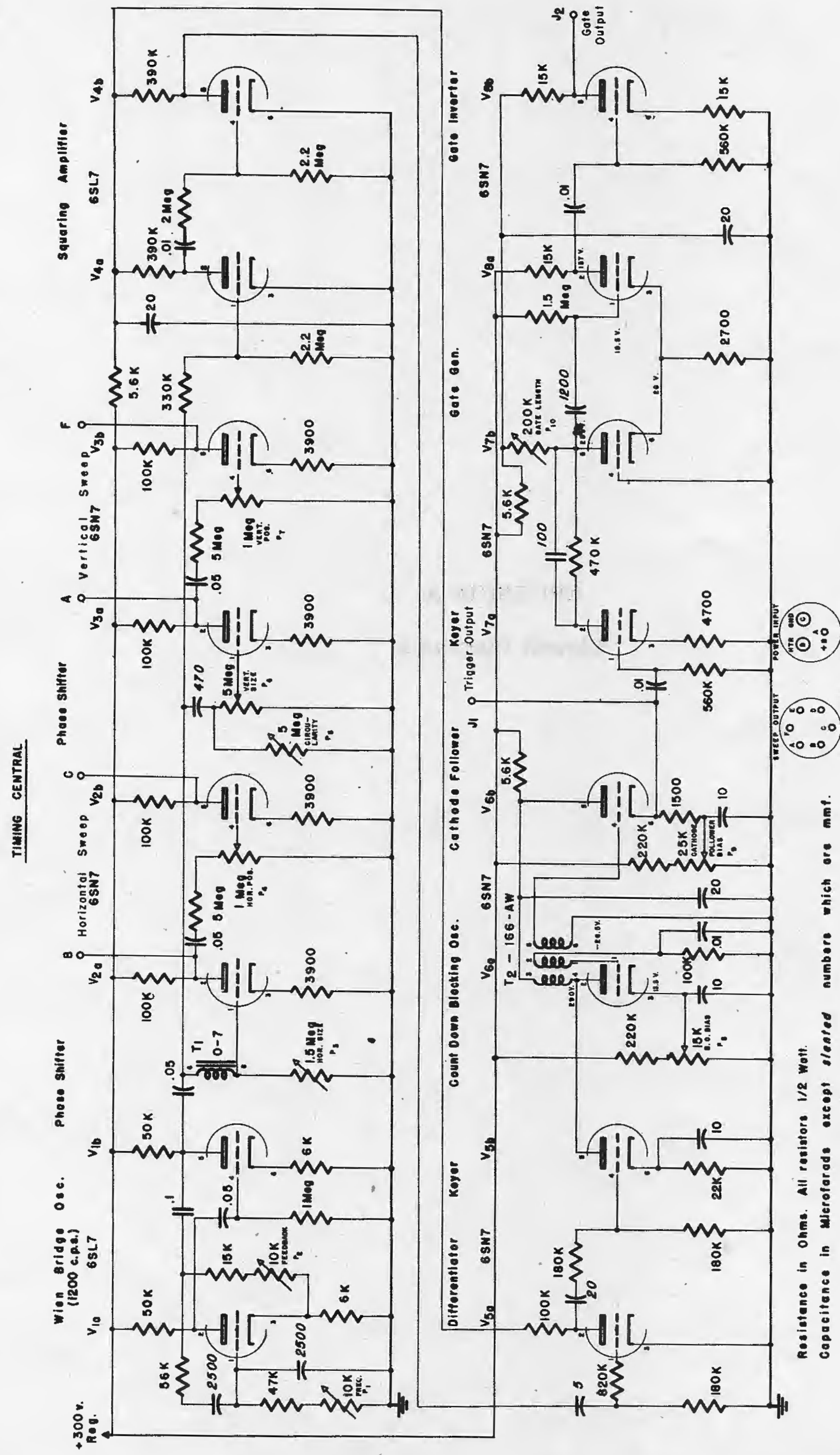

Figure A1 - Compressor timing center

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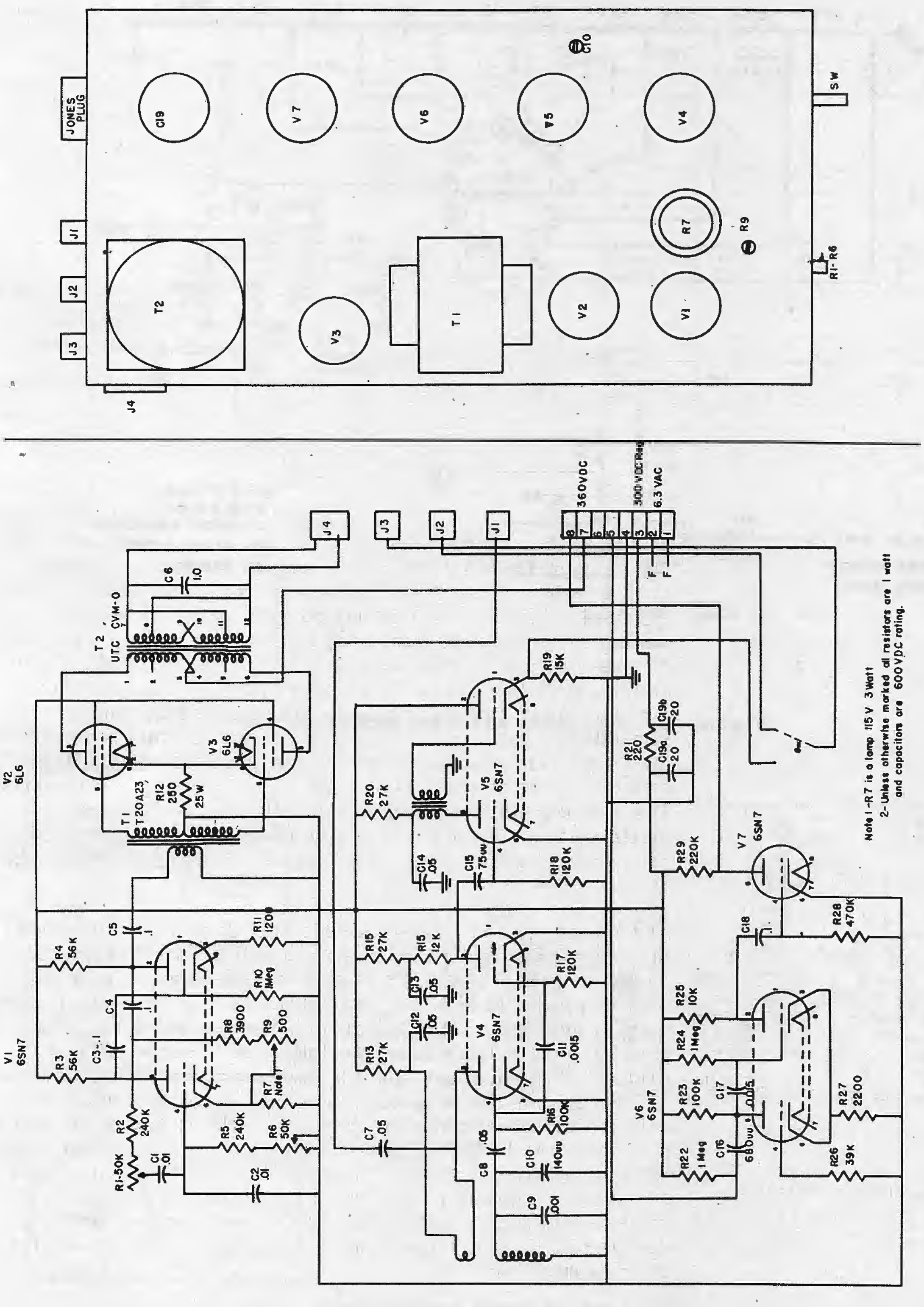

Figure A2 - Scanning-disk-motor driver

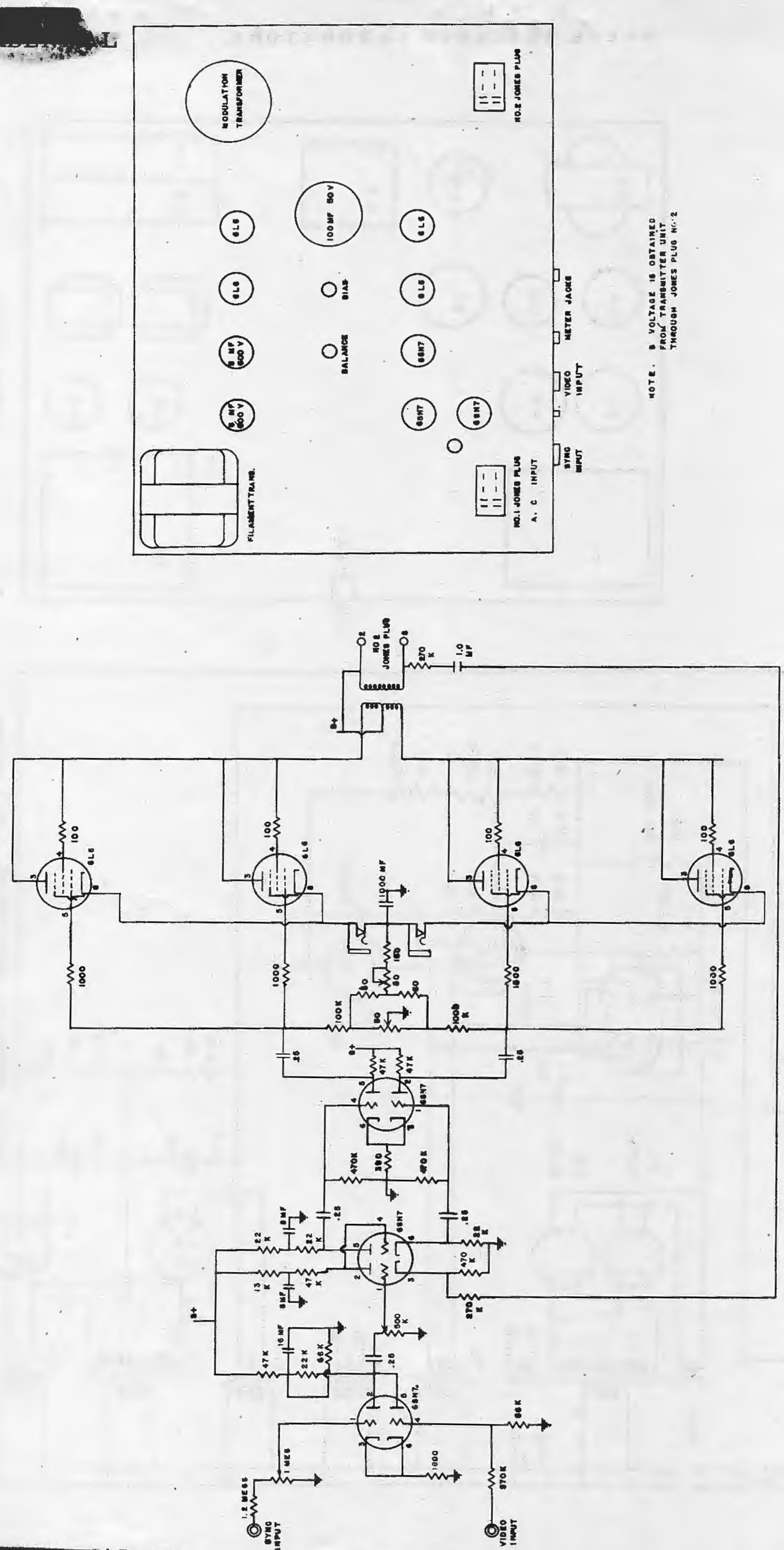

Figure A5 - Modulator

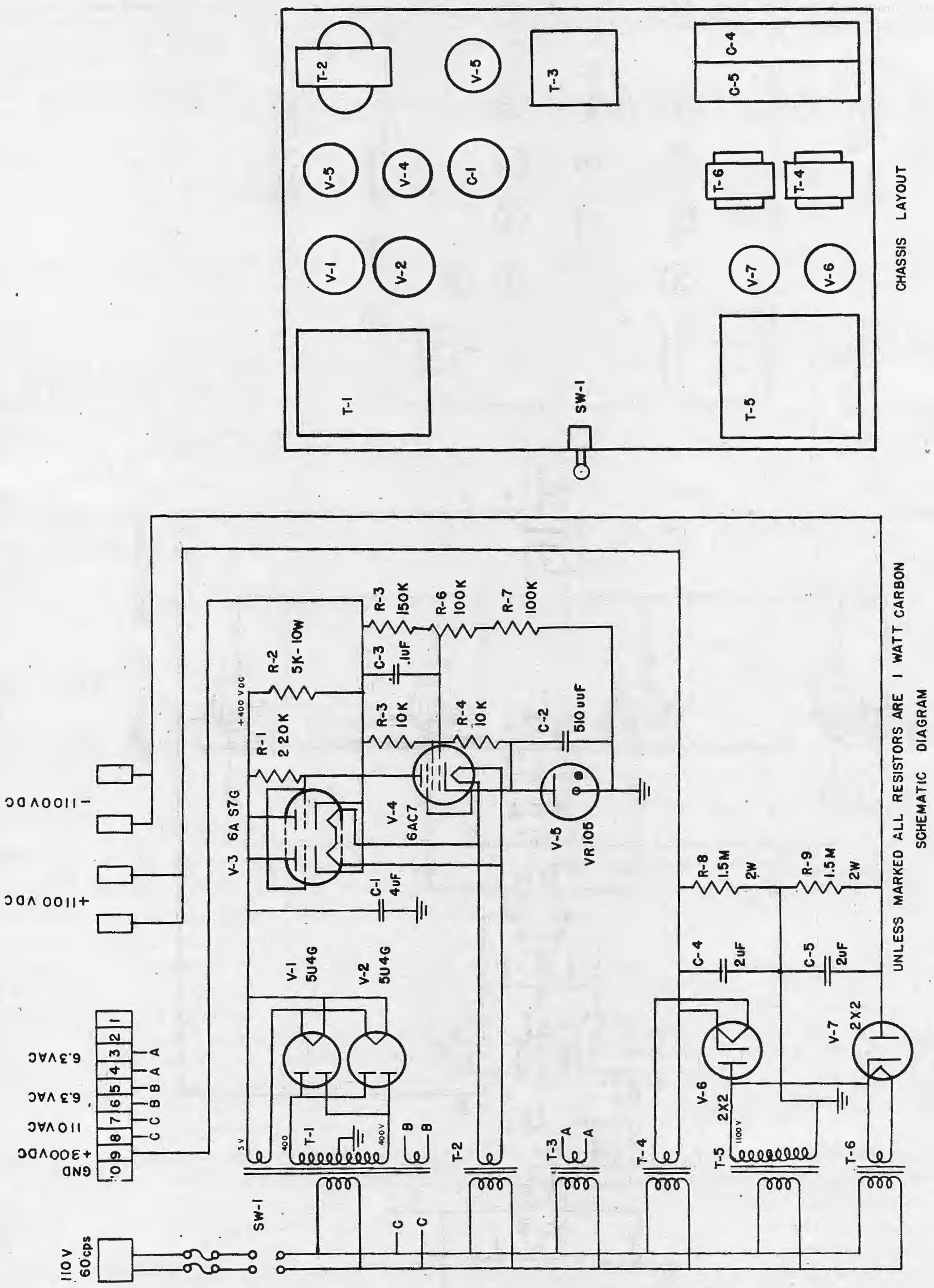

Figure A6 - Transmitter power supply

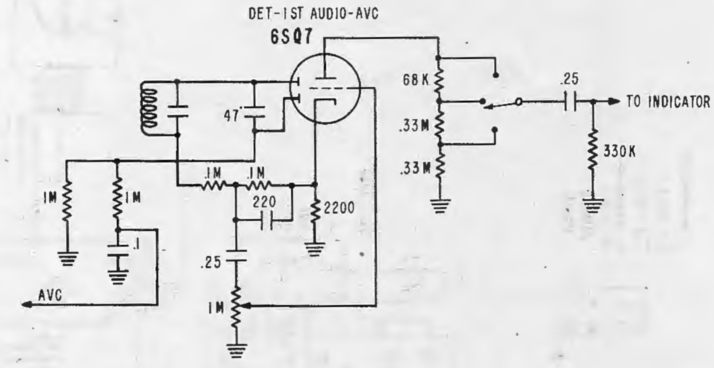

Figure A7 - Receiver modifications

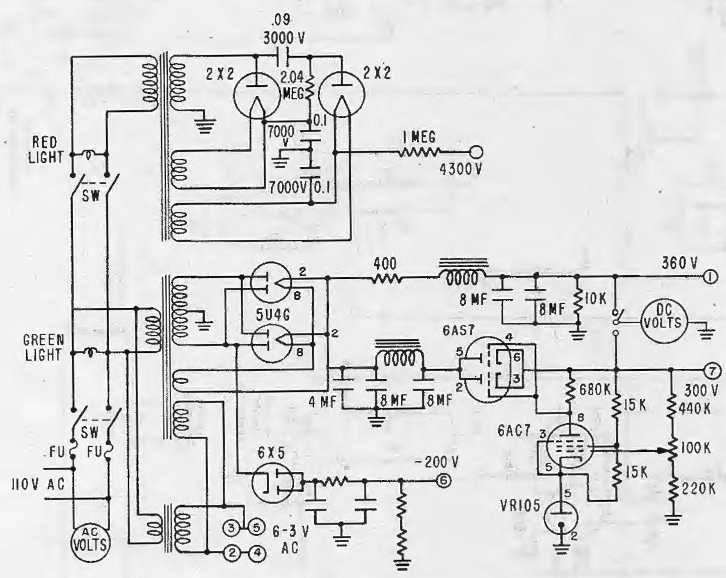

Figure A8 - Decoder-indicator power supply

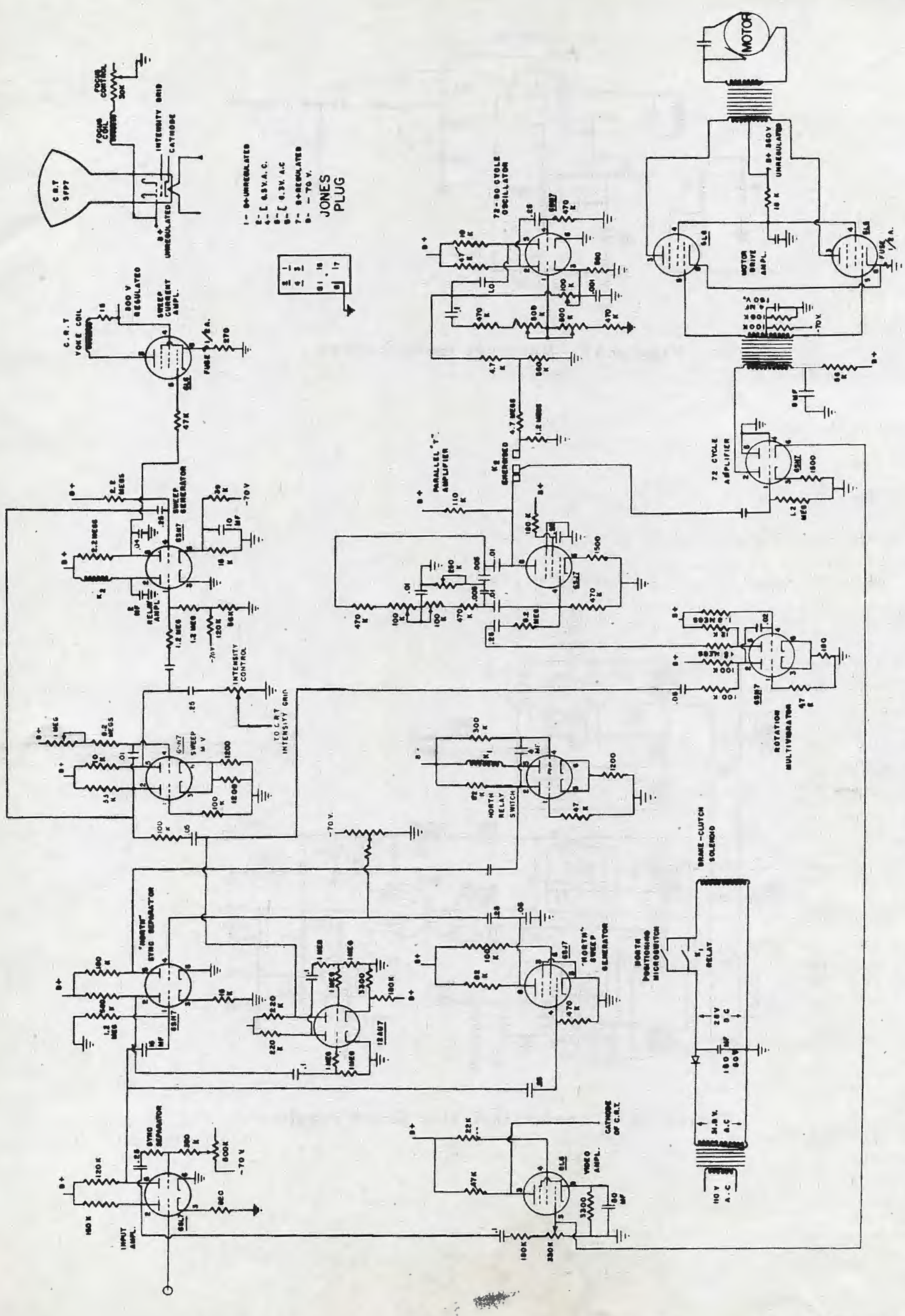

Figure A9 - Decoder-indicator

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