DESIGN OF A SERVOMECHANISM FOR USE IN TAKING MICROWAVE ANTENNA PATTERN MEASUREMENTS

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ABSTRACT

This thesis gives an account of the design and building of a feedback control system for the purpose of measuring microwave antenna patterns. The text begins with a statement of the problem thus establishing the essential characteristics of the control system. Next a preliminary investigation into existing equipment and a final system choice is made. The problems encountered with this system and their solution are discussed and finally the complete characteristics of the control system and its method of operation are given.

ACKNOWLEDGEMENTS

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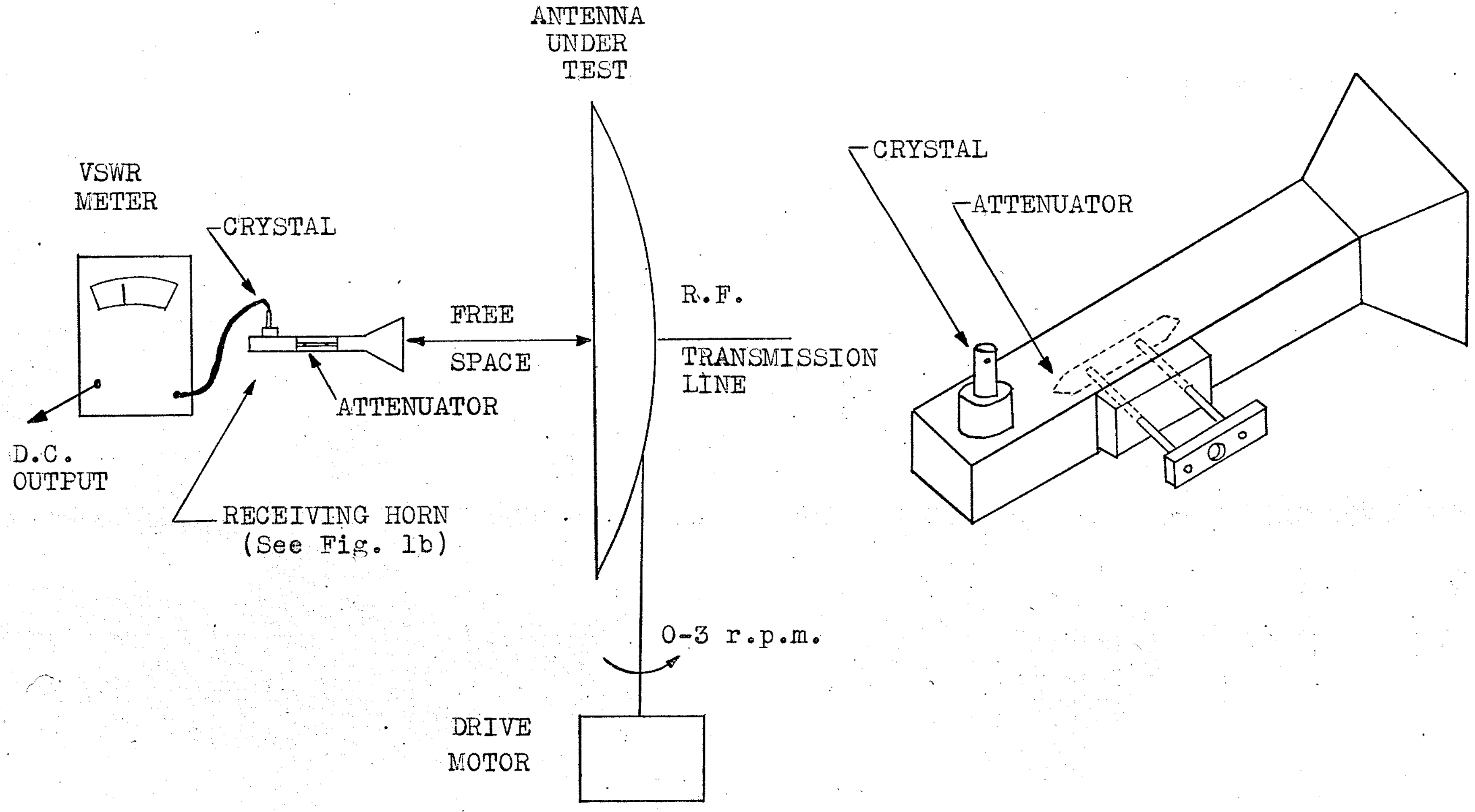
CHAPTER 1

AN INTRODUCTORY STATEMENT OF THE PROBLEM AND ITS IMPLICATIONS

Basically the problem was to design and build a servomechanism unit with which microwave antenna pattern measurements could be made. This was to be accomplished by employing existing control equipment at the University of Manitoba which was not in continuous use.

The microwave antenna pattern range consisted of a test antenna capable of rotating at 0 to 3 r.p.m. and a receiving horn as can be seen in Fig. 1a. The receiving horn contained a variable attenuator behind which was a crystal as shown in Fig. 1b. From the crystal the signal went to a voltage standing wave ratio meter (hereafter designated VSWR meter) where it was transformed into a D.C. voltage.

Since it is necessary that the crystal not exceed the range of square law operation, the variable attenuator must move in such a fashion that microwave signal strength does not surpass this range. Thus the servomechanism must move the attenuator to meet this requirement and by so doing its position is automatically a function of input microwave strength. A block diagram of the system appears in Fig. 2 where it can be seen that the output potentiometer, by being mechanically linked to the attenuator, will have a wiper voltage directly proportional to the attenuator position.



a)

b)

FIGURE 1 a) MICROWAVE ANTENNA PATTERN RANGE EQUIPMENT

b) INPUT HORN CONTAINING VARIABLE ATTENUATOR AND CRYSTAL

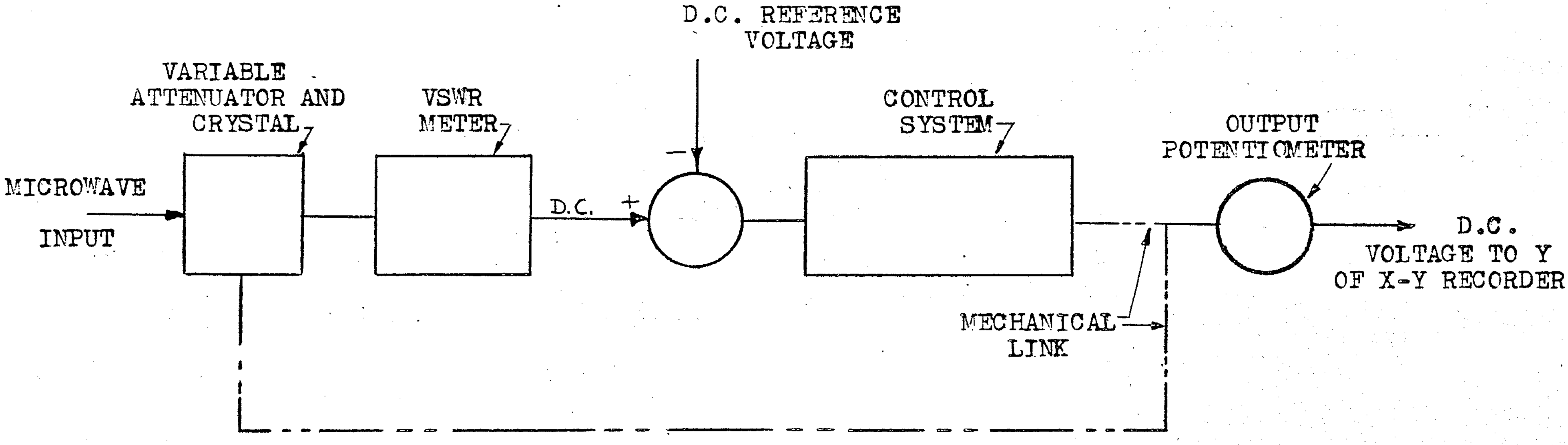


FIGURE 2 ANTENNA PATTERN MEASURING SYSTEM

The D. C. voltage from this potentiometer gives the Y reading on the X-Y recorder. At the same time the X reading is a direct function of the angular position of the transmitting antenna.

No rigid specifications were given for the control system to meet. It must, however, be capable of handling a 40 db. range with the least error and best response characteristics obtainable.

The main justification for building such a system is quite simply one of economy. To buy an antenna pattern analyzer to do the same job would mean an expense of two to three thousand dollars. The cost of the servomechanism unit, on the other hand, centers around the servomotor, gears, an amplifier, and the variable attenuator which may run to three hundred dollars. The remainder of the necessary equipment, the VSWR meter, D. C. amplifier, and equipment necessary for the 400 cycle supply, can all be used for various other purposes. Therefore this alternate procedure for taking antenna pattern measurements offers a considerable saving.

As well as being economical it is theoretically possible for this servo system to at least match the accuracy of a receiver type system which is in the order of 0.1 db. per 10 db. of dynamic range.[1] The only conceivable disadvantage would be a longer time required for one pattern measurment due to slower response time on the part of the servo system.

The following chapters consist, respectively, of preliminary investigations into available control equipment for the project, a study of the problems associated with the system eventually chosen, attempts at compensation, and the final resulting system and its characteristics.

CHAPTER 2

PRELIMINARY INVESTIGATIONS INTO EXISTING EQUIPMENT AND FINAL SYSTEM CHOICE

Since the problem involved no rigid design specifications but rather that a system "that will be satisfactory" be constructed, the choice of the system could only be made on an assumptive basis.

The prime mover which has the most desirable dynamic characteristics and which also meets power requirements should be chosen, provided of course that it is backed by an adequate power supply and amplifier. The power required was an unknown but the load would consist of a reference potentiometer and a mechanism driving the attenuator. It was assumed that the attenuator drive mechanism would constitute a load of about the same magnitude as that of the potentiometer.

With this rough guess in mind, servo control unit #921B1, consisting of a D.C. input to a chopper amplifier to a 60 cycle Holtzer Cabot type RBC2505 servomotor, equipped with feedback, was tested. The test consisted of mounting the motor geared to a potentiometer on a breadboard, applying a specific step input and recording the output signal. The same test was used with a system consisting of a D.C. signal modulated to 400 cycles and fed to a Kearfott Co. Inc. type R-603-1A magnetic amplifier, which in turn drove a motor. Several motors were tested with this system and the best dynamic response was recorded with the 400 cycle Beckman Model 18SM491 servomotor.

Briefly then, the system chosen consisted of a 400 cycle power supply, modulator, magnetic amplifier and servomotor as can be seen in Fig. 3. Although inherent with this system were a considerable number of practical problems, which will be explained in the next chapter, it was felt that it would ultimately do the most satisfactory job and for this reason alone was selected.

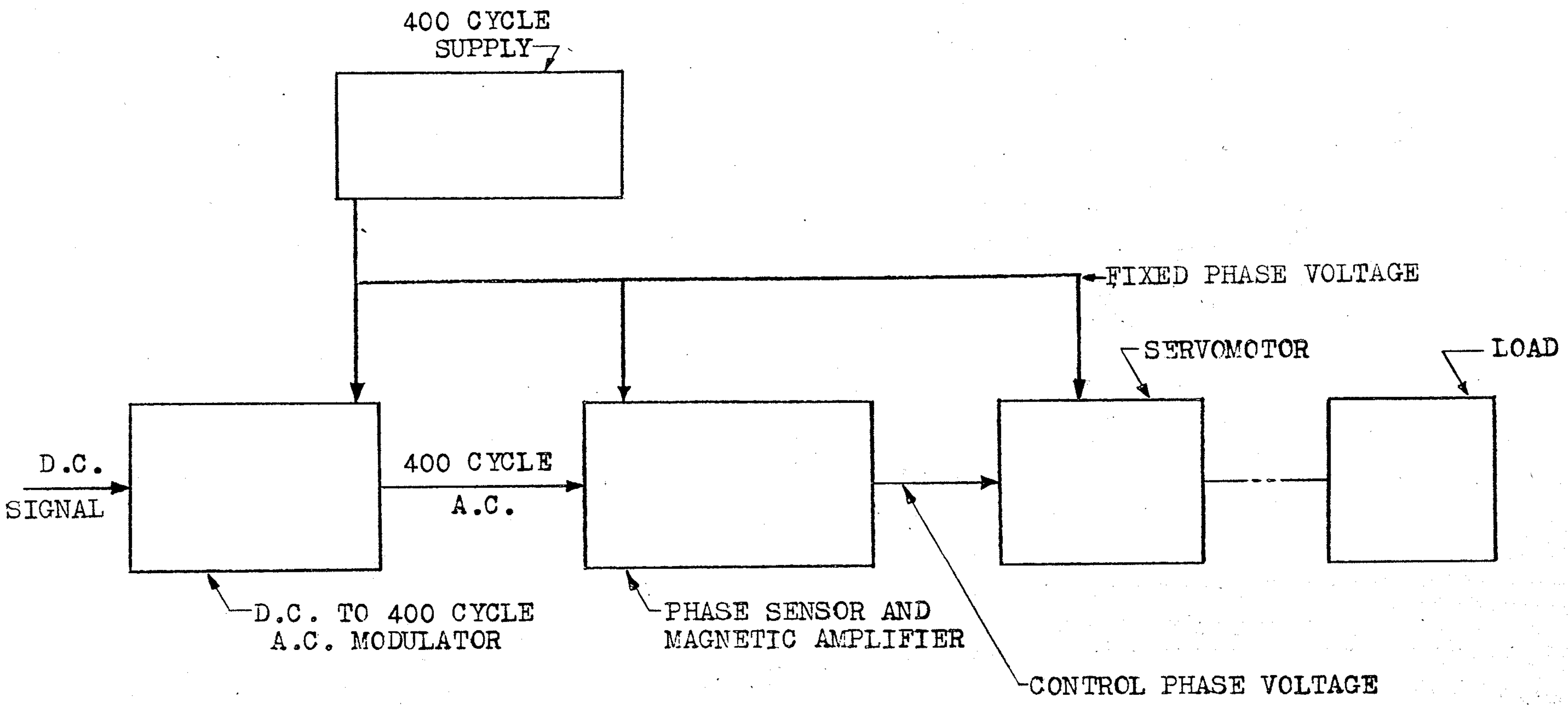


FIGURE 3 FINAL CONTROL SYSTEM CHOICE

CHAPTER 3

CONSTRUCTING THE SYSTEM

Many practical problems were encountered with the equipment in each control block. This chapter will deal with these problems as well as the problem of piecing all the blocks together to give a working system.

1. INDIVIDUAL BLOCK DIAGRAM PROBLEMS

The 400 cycle supply[2] (See Appendix A) available was a D.C. to A.C. parallel inverter employing silicon controlled rectifiers which was capable of producing about 19 watts, 115 volts r.m.s. at loads of 300 ohms to open circuit. The servomechanism was expected to draw about 18.5 watts. Thus overloading of the 400 cycle supply was not expected to be a problem, but in any case a thermal overload switch on the Lambda D.C. power supply driving the 400 cycle supply would prevent damage to the equipment should the load drop below 300 ohms.

Some difficulty was experienced in making this unit operate. Larger silicon controlled rectifiers were substituted and with appropriate adjustments of the Lambda Regulated Power Supply Model LA 50-03 AM and the Tektronix type 105 square wave generator, it functioned satisfactorily when droving all the required loads. Final operating values were 22 volts for the Lambda and maximum output for the Tektronix.

The output voltage waveshape of the 400 cycle supply as shown in Fig. 4 caused considerable consternation. The possibility of filtering was rejected since it would absorb too much power.

The only literature that could be found on the effects of non-sinusoidal excitation for servomotors[3] indicated that for square wave excitation on both reference and control phase, motor velocity and acceleration were similar in form but more oscillatory than for normal sinusoidal excitation. This waveform would then likely be satisfactory in driving the servomotor even though the motor would be noisy and heat more than normal. Thus it was assumed that this power supply would be adequate.

The D.C. to 400 cycle A.C. modulator chosen was of the form shown in Fig. 5. The A.C. output of this modulator is proportional in magnitude to the D.C. input and of a polarity depending upon the polarity of the D.C. input. Thus for a positive D.C. input, the output will be 180° out of phase with that for a corresponding negative D.C. input. The diodes were matched so that they all had similar characteristics and all resistors are within 10 ohms of each other. Care was taken in soldering resistors and diodes together so that their values would not change. Two alterations were required in this circuit which will be shown later.

The input to the Kearfott magnetic amplifier required the circuit suggested in the Kearfott Manual and shown in Fig. 6. The 5963 Tube is an "ON-OFF" control tube ideal for this purpose. Capacitor values of C_{12} and C_{34} were chosen by testing various values and observing the control voltage waveshape. (Their final values appear later in this chapter.) C_{12} and C_{34} must be equal or asymmetry results in the control phase voltage.

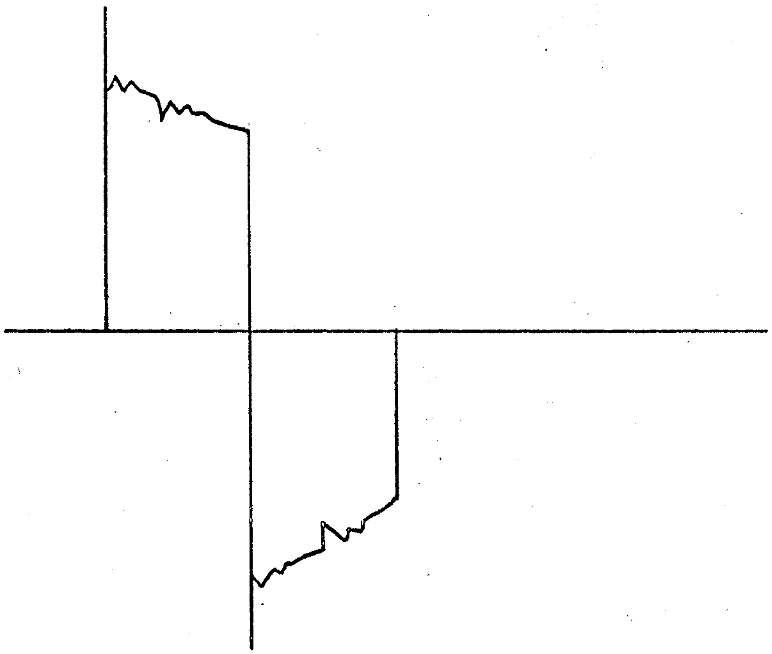


FIGURE 4 THE 400 CYCLE SUPPLY VOLTAGE OUTPUT WAVEFORM

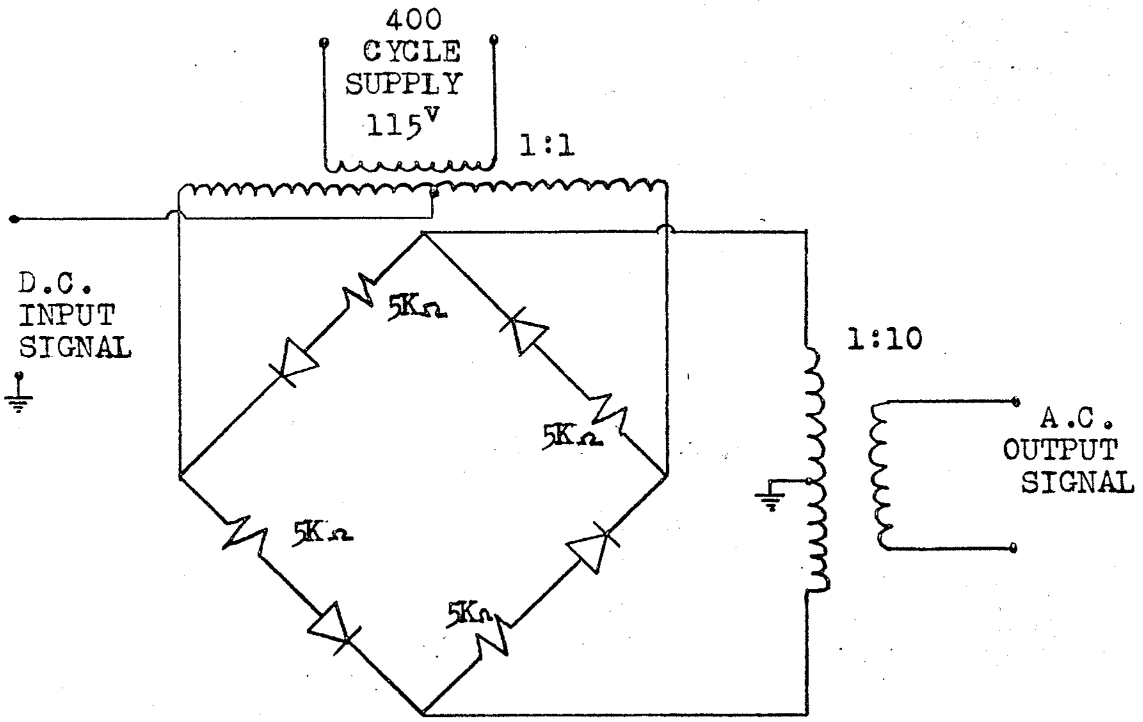


FIGURE 5 D.C. TO 400 CYCLE A.C. MODULATOR

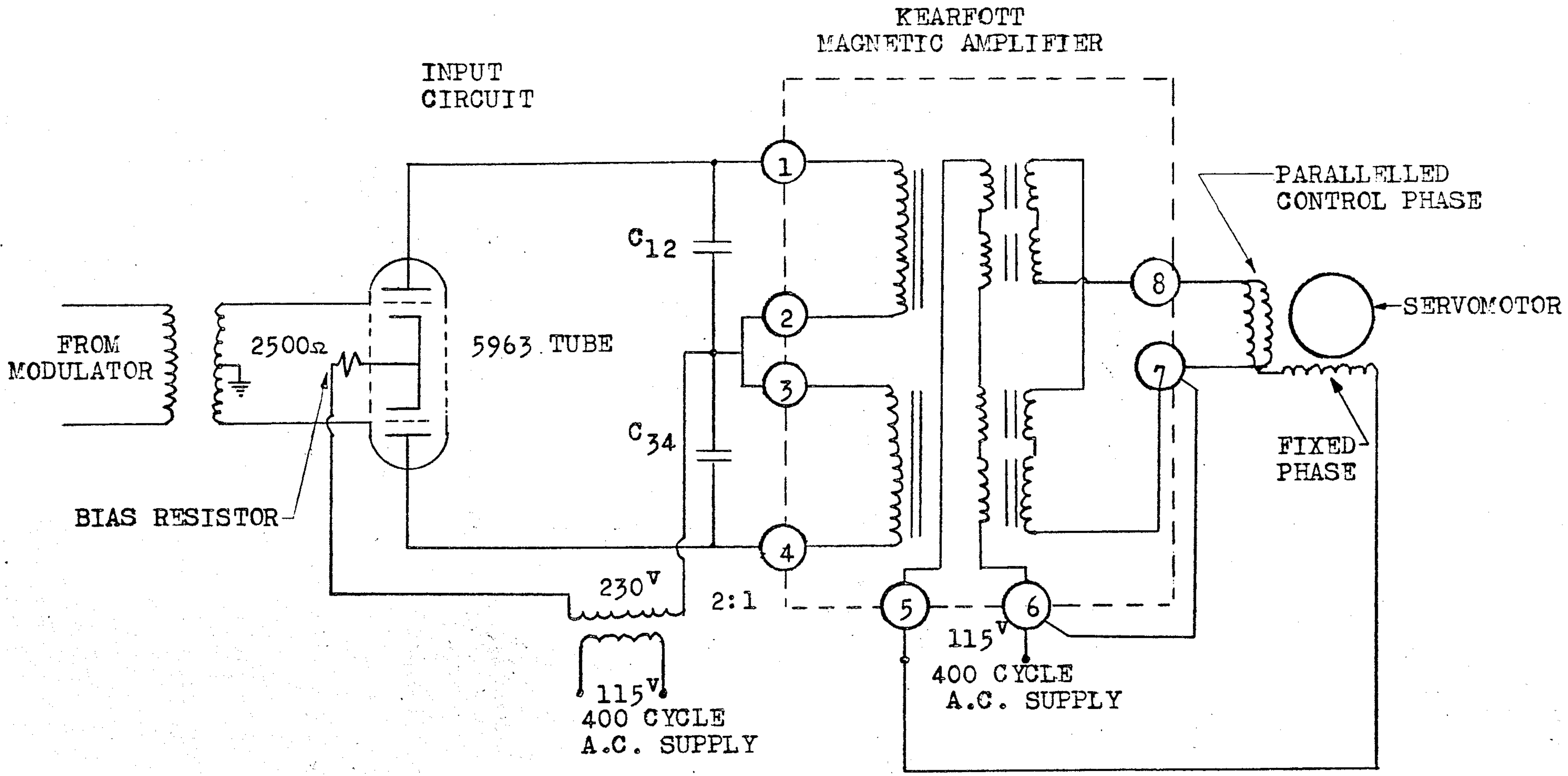


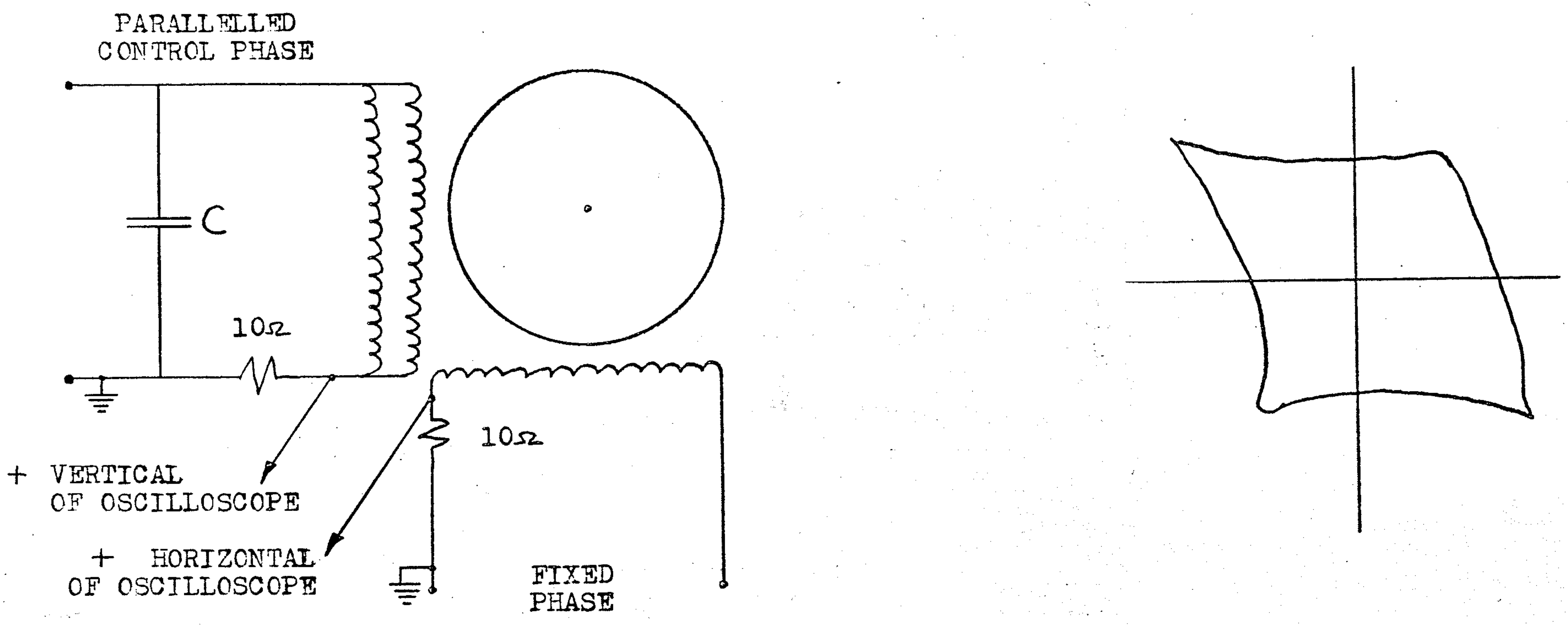
FIGURE 6 INPUT CIRCUIT, MAGNETIC AMPLIFIER, AND SERVOMOTOR

The value of the biasing resistor, about 2500 ohms, was chosen by varying its value to give a maximum control phase voltage. It may be noted here that a balanced 12AU7A may be used in place of the 5963, but will not give as good results since it does not have a specially designed long life cathode for use under on-off conditions.

The optimum capacitor value to be used in the control phase of the motor was found by recording motor torque while changing the value of the capacitor. To measure the torque, the motor was connected to a series of gears which stepped up the torque considerably and from the gears via an arm attached to the last gear which pressed on a small weigh scale. Although rather crude, this arrangement gave a resolution of about 5% in the choice of capacitor value (recorded in part 2 of this chapter).

A Lissajous Figure test was also attempted to insure that control phase and fixed phase voltages were 90° out of phase. However due to the odd waveshape of the fixed phase voltage a circle could not be obtained. As capacitance was increased toward the correct value as found in the torque test the Lissajous figure broadened and approached a square shape at the optimum value, returning to a narrower figure as this value was surpassed. The circuit and results of the Lissajous Figure test may be seen in Fig. 7.

The capacitor value could also have been determined by calculation. However due to lack of knowledge of source impedances, the quicker practical method was chosen.



a)

b)

FIGURE 7 a) CIRCUIT FOR LISSAJOUS FIGURES TEST
b) RESULTING FIGURE

Setting the attenuator simply involved the mechanical problem of changing rotary motion into linear motion. This was accomplished by using a linear translator and building appropriate connections. A reference potentiometer was connected to the translator such that for full travel of the attenuator, the potentiometer would make approximately a complete revolution.

A D.C. feedback system as shown in Fig. 8 was designed for temporary use so that system components could be connected together and the system could be checked in the rough. The 1500 ohm resistor was used since it was known that this was the source impedance of the VSWR meter, which was to be in the final design. Intuitively it would be expected that the smallest potentiometers available should be used since this allows maximum error current to the modulator. This is verified mathematically in Appendix B, and thus 1000 ohm potentiometers were used.

2. PIECING THE SYSTEM TOGETHER AND SOLUTION OF EXISTING PROBLEMS

The complete system was now connected together as shown in Fig. 9 and tests on its performance were carried out.

The first problem encountered was the magnitude of the control phase voltage (across terminals 7 & 8 Fig. 9). Attempts were made to increase this voltage to its required value of 150 volts r.m.s. by turning up the 400 cycle supply voltage. However this resulted in the control phase voltage waveform starting to collapse from a good sinusoidal waveform at about 300 volts peak to peak.

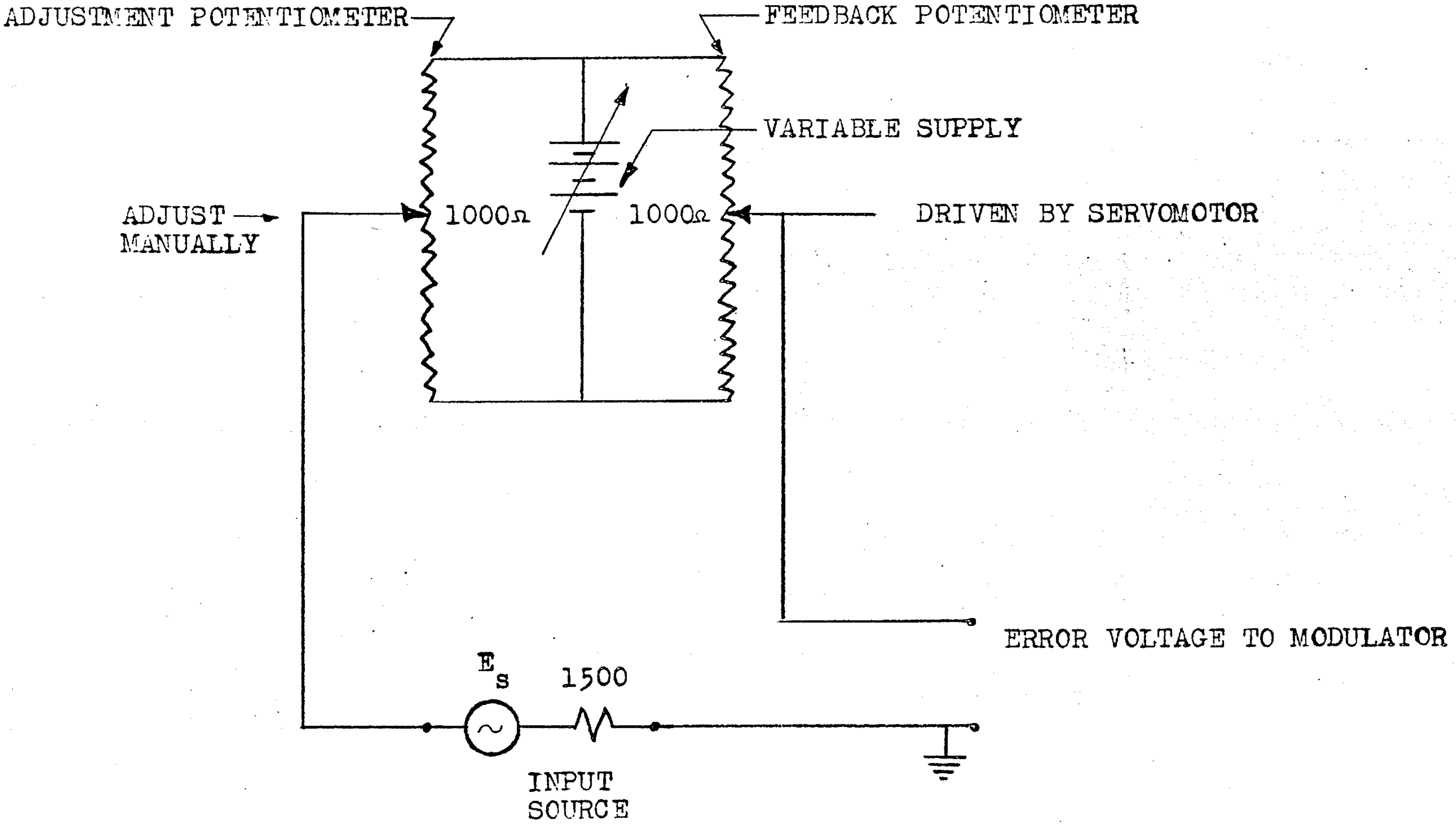


FIGURE 8 TEMPORARY D.C. FEEDBACK SYSTEM

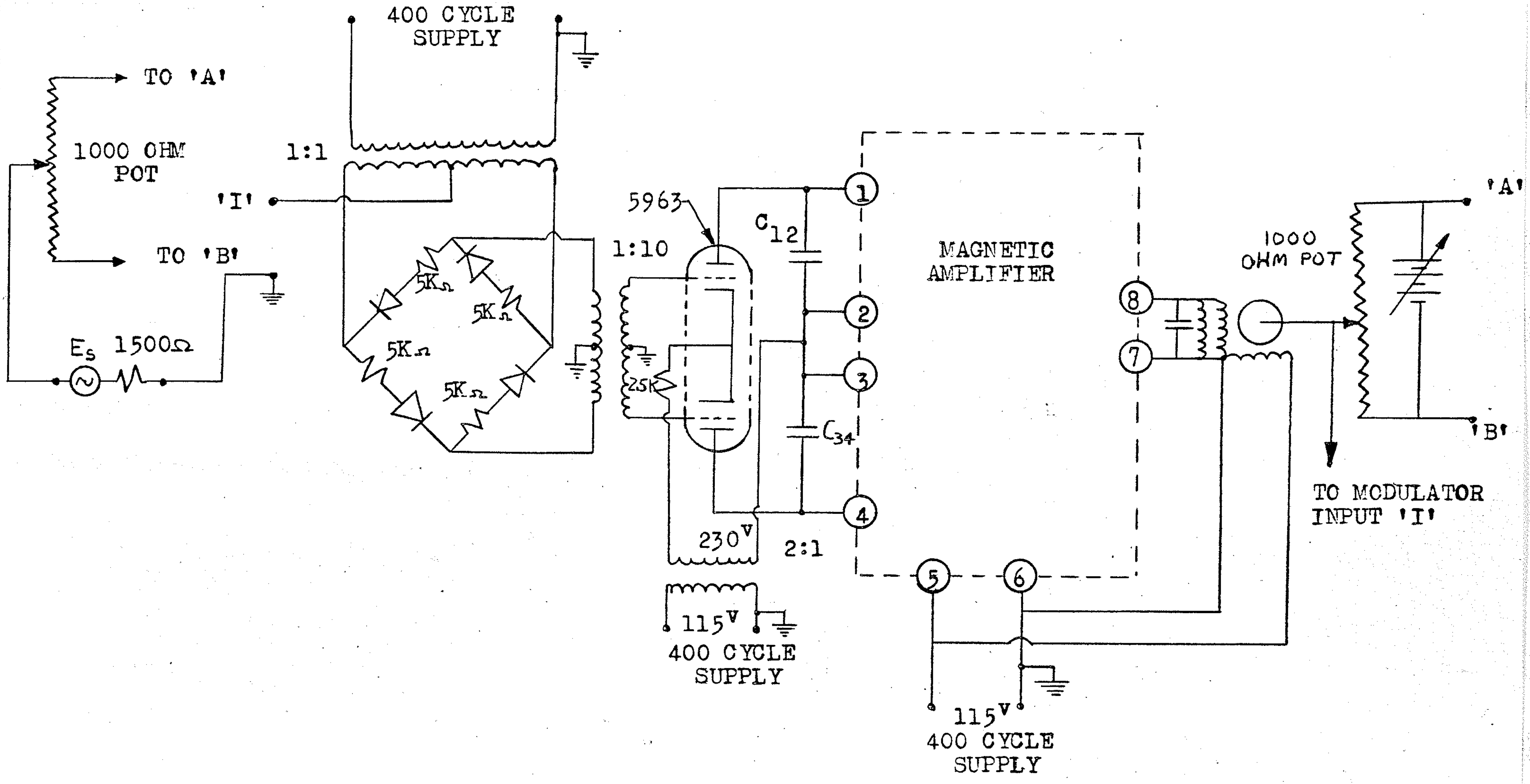


FIGURE 9 THE COMPLETE SYSTEM AS IT WAS FIRST CONNECTED

Consequently the servomotor would have to run at slight undervoltage. This seemed particularly acceptable since the non-sinsoidal waveform to the fixed phase was causing the motor to heat.

It was difficult to zero the motor since transients leaking through from the 400 cycle supply caused the motor to jitter. This was cured by the system of grounding as shown in Fig. 9.

Since the output from the VSWR meter was specified to be 0 to ± 1.5 volts D.C., the control system was now tested with this voltage as input. An oscilloscope showed that the voltage to the control phase was of a different magnitude for the same value of positive and negative input voltage. This asymmetry was traced back to the modulator. All modulator components were checked and replaced but the non-linearity still existed. The problem basically was to zero the motor with zero D.C. input (i.e. input shorted) and at the same time have the control phase voltage equal in magnitude for both positive and negative D.C. inputs, which saturated the system. This necessitated the establishing of independent control over zeroing the motor and over the magnitude of the control phase voltage.

Several biasing arrangements were tried in the circuit of the 5963 tube, but were unsuccessful. Finally it was found that a balance potentiometer placed in the modulator, as can be seen in Fig. 10, corrected the motor zeroing problem. The maximum magnitude adjustment of control phase voltage for positive and negative inputs was solved by placing variable resistors in series with diodes which were back to back in the modulator circuit as can be seen in Fig. 10. Fig. 11 gives a curve of control phase voltage versus D.C. output voltage.

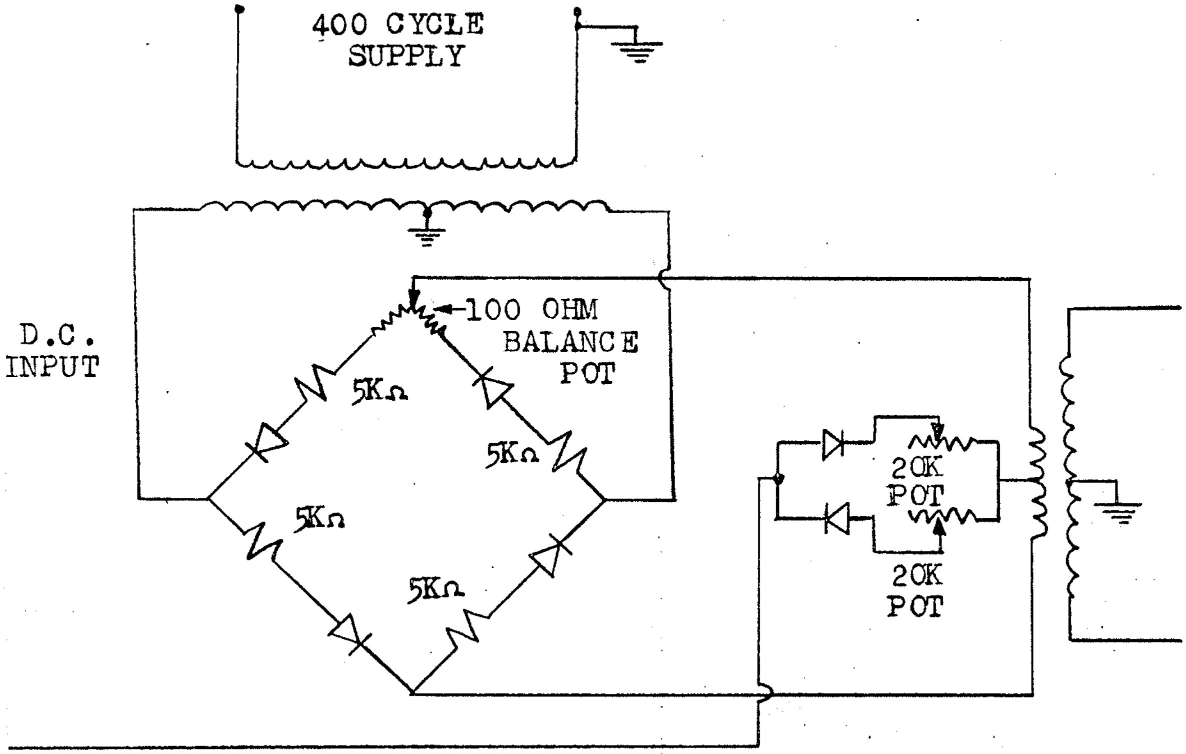


FIGURE 10 MODULATOR CIRCUIT AFTER CHANGES

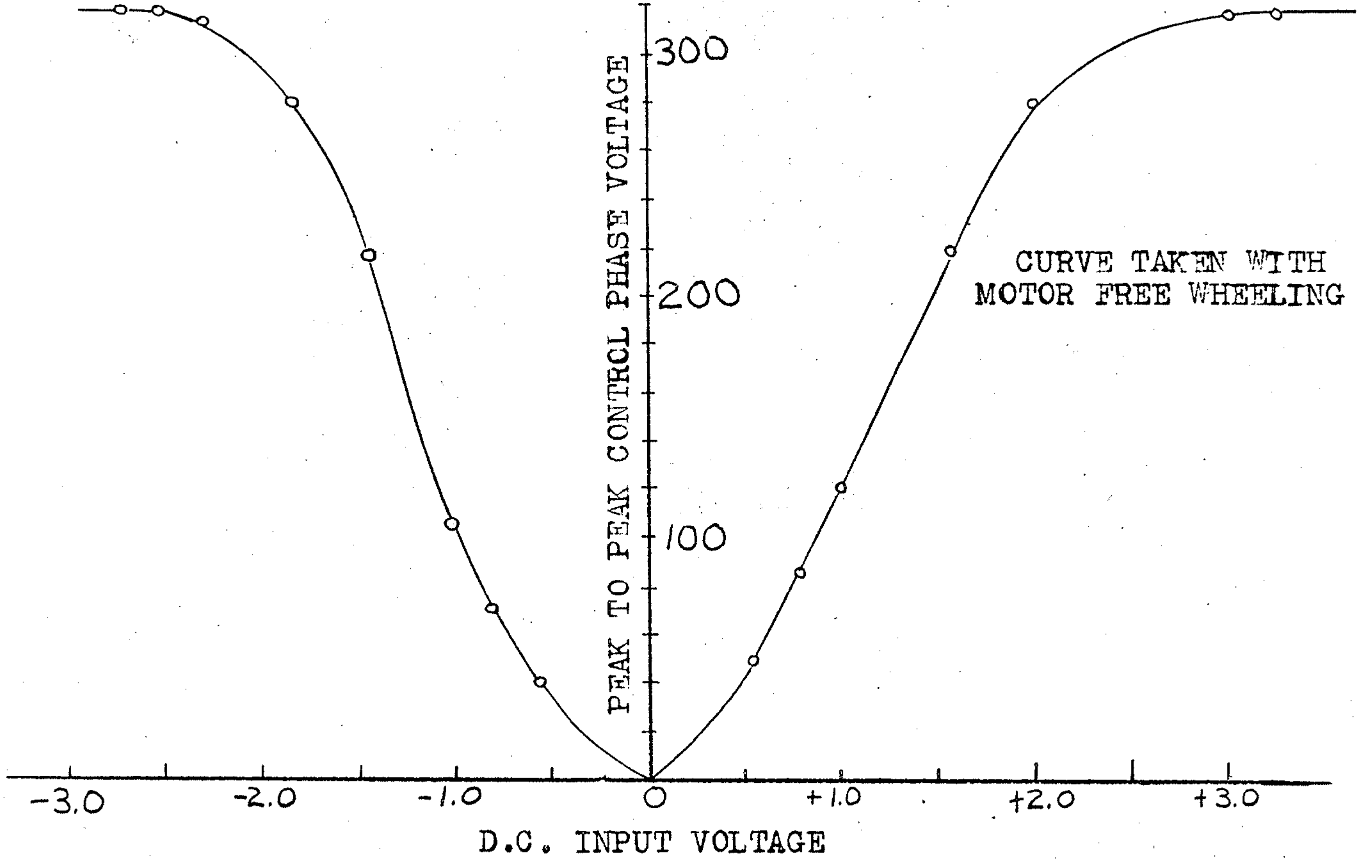


FIGURE 11 D.C. INPUT VOLTAGE VS. CONTROL PHASE VOLTAGE PEAK TO PEAK

Thus independent motor zeroing and maximum value of control phase voltage were established.

However with this new arrangement excessive noise leaked through to the control phase causing motor jitter and a new grounding system had to be instituted, as shown in Fig. 10.

It was found that with these changes, values of C_{12}, C_{34} and C had to be altered to $C_{12}= C_{34}=0.1\mu f$ and $C = 1,8\mu f$ from $C_{12}= C_{34} = .05\mu f$ and $C = 1.7\mu f$. This was again done by the same method as previously stated to obtain maximum motor torque.

The system was then completely connected together using feedback and tested with the attenuator and output and feedback pots as load. It was found to have a critical lack of gain since it was sluggish and displayed no overshoot ot step inputs.

To improve gain several amplifying arrangements were tried in the 400 cycle A.C. section between the 5963 tube and magnetic amplifier. These were unsuccessful however, and finally the Philbrick Model UPA-2 D.C. amplifier was found to be satisfactory when placed in front of the modulator.

When the UPA-2 was set for a gain of about 20, and with a gear ratio of 40/130 x 40/130 = 1.10.6 from motor to translator, a good response was obtained for a step input of 1.5 volts. The value 1.5 volts was used since it was expected that it would cover the complete dynamic range of input voltage. A smaller step input, if large enough to put the motor into saturation, would still give an identical overshoot.