AUTOMATIC RECORDING OF
MICROWAVE FIELD INTENSITIES

by

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TABLE OF CONTENTS.

TABLE OF CONTENTS (Continued).

ABSTRACT.

A method of automatic measurement and recording of intensities in the near-field range of a microwave (X-band) antenna is described.

The measurement is independent of the detector law, and incorporates compensation for fluctuations in the absolute level of the source.

Recordings are possible in linear scales in decibel, relative power, or relative field strength units.

The system is an adaptation of the r.f. substitution method of attenuation measurement. A servo-driven Bowen type attenuator is used as the reference standard. The attenuator settings are translated by a function generator into a voltage analog signal for recording on a strip chart recorder.

ACKNOWLEDGEMENTS.

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LIST OF ILLUSTRATIONS.

CHAPTER 1.

INTRODUCTION.

The detection and investigation of electromagnetic waves at radio frequencies started in the latter part of the 19th century. Experimental work in microwave optics was carried out by Hertz, Bose, Lodge and others. The achievements of these pioneers are reviewed by Ramsay[1].

The only source of r.f. energy available at that time was of the space discharge type. A significant development came when Barkhausen discovered the positive grid oscillator. This type of oscillator is named after him. The concept of interaction of an electron beam and a microwave field has led to the development of other microwave tubes. A thorough survey of microwave tubes is given by Dix and Willshaw[2].

Experimental measurement of radiated fields is essential to the understanding and application of electromagnetic waves. Such measurements are important in the investigations of the behaviour of electromagnetic waves, antenna design procedures, and in the testing and assessment of antennas and radiating systems.

The basic measurements in the microwave range are those of intensity and phase. Through the years a number of measuring devices have been developed to measure these quantities.

The intensity recorder to be described here is to be used in conjunction with Pavlasek's[3] phase plotter. In this device the intensity and phase of a microwave field are recorded simultaneously. The field produced by a microwave radiating system is scanned and corresponding continuous records of phase and intensity, as a function of position, are formed.

The phase plotter is based on the homodyne principle. In this principle an amplitude-modulated suppressed-carrier signal is mixed with a reference carrier. The combined signal is then detected. It has been found that the detector output has the following components:
(a) the fundamental and (b) the harmonics of the modulating frequency. It can be shown that the fundamental varies in amplitude as the cosine of the relative phase angle of the reference r.f. signal. The null occurs when the reference carrier is at quadrature to the original carrier.

In the phase measuring system the r.f. source signal is amplitude modulated at an audio frequency (ω) by a balanced ferrite modulator. This produces a double side-band signal with suppressed carrier. A c.w. carrier is derived from the source by a directional coupler. This reference carrier is passed through a variable phase shifter, and is mixed with the sampled signal. An amplifier tuned to the modulating frequency rejects the harmonics of the detector output. The amplifier output constitutes the error signal of the servo system. The servo-motor drives the variable phase shifter, in such a manner as to maintain the quadrature relationship. A relative phase change in the measured signal is thus compensated for and measured by the servo-driven phase shifter.

A block diagram of the phase plotter is shown in Fig. 1.1.

The intensity recorder described in this thesis is of the r.f. substitution method, and although it was developed specifically for use with the phase plotter it may be used in other applications also. Its principle of operation is illustrated diagrammatically in Fig. 1.2. The r.f. power illuminating the detector is kept at a constant level by a servo-driven attenuator. With the amplitude-modulated suppressed-carrier signal the detector output is of twice the modulating frequency (2ω) if no carrier is reintroduced. Higher harmonics produced by the detector are rejected by a tuned amplifier, whose output is rectified and compared with a reference d.c. level. The reference d.c. voltage is derived by a directional coupler preceding the radiator from the r.f. source. The difference voltage forms the error of the servo system. Basing the reference on the original r.f. source provides automatic compensation for possible changes in absolute level of the source.

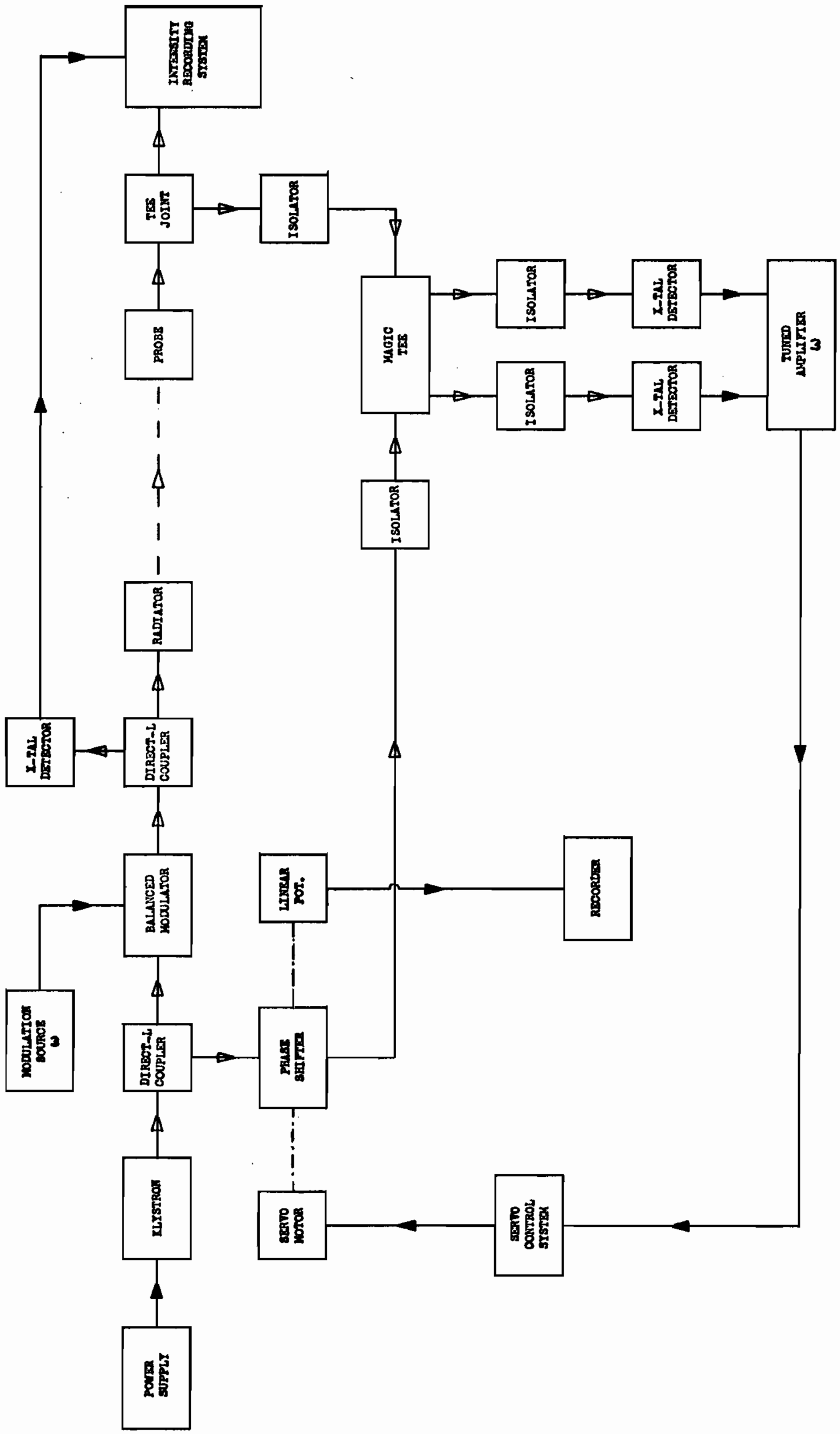


Fig. 1.1. PHASE PLOTTER BLOCK DIAGRAM.

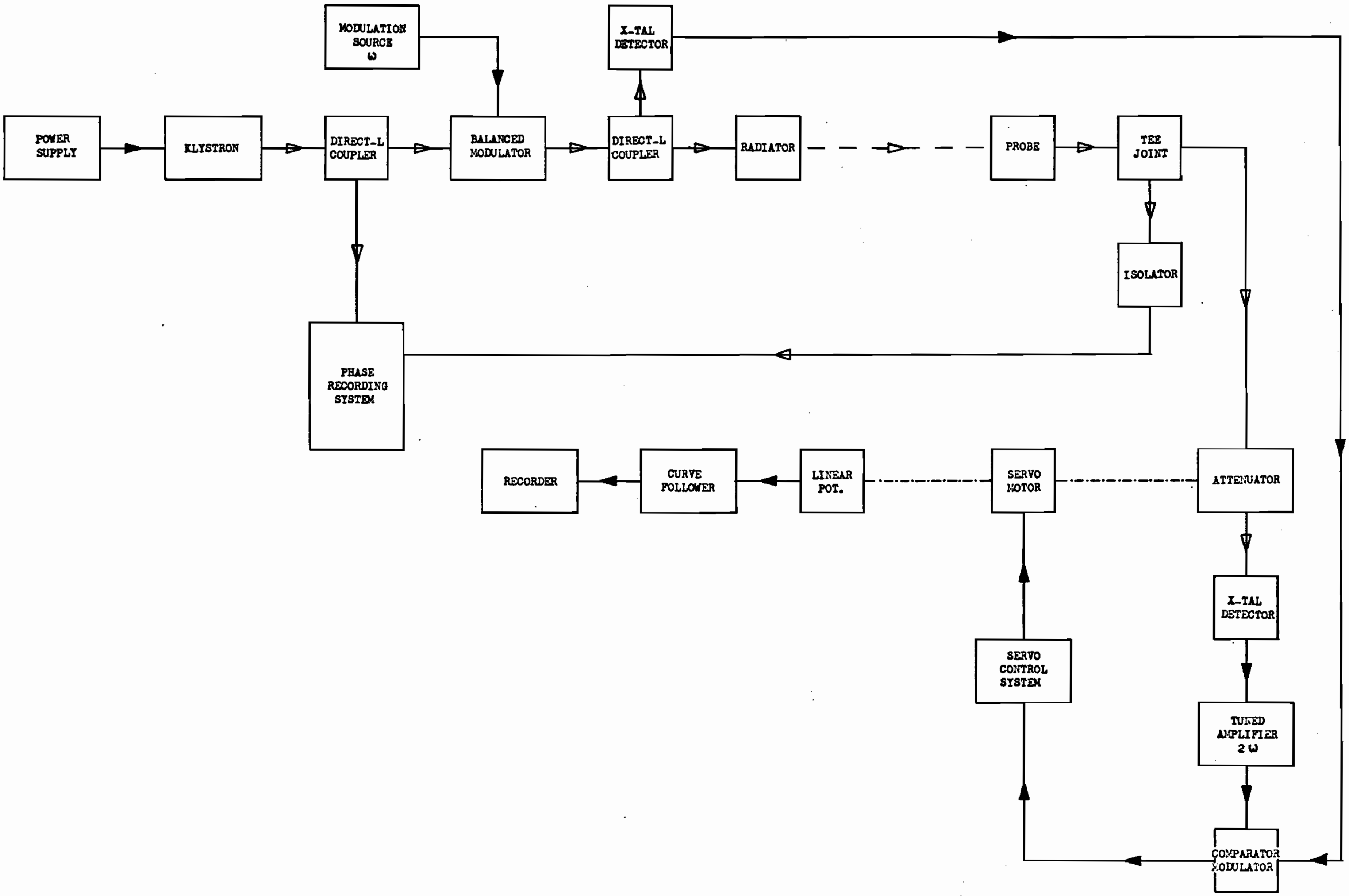


Fig. 1.2. INTENSITY RECORDER BLOCK DIAGRAM.

The attenuator is of the Bowen type which has a known mathematical function of attenuation vs. angular position. The attenuation in db vs. a function of position is as 40 log cos θ. A curve follower is employed to translate the position of the attenuator. Recordings in linear db, linear power and linear field strength are obtained by changing the function curve of the curve follower. These recordings are thus of relative field strength on a logarithmic, linear power, or linear field strength scale.

The constant power system is adopted here to overcome the short-comings of the detector. The crystal diode is used as detector for its high sensitivity, but the nature of the detector law does not affect the measurement.

The range of the recorder is approximately 40 db. Its performance details are considered subsequently.

The intensity and phase recording system is for measurements in the near field of microwave lenses or antenna arrays. The mechanical scanning equipment is capable of producing line scans contained in a volume 30 cms high, 100 cms wide and 130 cms in depth. The system operates at a wavelength of 3.2 cm.

CHAPTER 2.

METHODS OF INTENSITY MEASUREMENTS.

Early experiments at microwave frequencies were concerned only in detecting the presence of the electromagnetic waves. The detectors had different forms. In his experiments Hertz used the spark gap detector. In their receivers Lodge and Fleming had the "coherer" consisting of a glass tube filled with coarse iron filings. A form of semi-conducting detector of a point contact type was first used by Bose. It consisted of rows of spiral steel springs subjected to an adjustable pressure. A small voltage was used for biasing his detector.

As the art of measurement progressed, more stringent requirements had to be met. A range of intensity measuring devices have been developed through the years. Some of the methods used are mentioned in this chapter.

2.1. Field Scattering Method.

Justice and Rumsey[4] describe a method of measuring field intensities by using a dipole scatterer. The method uses a hybrid junction as shown in Fig. 2.1. The collinear arms are terminated in the radiator and a resistive load. The signal source is connected to the E-arm and the receiv-

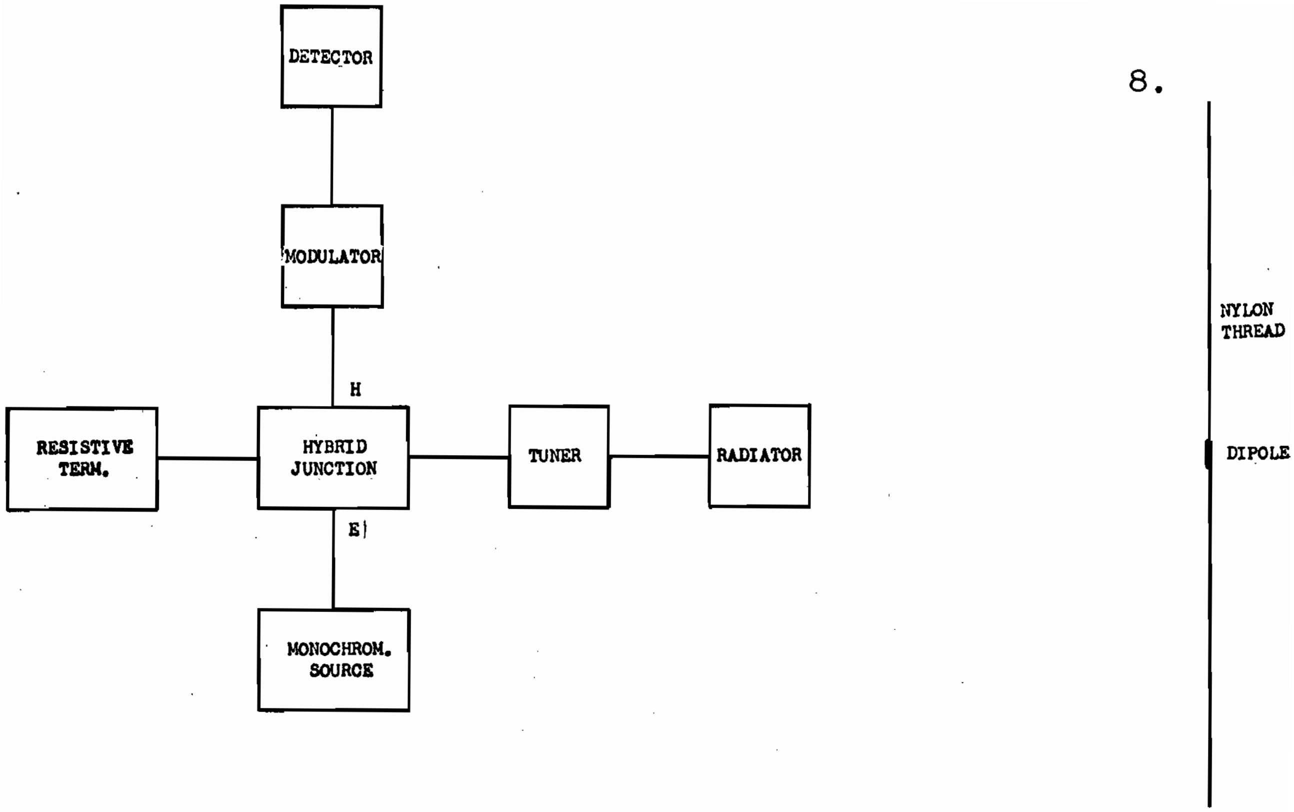


Fig. 2.1. FIELD SCATTERING SYSTEM.

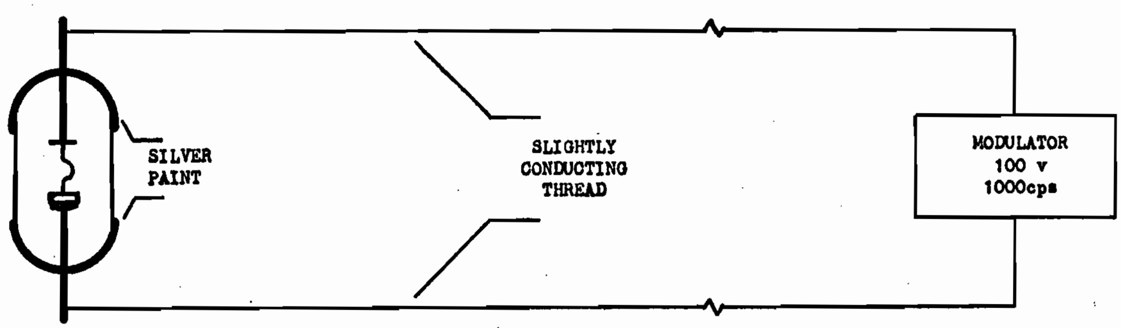


Fig. 2.2. MODULATED DIODE SCATTERER.

er to the H-arm. Separation of source and receiver has to be about 90 db. This requires the source to be as nearly monochromatic as possible. The scattering produces a reflected wave at the radiator input terminal. The reflected wave enters the E-branch of the hybrid. It is passed through the modulator and is detected.

It may be shown that the voltage produced at the receiver with the scatterer at a given position is proportional to the square of the tangential electric field strength (the component parallel to the scatterer) at the same position in the absence of the scatterer. This requires the length of the dipole to be one-half wavelength or less. To discriminate against orthogonal polarization it has been found that the length to diameter ratio must be 30 or better. The absence of a cable connected to the scatterer improves on the field distortion.

The size of the dipole makes it possible to carry out electric field intensity measurements in waveguides.

A modification to the above system is given by Richmond[5]. He modulates the reflected wave at the dipole. A nonlinear impedance (diode) is placed in the center of the dipole. The modulating audio voltage is applied to it through slightly conducting threads (Fig. 2.2). This modification reduces the required hybrid junction isolation by 55 db.

Silver paint is applied over a small area of each end of the glass envelope of the modulated diode to resonate the dipole to the operating frequency.

This method is not compatible, in the present application, with the phase measuring equipment. Moreover the dipole with its thread support requires too delicate a scanning mechanism.

2.2. Calorimetric Method.

The basis of this method is to dissipate all the incoming power in some convenient medium and to determine the resultant effect by ordinary calorimetry. The use of a matched termination enables the use of the power measurement as field strength indication.

Calorimeters for the measurement at the lower portion of the microwave power range have been developed in recent years. The analysis and design of one type are given by Sucher and Carlin[6]. James and Sweet[7] describe its construction and performance. Several models have been built covering a frequency range of 0 to 75,000 mc. These meters are intended for use as standards of microwave power measurement in the milliwatt range. They are of the nonadiabatic, twin dry-load type. The substitution of d.c. power is utilized. The thermopile is employed as the temperature sensor.

The minimum detectable power ranges from several tenths of a microwatt to 5 microwatt. The overall accuracy is $\pm$ 1 % to $\pm$ 2 %. Thermopile output is found to be from

23 μv to 51 mv per milliwatt, and the time constants are from 1 to 4 minutes.

The method does not lend itself to automatic operation with its low sensitivity and long time constant.

2.3. Audio Voltage Measuring Method.

Automatic recorders based on this method are described by Tyson[8], and Tiley[9]. Fig. 2.3 shows a block diagram of the system. The system depends on square-law detectors. The detected audio signal is passed through a tuned amplifier. Its output is connected to a nonlinear potentiometer. The tap-off voltage is amplified and compared with a constant voltage. The difference voltage is the error signal actuating the servomechanism. The latter drives the nonlinear potentiometer tap-off to such a point as to reduce the difference voltage to zero.

A more sophisticated version is given by Hamer and Foot[10] (Fig. 2.4). In their system the source signal is modulated at a high audio frequency. A preamplifier is used to increase the detector output level. Its output is then compared with the output of a standard local oscillator of identical frequency. Gate switching is utilized. The switching frequency is that of the power mains. If the two signal levels are different, there will be a power frequency component after demodulation of the tuned amplifier output.

This component is then fed into the servo control

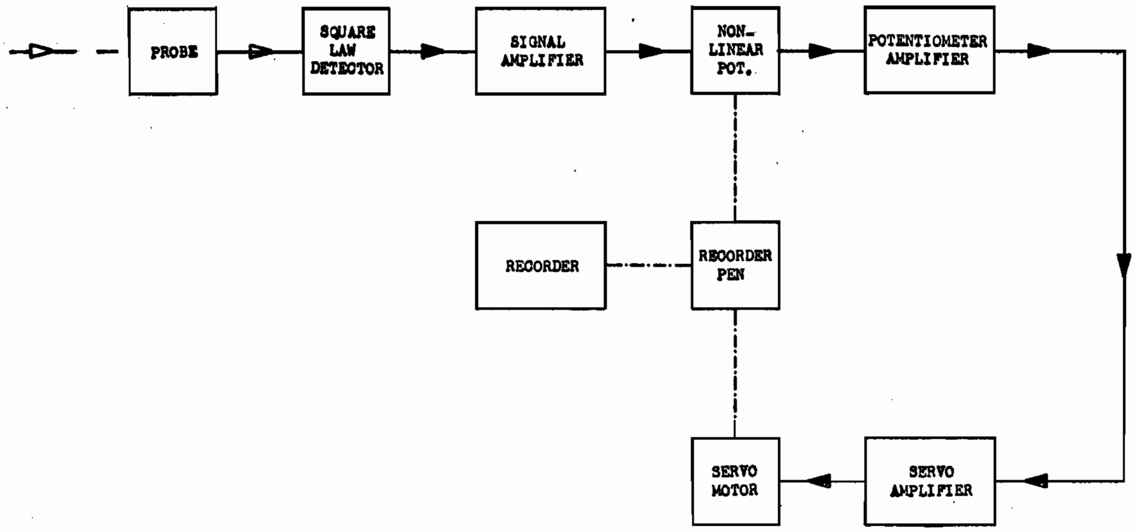


Fig. 2.3. AUDIO VOLTAGE ANTENNA PATTERN RECORDER.

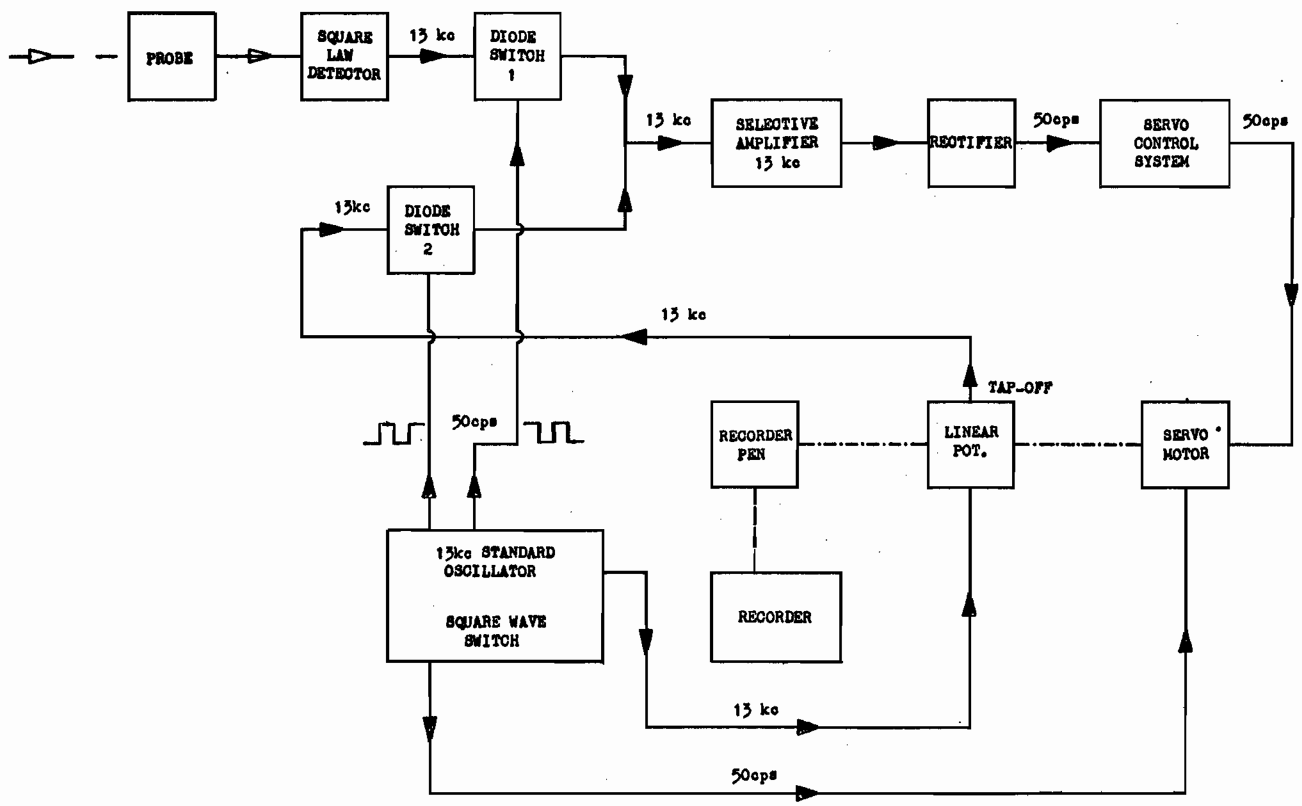


Fig. 2.4. AUDIO COMPARISON INTENSITY RECORDER.

system.

The servo-motor drives the potentiometer adjusting the output of the local oscillator. The position of the potentiometer tap-off is recorded as the measured field intensity.

The system here depends on the square-law characteristic of the detector from which the crystal diode deviates. Bolometers have very good square-law characteristics. They, however, have lower sensitivities.

2.4. Heterodyne Method.

A method using the r.f. carrier wave rather than the audio-modulated output of a square-law detector is reported by Symonds[11]. In this method a calibrated i.f. attenuator is employed. The source can be either c.w. or modulated. A local oscillator and a mixer are required here (Fig. 2.5). The i.f. signal is passed through the calibrated attenuator and is amplified. It is then detected and compared with a reference voltage. The difference voltage is used to control the servo-motor. The latter drives the calibrated attenuator.

Limitation to this method arises from the necessity of having a local oscillator and mixer. The mixer is often not linear.

2.5. Substitution Method of Attenuation Measurement.

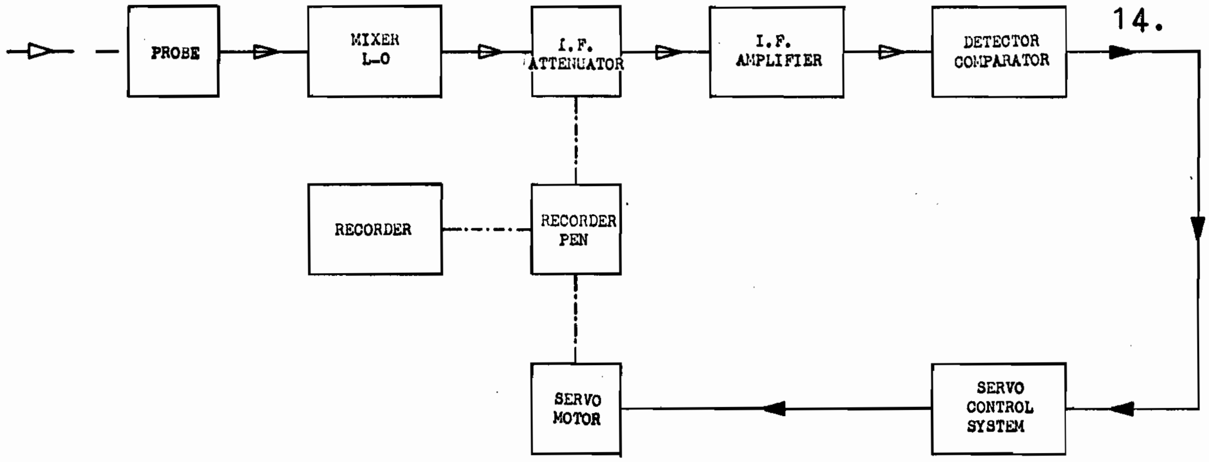
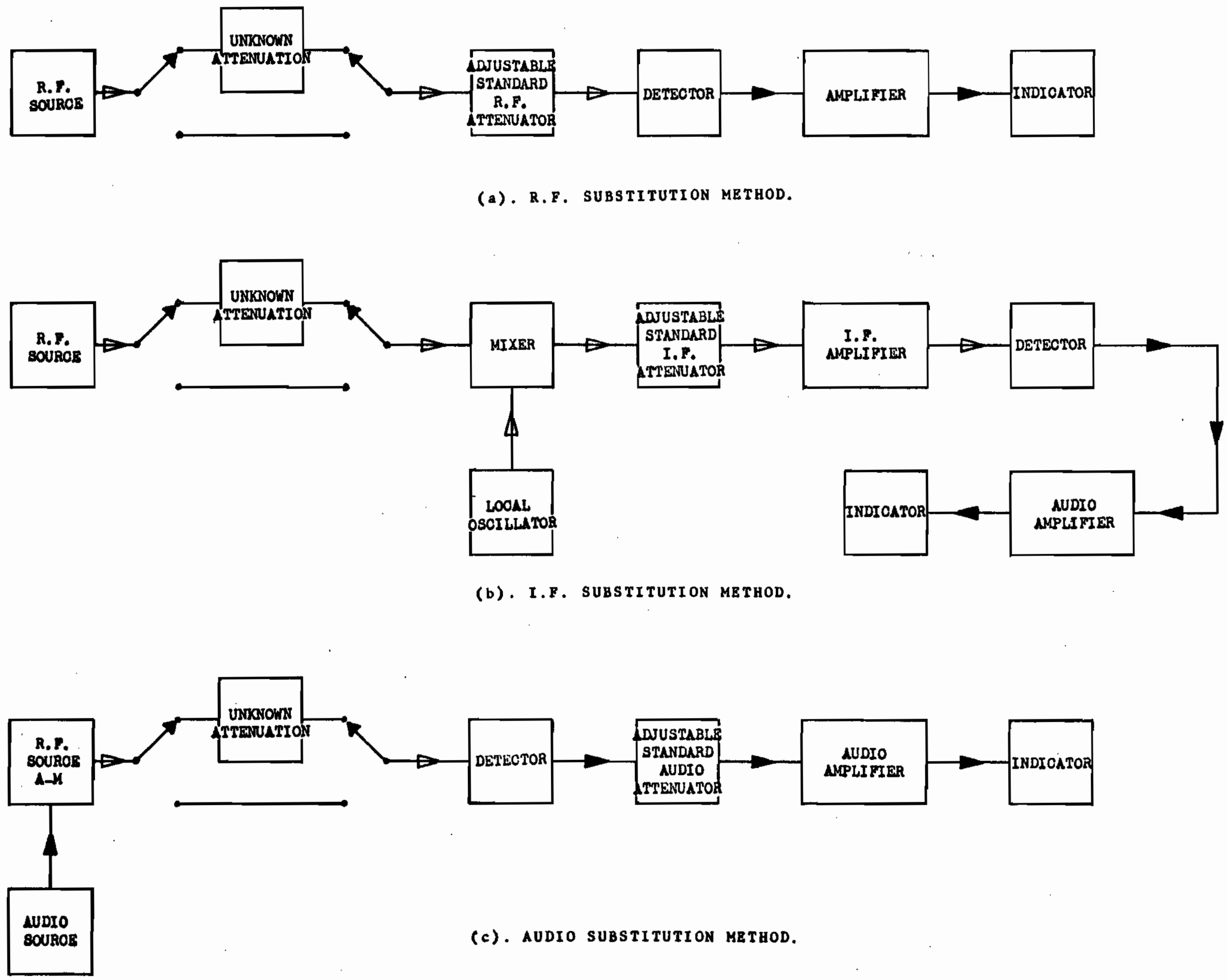


Fig. 2.5. HETERODYNE ANTENNA PATTERN RECORDER.



(a). R.F. SUBSTITUTION METHOD.

(b). I.F. SUBSTITUTION METHOD.

(c). AUDIO SUBSTITUTION METHOD.

Fig. 2.6. SUBSTITUTION METHOD OF ATTENUATION MEASUREMENT.

2.5. Substitution Method of Attenuation Measurement.

Reviewing the substitution method of attenuation measurement[12] it is found that sections 2.3 and 2.4 conform with the audio and i.f. substitution methods respectively (Fig. 2.6). The electric field intensities are measured in terms of attenuation settings.

The r.f. and i.f. substitution techniques offer the greatest possible accuracy. In both cases the detectors are illuminated by a constant r.f. power wave. This means that no stringent requirements are put on the characteristics of the detectors.

The audio substitution method places high accuracy requirements on the response law of the detector in the range of measurements. The i.f. substitution system is independent of the response of the detector, however, it requires a local r.f. oscillator and depends in its accuracy on the linearity of the mixer. The insertion of an active element in the r.f. link makes the system complex, and it would affect its stability over extended periods of time. The availability of stable precision r.f. attenuators makes the r.f. substitution technique readily adaptable to automatic operation. Its independence of detector characteristics makes this method attractive. It has therefore been adopted for the intensity recording system described in this thesis.

CHAPTER 3.

INTENSITY MEASURING SYSTEM.

The system of field intensity measurement described here is based on the r.f. substitution method as mentioned in section 2.5.

In this method the r.f. wave is passed through both the unknown attenuating system and a calibrated r.f. attenuator. In the basic method the unknown attenuating system is then removed and the detector output restored to its original level by adjusting the calibrated attenuator. The difference of the setting of the attenuator is the insertion loss of the unknown attenuating system.

The measurement in this method is done by restoring the r.f. power at the detector to a reference level. This means that the system is independent of the detector characteristic. The detector is operated at a constant point.

The audio voltage measuring method of section 2.3 on the other hand hinges on the square-law characteristic of the detector, which can be either a bolometer or a crystal. Investigations have been carried out on the deviation of these detectors from their square-law characteristics. Papers to this effect have been written by Carlin and

Sucher[13], Sorger and Weinschel[14], and Staniforth and Craven[15].

The r.f. substitution method has been adapted to the field intensity measuring system. The removal of the unknown attenuator, however, is replaced by varying field intensities as sampled by the probe moving through the radiated field, which has some space pattern.

3.1. Manual Operation (Fig. 3.1).

The r.f. substitution method is preserved in its original form in the manual operation of the system.

In this operation the calibrated attenuator is adjusted manually to restore the detector output to a selected reference level. The output is indicated on the meter at the tuned amplifier 2ω. As mentioned in chapter 1 the radiated r.f. wave is a suppressed-carrier amplitude-modulated signal. Thus the fundamental of the detector output is twice the modulation frequency. The harmonics are rejected by the tuned amplifier.

It is quite obvious that the measurements are in relative units of intensity. By means of calibration curves the intensity measurements can be expressed in terms of logarithmic, relative power or in relative electric field strength units.

This method of measurement depends primarily on the calibrated attenuator. A description of the attenuator

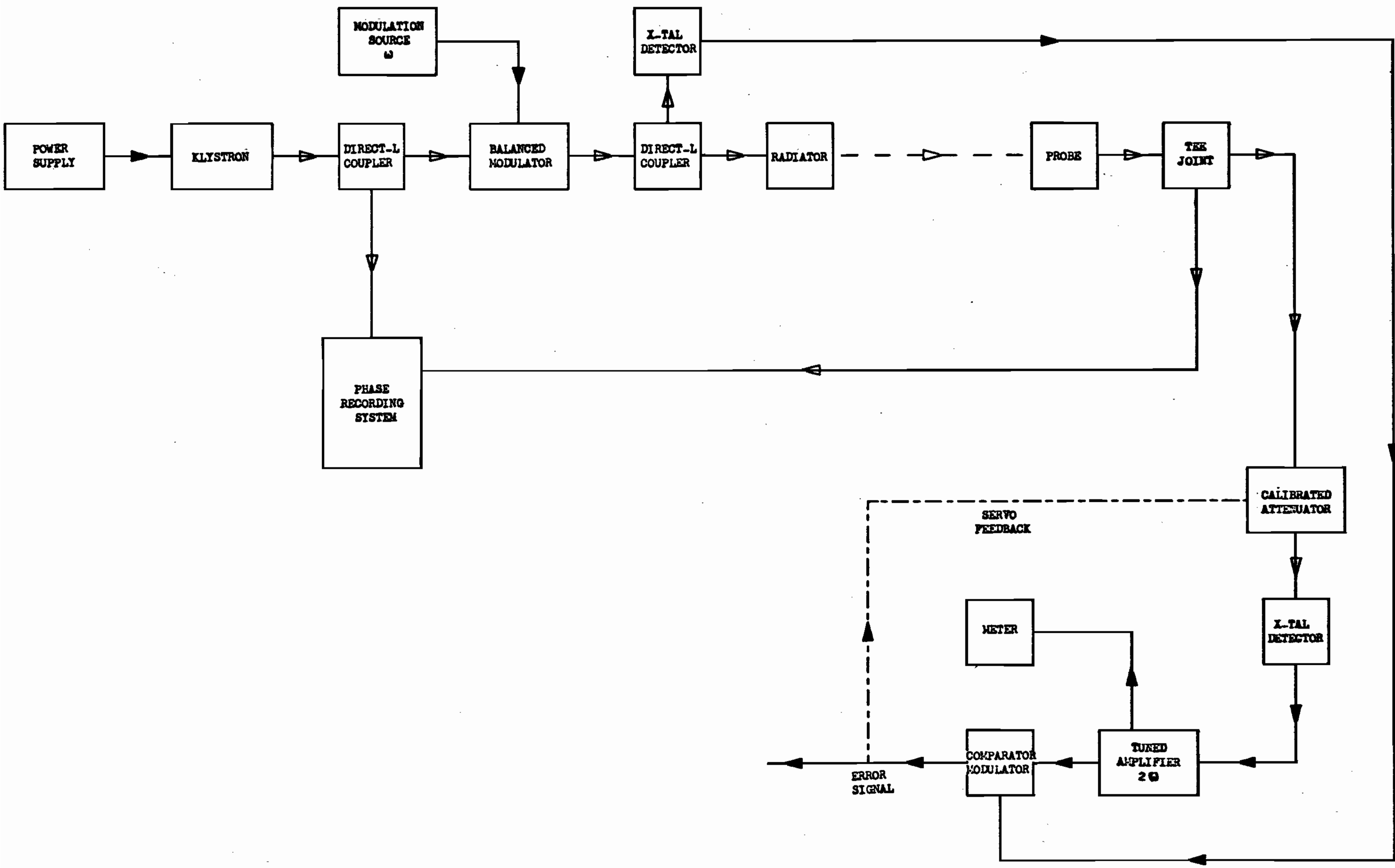


Fig. 3.1. R.F. SUBSTITUTION METHOD OF INTENSITY MEASURING SYSTEM.

used in this system appears below.

3.2. Automatic Operation.

The system described is adapted to automatic operation by making the attenuator servo-driven. The servo-motor is used to drive the attenuator to maintain the r.f. power at the detector at a constant level. The error signal actuating the motor is the difference of the detector output level and a reference derived from the r.f. source. Recordings of field intensities can then be made in terms of attenuator settings.

The automatic system is shown in Fig. 3.2 in block diagram. A functional description of the system is given here.

The tuned amplifier 2ω is employed to raise the level of the detector output. It is tuned to the fundamental frequency of the detected signal. The selectivity increases the signal to noise ratio of the detected signal. It thus improves the sensitivity of the detector allowing detection of lower power levels.

The output of the tuned amplifier is rectified and compared with a reference voltage. The latter is derived from the r.f. source using a directional coupler preceding the radiator. A null is obtained, when the rectified signal and reference voltage are equal. As the two voltages are subjected to similar rectifying networks, any fluctuation

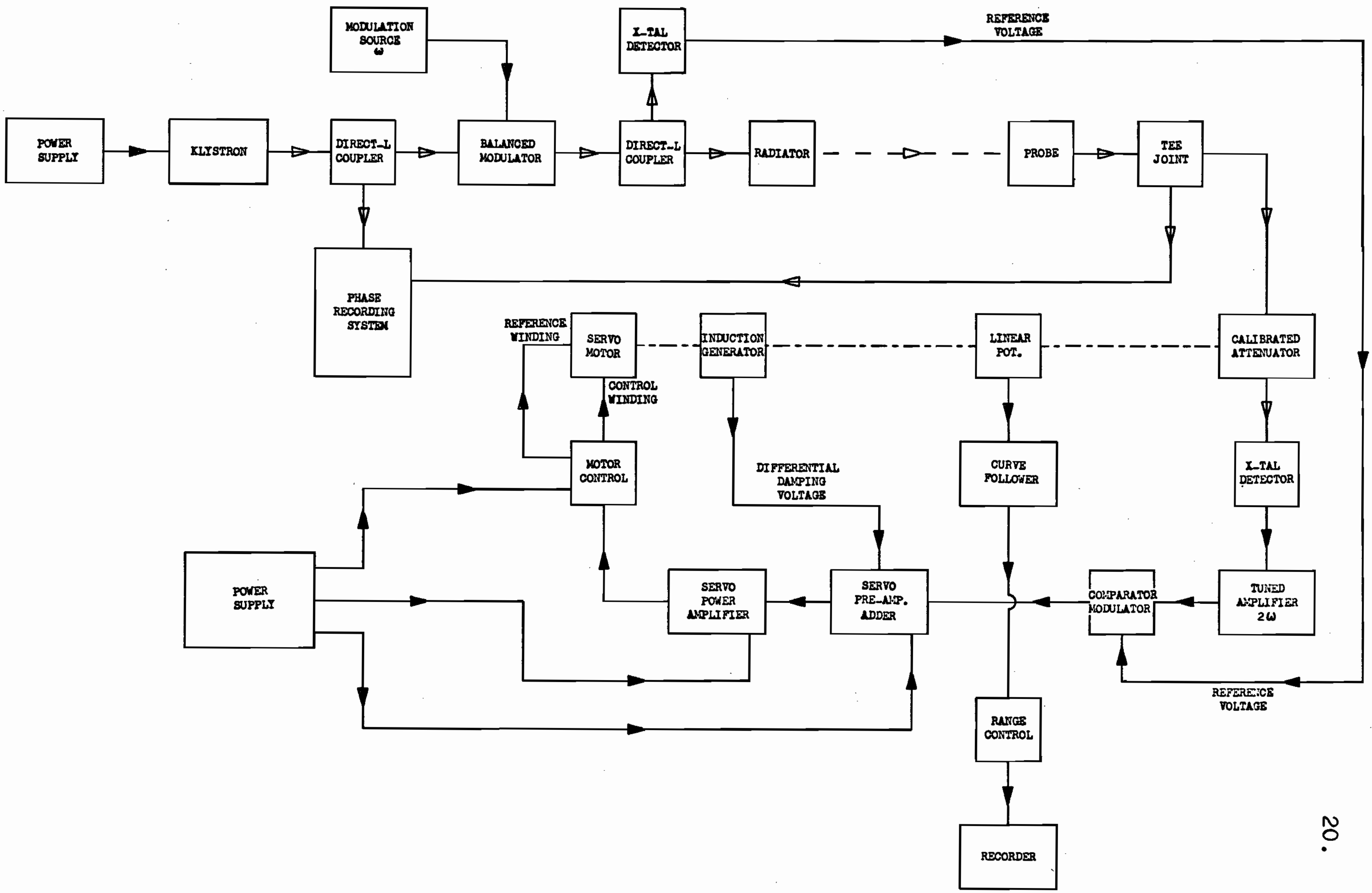


Fig. 3.2. AUTOMATIC INTENSITY RECORDER.

in the absolute level of the r.f. source tends to be compensated.

The difference of the two voltages provides the error signal actuating the servo-motor. As a 60 cps servo-motor is used the error signal is chopped at that frequency using a SPDT chopper as a gating switch. The output terminal is alternately switched to the two input terminals at a repetition rate of 60 cps. Comparison and modulation are therefore achieved simultaneously. There is no problem of polarity as the error signal changes through 180° ac-wise with the change of r.f. power at the detector from higher to lower than the reference level and vice versa. The servo system is thus self null seeking.

Derivative damping is used in the servo control system. The damping voltage is taken from an induction-generator, which is integrally coupled to the servo-motor.

In the servo preamplifier both the error signal and the derivative damping signal are passed through identical amplifying circuits. Both signals are combined at the output through an audio transformer. Phase shift control of the damping signal is provided at the input of its amplifier part. The error signal gain and phase may be adjusted at the servo power amplifier.

The servo-motor control panel is for monitoring the motor supplies. The reference winding excitation is provided through an isolating transformer at this panel. This is to facilitate a common ground for both winding supplies. The servo-motor drives the calibrated attenuator, on which the measuring system hinges.

The attenuator used here is of the rotary type, whose invention is attributed to the late A. E. Bowen. This type of attenuator obeys a mathematical law. The functional description of the attenuator is given by Southworth[16], and Hand[17]. The attenuator consists of three wave-guide sections. Resistive films are placed across the guide in each section with the E field of the r.f. wave normal to them. The middle section is a circular guide, which is freely rotatable with respect to the two fixed end sections, which are rectangular-to-round transitions. With the films aligned, i.e. normal to the E field of the wave, no attenuation occurs. The attenuation in logarithmic (db) units as a function of the angle θ of the center film with respect to its aligned position is as 40 log cos θ. This is easily shown by assuming that the component of the E field tangential to the plane of the film is absorbed completely. The E field is resolved into its normal and tangential components in the center section and again in the third when the center section is turned from its aligned position. Thus absorptions take place in the films of both guide sections. Practical limitations to the above assumption result in the usable calibratable range of 50 db.

Prior to recording, the attenuator setting has to be translated into the desired units of field intensity. This can be achieved by using a suitable function generator. to facilitate experimental development a curve follower is employed for the translation, because it was readily available and the function to be generated can be altered easily. The attenuator setting is passed on to the curve follower input by means of a linear potentiometer, whose tap-off is driven by the servo-motor. Different modes of recording are obtained by changing function-curves of the curve follower. Thus experience in recording at different modes can readily be gained. As experience is gained regarding to preferred modes, potentiometers wired to fixed functions can be substituted. They would replace the servo-driven linear potentiometer. Specifications of the function potentiometers for the different modes are listed in the appendix.

The change in intensity of the measured field is a result of moving the probe in the field to be recorded. It is therefore necessary to record both the intensity and the probe position. The latter is transmitted to the recorder by a Selsyn generator and motor combination. This synchronizes the paper feed of the recorder with the movement of the probe. The resolution of recording in logarithmic units has a spread from 4 db/cm to ½ db/cm. The choice is done at the range control, which supplies the different voltages to the curve follower output potentiometer.

The functional description of the system and its components has been dealt with in this chapter. The next chapter gives the details of the different components.

CHAPTER 4.

DETAILS OF SYSTEM COMPONENTS.

This chapter deals with the details of the components, whose functional description is given in chapter 3.

It has been pointed out in chapter 1 that this intensity recorder is to be used in conjunction with an existing phase plotter. The basic mechanical arrangement of the system is retained, and only minor changes are made, where required, without upsetting the system.

4.1. The Microwave Source.

It has been found necessary to have a high output klystron as the microwave source. This is evident by considering the r.f. substitution method (Fig. 2.6), which forms the basis of the system of intensity recording. The range of attenuation measurement in this method is directly proportional to the maximum attenuation of the r.f. signal possible with a detectable output. This range can be increased with the following schemes.

(a) A higher level of the radiated power,

(b) amplification of the sampled r.f. signal.

Scheme (b) requires a linear microwave amplifier over the level range of the system. It would make the system too complex and expensive. Furthermore there are the usual noise limitations to the increased sensitivity.

Scheme (a) is the preferable alternative. There are two ways in achieving this.

The modulated microwave signal could be amplified. However such a system is again costly and complex.

The second method consists simply of increasing the c.w. output of the primary microwave source. A Varian V63 double resonator klystron operating at 9358.5 mc/s and having a power output of 6 watts is used.

The power supply used for this klystron is a PRD type 812.

As a direct consequence of the increased c.w. level it has been found necessary to introduce a second ferrite isolator at the Tee junction branch-off to the phase measuring system (Fig. 1.1). This is dictated by the necessity of reducing the reference carrier leakage into the intensity measuring system to a tolerable level.

4.2. Scanning Mechanism (Fig. 4.1).

This mechanism is retained in its entirety. The probe here is mounted on an optical bench, which enables scanning in a direction parallel to the screen. The bench itself is on rails, allowing it to be moved perpendicularly to the screen. Provision is also made for the vertical positioning of the probe manually.

A lead-screw is used for the scanning movement of the probe along the optical bench. A d.c. motor is employed to drive the lead-screw, allowing the scanning speed to be varied as required.

With these arrangements measurements of the unknown field can be made within a space of about 100x30x130 cms; with two of the co-ordinates adjusted manually between scans.

The probe position is transmitted to the intensity and phase recorders by means of Selsyn generator-motor sets, which are coupled to the lead-screw. The Selsyn motor replaces the constant speed motor of the recorder (Varian type G10). The rate of chart feed is thus in accord with the scan speed of the probe.

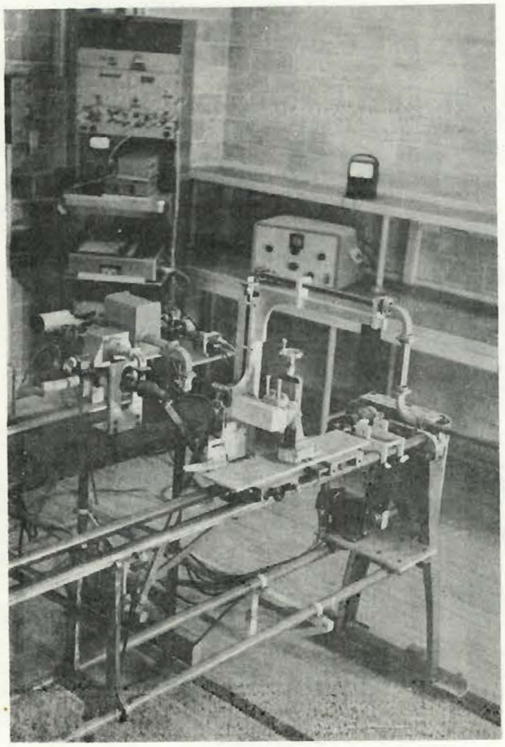
4.3. Recording Assembly.

4.3.1. Attenuator Assembly (Fig. 4.2).

A Hewlett-Packard type X382A Precision Attenuator is used as the calibrated r.f. attenuator. Its calibrated range is 50 db with an accuracy of $\pm$ 2 % and a phase shift variation of less than 1^{o}.

The attenuator has been mechanically adapted to be servo-driven by a Diehl type FPE-25-11 60 cps motor. An induction-generator is integrally coupled to it, providing derivative damping of the servo system.

The motor also drives a Spectrol type 810 2000



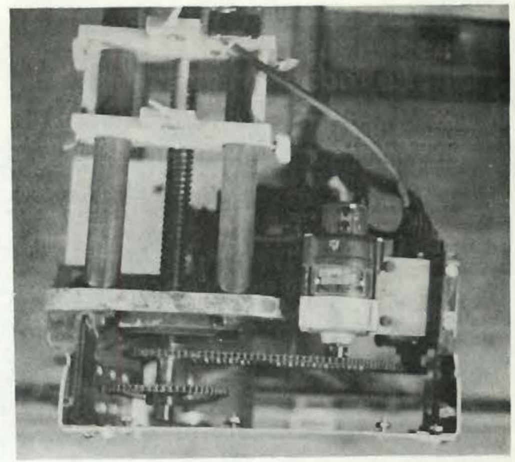


Fig. 4.1. Optical bench and scanning mechanism (left). Lead-screw drive arrangement with 2 Selsyn generators (above).

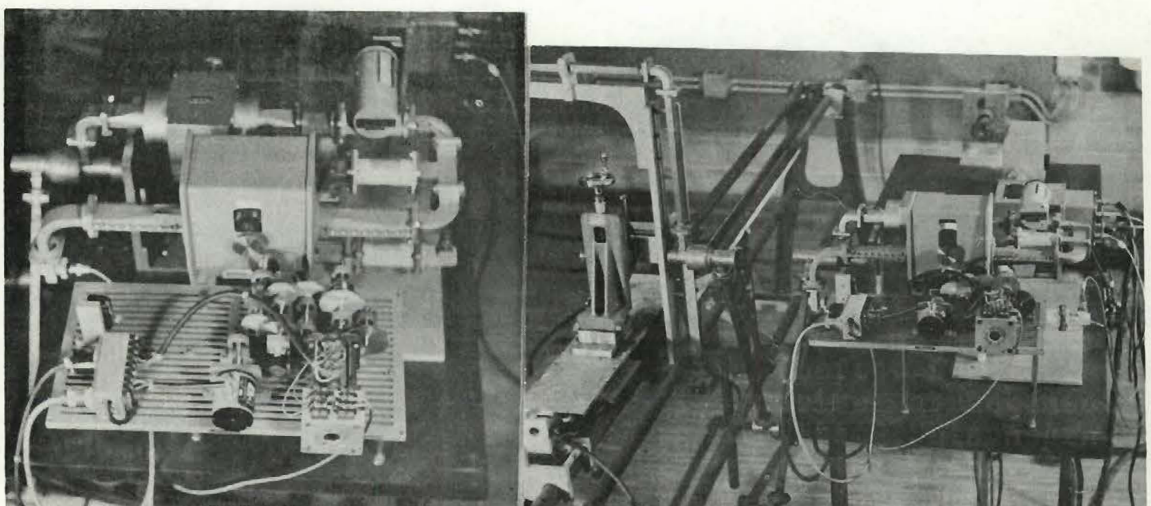


Fig. 4.2. Attenuator assembly with linear potentiometer (left), and in relation to the general lay-out (right).

ohm linear potentiometer, from which is derived a signal indicating the attenuator setting.

4.3.2. Curve Follower.

A Moseley Autograph X-Y Recorder model 3 is used in its curve follower function. As a fine copper wire is used instead of conducting ink for tracing the function curves, a 1000 ohm resistor has been connected in the adapter in series with the curve.

4.3.3. Recorder Range Control (Fig. 4.3).

This is essentially a precision voltage divider. The d.c. voltage is supplied by a Lambda Regulated Power Supply. The recorder scale is adjustable in accordance with one of the following scales.

Range setting	Full scale range	db/cm
8	48 db	4
4	24	2
2	12	1
1	6	½

Connection for an external precision resistor is furnished for the adjustment to any other desirable scale factor.

The range control allows overall coarse grain

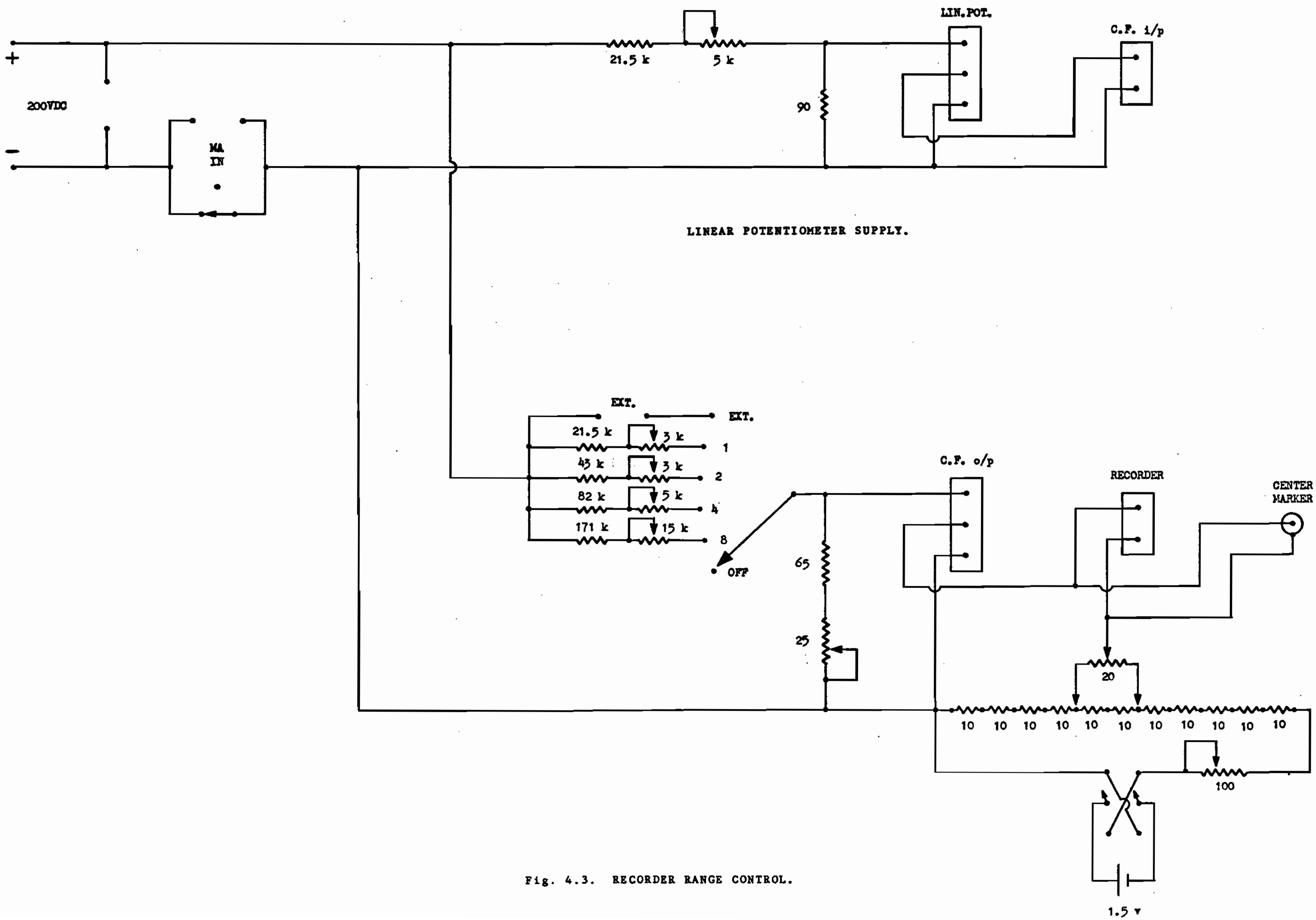


Fig. 4.3. RECORDER RANGE CONTROL.

measurements or fine scale examination of specific regions as may be required.

4.3.4. Recorder.

The x-y recorder used here is a Varian model G10. Its linear time chart drive motor is replaced by a Selsyn motor for the indication of the probe position, thus making it an x-y recorder.

4.4. Servo Control System.

4.4.1. Preamplifier (Fig. 4.4)

Inputs for both error and derivative voltages are provided. The voltages are summed at the output transformer. Isolation of the primary windings is provided by the 100k ohm series resistors, thus reducing interaction between them by effectively driving the primaries by an equivalent current source.

The derivative signal has a phase shift control, and each signal is separately adjustable in magnitude. The error and derivative signals are to be monitored at the amplifier output terminals.

4.4.2. Servo Amplifier.

The servo amplifier used is an Industrial Control Co. type 410-A 60 cps Servo Amplifier with independent gain and phase shift controls, and an antihunt (rate control)

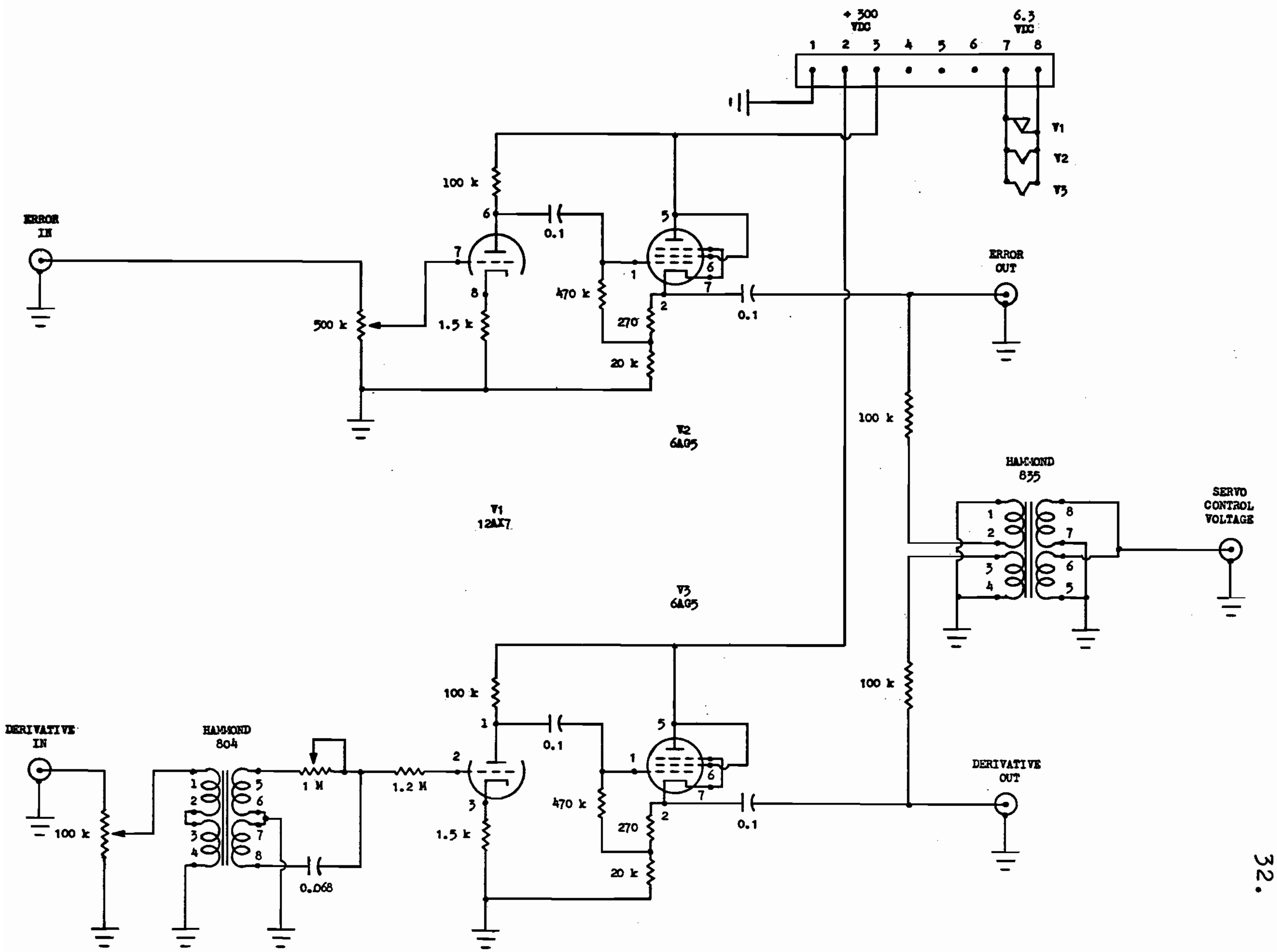


Fig. 4.4. PREAMPLIFIER CIRCUIT DIAGRAM.

network.

4.4.3. Power Supply (Fig. 4.5).

This panel supplies the power and filament voltages to the preamplifier and the servo amplifier.

Filament voltages are also supplied to the isolating transformer of the motor control panel and to the chopper of the comparator-modulator.

4.4.4. Motor Control Panel (Fig. 4.6).

A DPDT 115 VAC relay is used to switch the reference and control voltages from the motor to resistor terminations. Remote control of the relay is achieved by supplying its excitation externally.

Monitoring terminals may be switched to either the reference or the control voltage at either position of the relay.

A filament transformer with the windings reverse-connected serves as an isolating transformer for the reference supply voltage.

4.5. <u>Error Detecting Assembly</u>.

4.5.1. Tuned Amplifier.

A Hewlett-Packard model 415B Standing Wave Indicator is used as a selective amplifier. It is tuned to 800 cps and has a bandwidth of 40 cps.

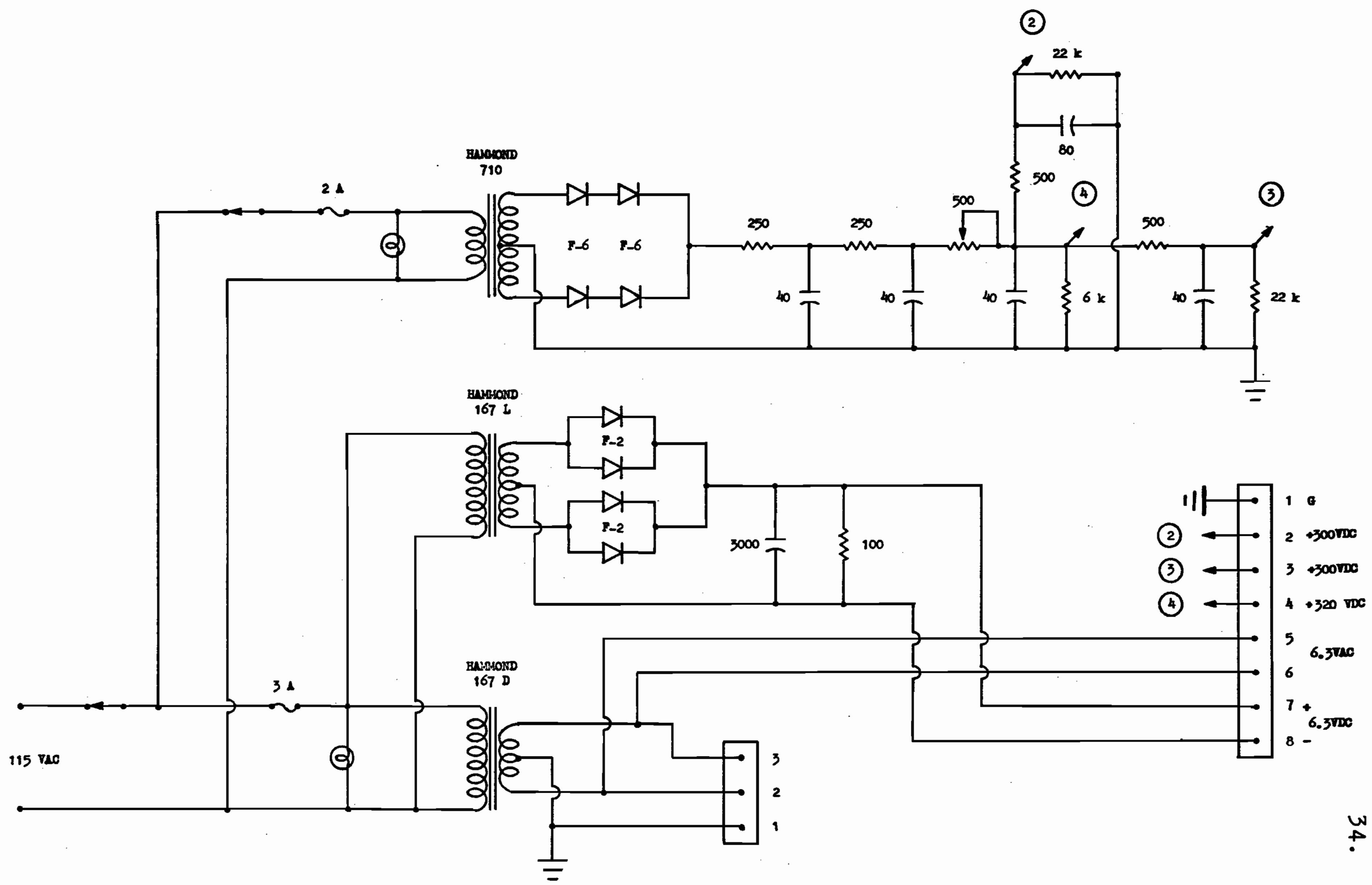


Fig. 4.5. POWER SUPPLY CIRCUIT DIAGRAM.

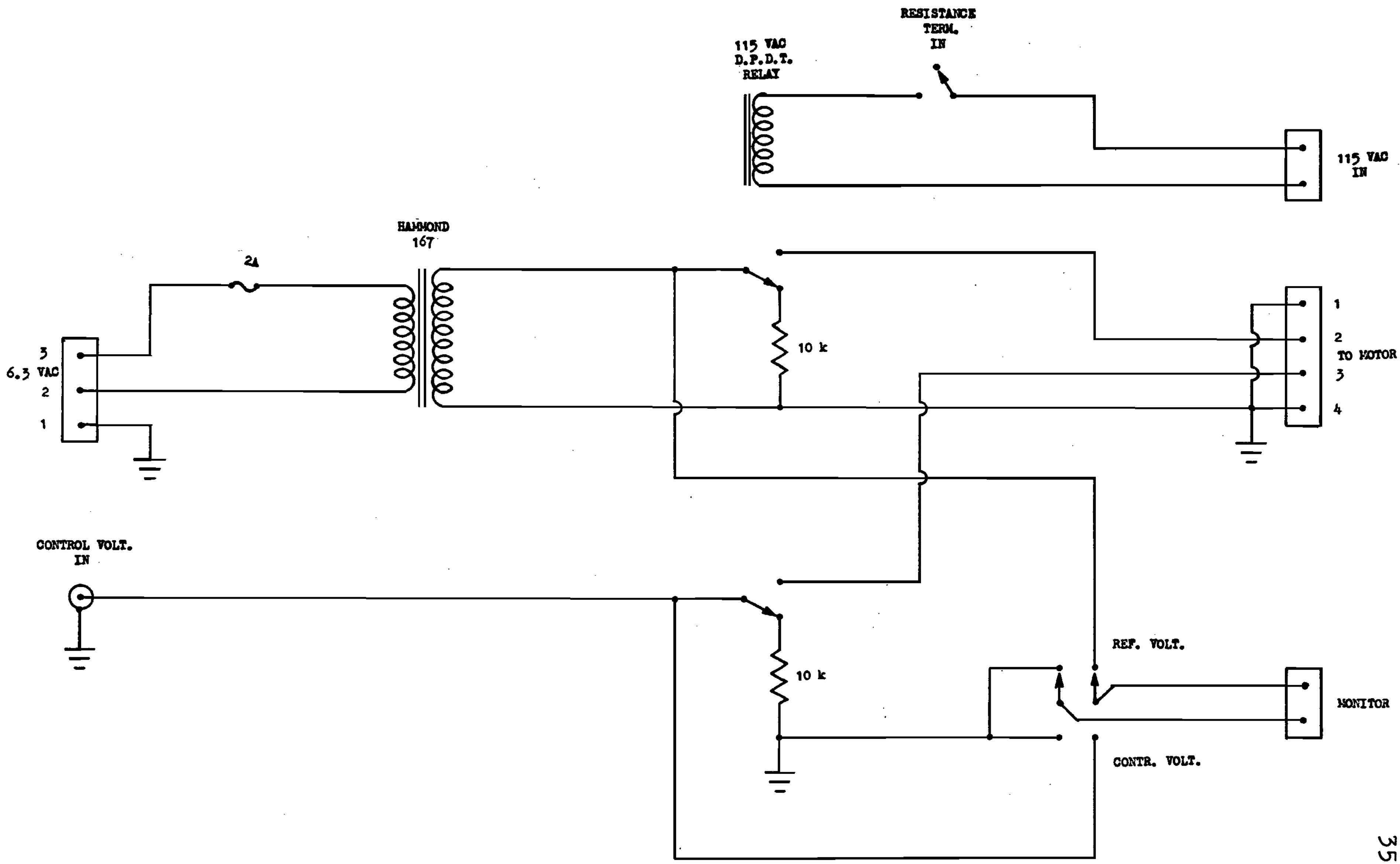


Fig. 4.6. SERVO MOTOR CONTROL DIAGRAM.

The amplifier is modified slightly. A cathode follower is built into its last stage with a BNC connector at the output for provision of an audio output which constitutes the measured level signal.

The meter is retained to show the reference level, and for manual operation of the recording system.

4.5.2. Comparator-Modulator (Fig. 4.7).

The tuned amplifier output and reference voltages are subjected to similar rectifying networks. The reference voltage level is adjustable through a 10 turn 100k ohm potentiometer.

A Stevens-Arnold C-12 BBM DC-AC Chopper is used as a switch connecting the output to the rectified audio voltage and reference voltage alternately at a rate of 60 cps.

The blocking condenser passes the a.c. error output to the servo preamplifier. Its peak to peak value is proportional to the difference of the two voltages.

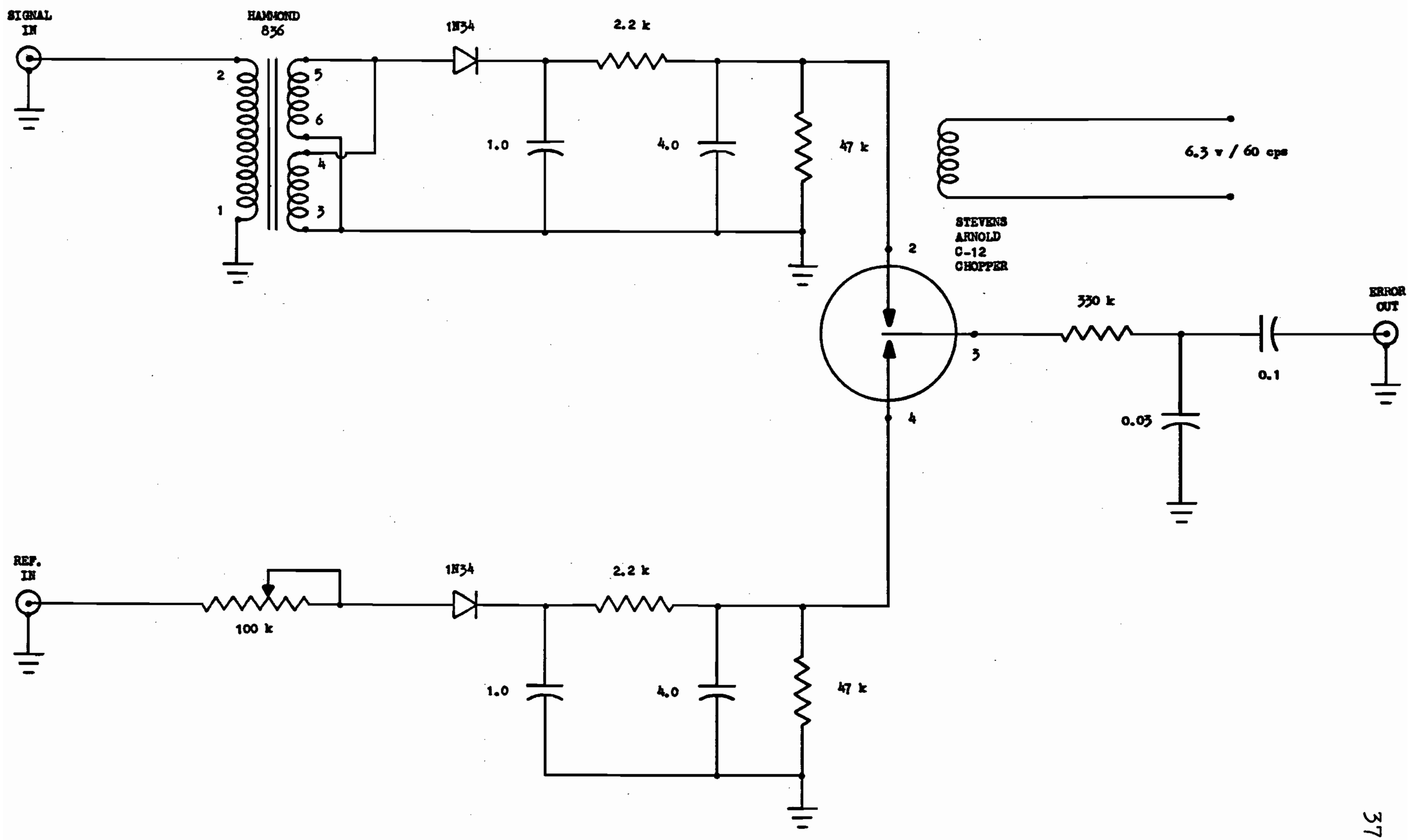


Fig. 4.7. COMPARATOR-MODULATOR DIAGRAM.

CHAPTER 5.

EVALUATION OF THE SYSTEM.

The performance of the system was evaluated by a variety of tests. The system was subjected to simulated controlled conditions and to actual operating conditions.

The test procedures were chosen to demonstrate some of the important aspects of the system; in particular the response speed and the accuracy. These tests were performed in logarithmic units.

For the response speed the tests were done at different settings of the attenuator. It is necessary to duplicate the test at these different settings as the attenuator does not have a linear scale. These tests would reveal the response speed of the system at these settings.

The test for the accuracy was carried out in two stages. The accuracy of the translating system was examined, and an operational test was performed to determine the accuracy of the overall system. In the latter part the results of an automatic operation of the system were compared with the manual measurement. Both measurements were done along the same scan in a microwave field.

5.1. Dynamic Test.

5.1. Dynamic Test.

To demonstrate its speed of response a servomechanism is usually subjected to a step function input, and its transient response is observed and evaluated (Getting[18]). The test selected here consisted of impressing a square wave function to the system with a period large enough to observe its transients.

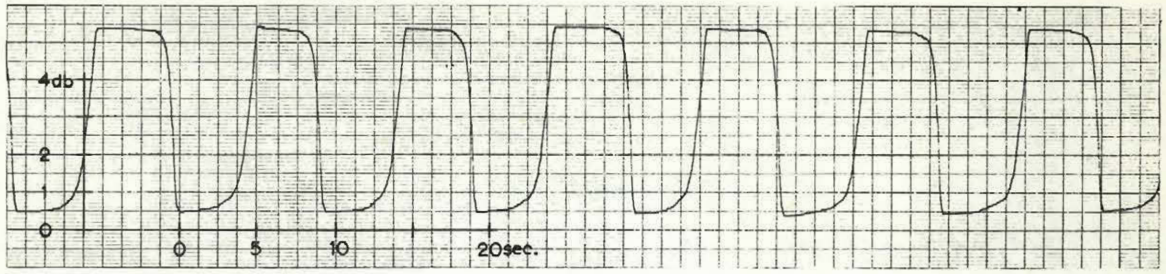
The intensity changes for the test were obtained by manually adjusting an additional attenuator inserted into the test path. To provide constancy of attenuation changes mechanical stops were built into the attenuator. The attenuator was varied periodically between these stops thus producing a square wave input signal to the system. As the intensity changes were produced by manual adjustment, the period of the square wave was at the discretion of the operator, and was not necessarily constant.

The amplitude of the simulated square wave was set at approximately 5 db peak to peak, and its period at about 10 seconds. A series of tests were carried out to determine the response speeds at the different scale values of the attenuator. As mentioned in chapter 3 the attenuator has a db scale of 40 log cos θ as a function of its angle of rotation. By virtue of this function the scale is more widely spaced at the lower end than at the higher values. An illustration to this is the fact that of the entire 50 db range of the attenuator more than 1/3 of the scale is taken up by the region of 0 - 2.5 db.

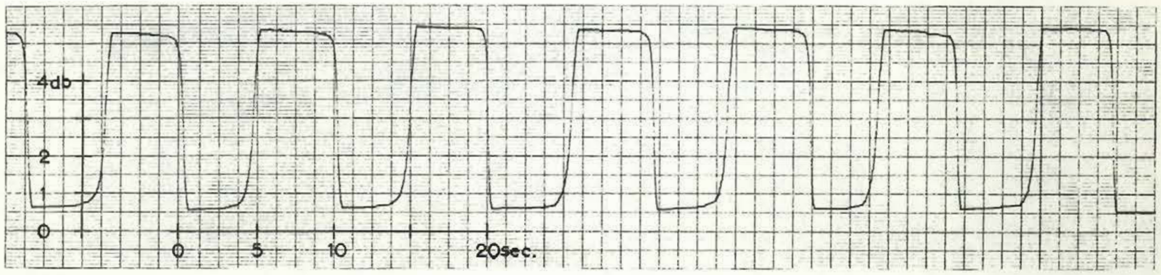
The tests were carried out for a series of attenuation values of 5, 10, 20 and 30 db. The results of the tests are shown in figures 5.1.1 to 5.1.4 inclusive in the same order. These are reproductions of the actual recorder charts as obtained from the system responding to the manually generated square wave inputs. As seen from the charts the rate of response ranges from 3 to 16 db per second corresponding respectively to the attenuator settings of 5 and 30 db.

To separate the response of the motor-attenuator unit from that of the curve follower (attenuator translator) and recorder, an electrical square wave generator was connected to the input of the curve follower. The point of operation of the curve follower was set to correspond to the 5 db attenuation value, and the square wave amplitude was such as to have about the same deflection at the recorder as during the former tests. The resulting record shown in Fig. 5.2 indicates a similarity to that obtained at the 30 db setting. Thus the slower response at the lower attenuator settings was obviously caused by the longer travel required of the attenuator servo during its null seeking. As may be seen from the r.f. substitution method low attenuation values correspond to low field intensity levels, and vice versa.

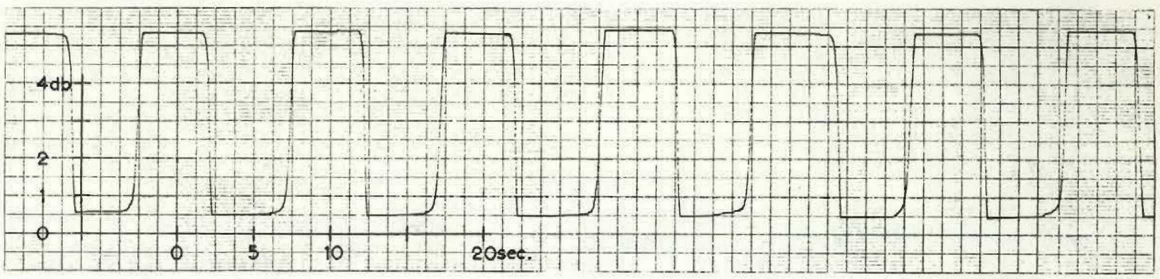
The recorder charts also show that the response of



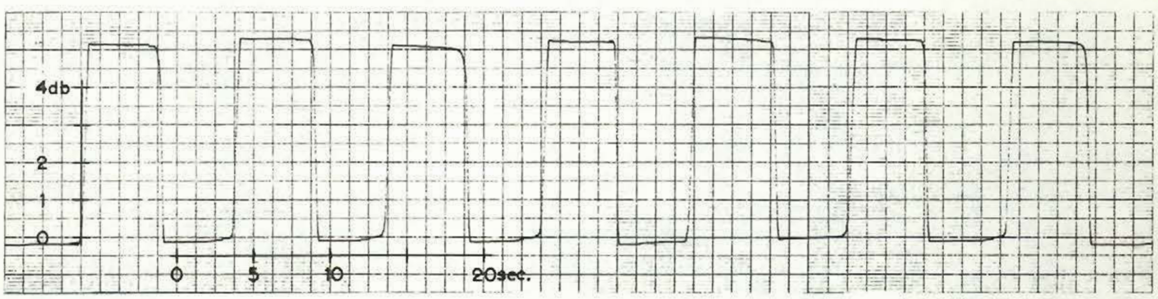
(1) RESPONSE AT 5 db.



(2) RESPONSE AT 10 db.



(3) RESPONSE AT 20 db.



(4) RESPONSE AT 30 db.

Fig. 5.1. SYSTEM SQUARE WAVE RESPONSE.
PERIOD APPROX. 10 SECONDS.

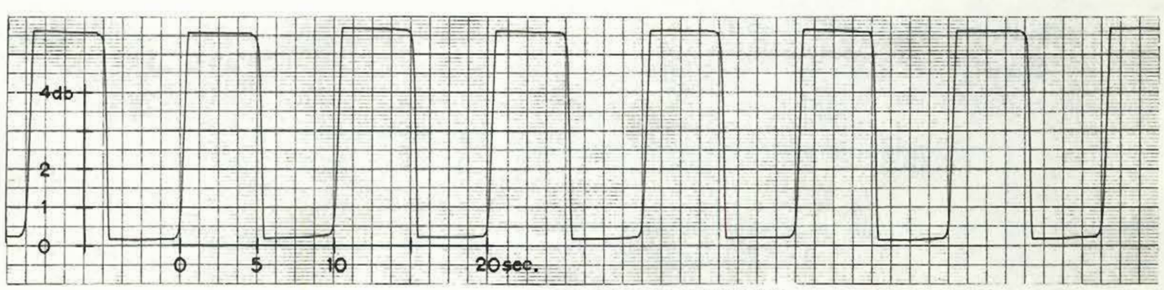


Fig. 5.2. TRANSLATOR-RECORDER SQUARE WAVE
RESPONSE AT 5 db.

the system was overdamped at these lower settings.

5.2. Calibration Tests.

A calibration test was carried out in two parts. The first part was intended to show the effectiveness and accuracy of the translating system of the attenuator. The second part was to demonstrate the performance of the overall system.

5.2.1. Translating System Calibration.

A calibration test was performed on the translating system to show its accuracy.

The attenuator was varied manually to different settings with the actual measuring system inoperative. The attenuator position recording system translated these settings into logarithmic units (db) and recordings were made with respect to time. The resulting step function records facilitate the reading of the different attenuation values. Recording was done in both directions of attenuation step changes (Fig. 5.3).

The attenuator settings were varied in steps of 4 db with the recorder range set at 48 db full scale. The recording shows that the accuracy is within two small divisions. This is equivalent to a deviation of 0.8 db. It also shows a combined dead-zone band of the curve follower and recorder of one small division or 0.4 db.

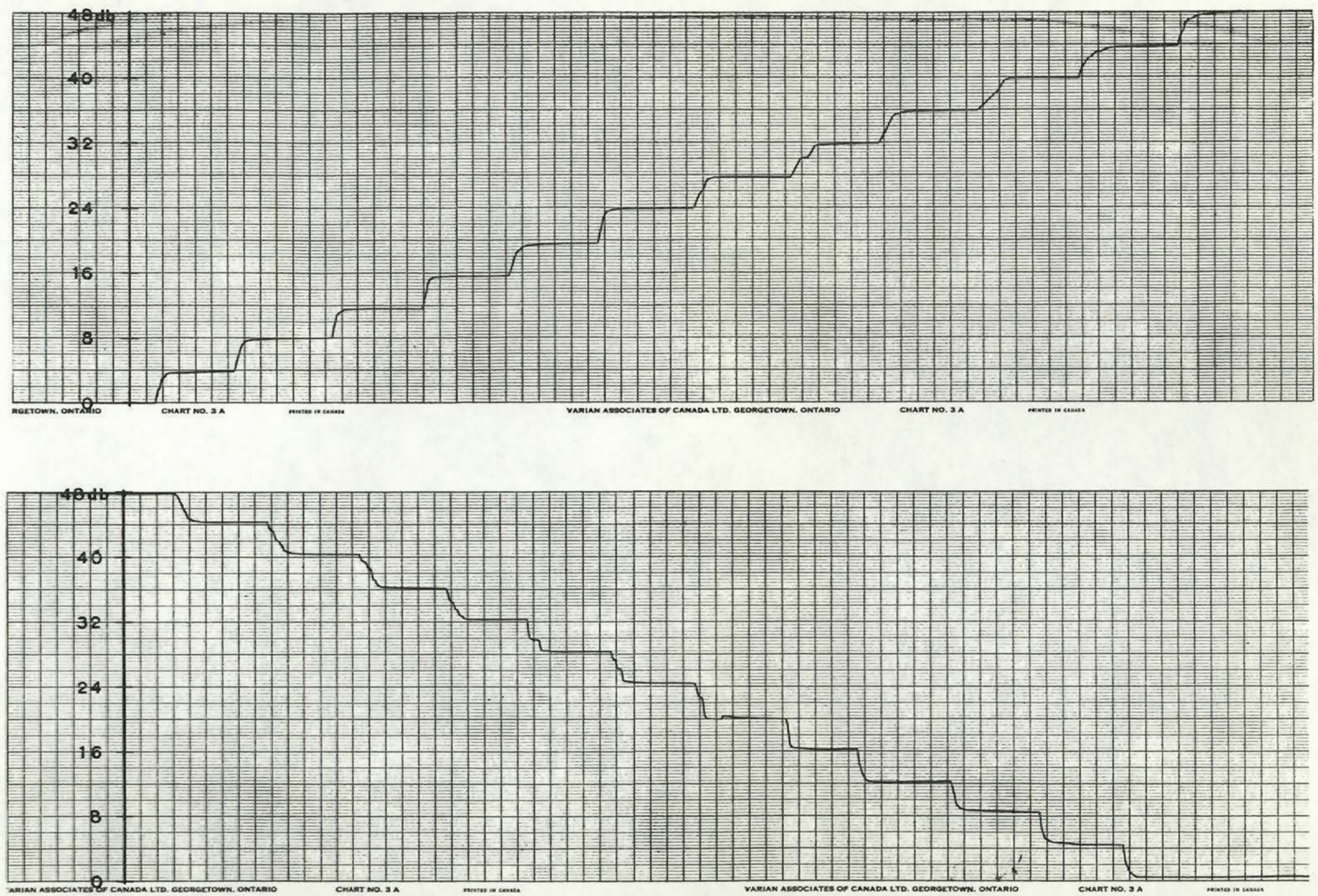


Fig. 5.3. TRANSLATING SYSTEM CALIBRATION (LOGARITHMIC).

Step function recordings in the other two units of measurements were also carried out. In both cases the attenuation was varied in steps of 3 db. These recordings are shown in Fig. 5.4.

5.2.2. Operational Test.

To assess the overall accuracy and response of the system an automatic recording along a scan was made. A field produced by a microwave lens was scanned along a line perpendicular to the lens axis. This recording was then compared with the values obtained by manual measurement. These values were superimposed on the recording as shown in Fig. 5.5. It shows that the overall system is accurate within 1 db in the higher intensity levels of the field. This accuracy deteriorates at the lower portion of the recording to about 2 db. This was obviously caused by the poorer response of the system at the lower attenuator settings.

The scanning speed in this test was set at 15 cm per minute. Decreasing the scanning speed would undoubtedly improve the accuracy, as the automatic operation then approaches the manual one.

The same scan was performed for the relative power and relative field strength translations. Recordings of both are shown in figures 5.6 and 5.7 respectively.

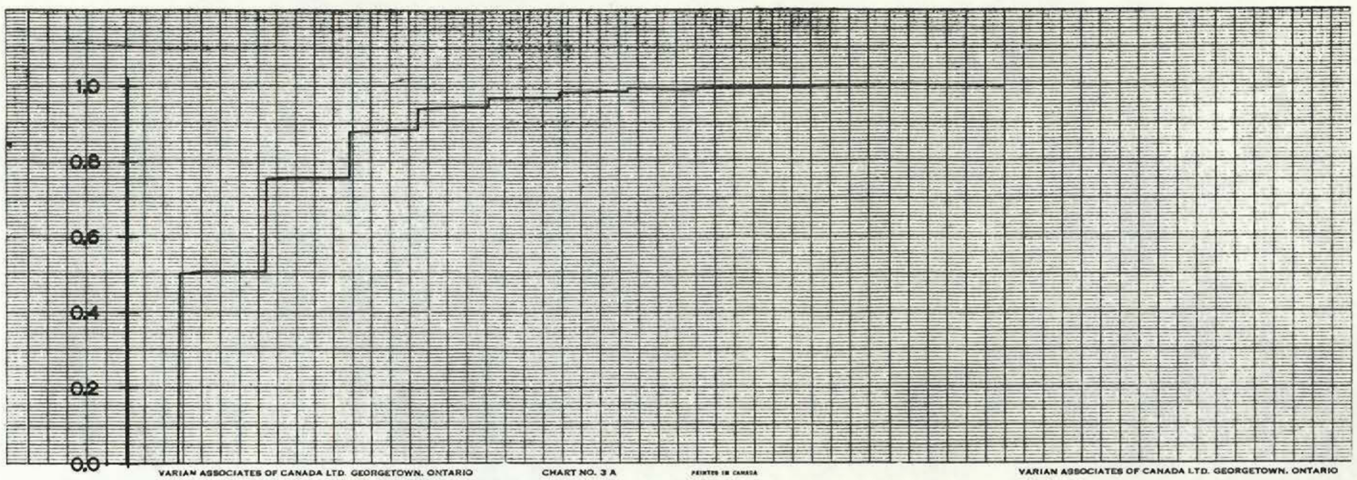


Fig. 5.4.1. TRANSLATING SYSTEM CALIBRATION (RELATIVE POWER).

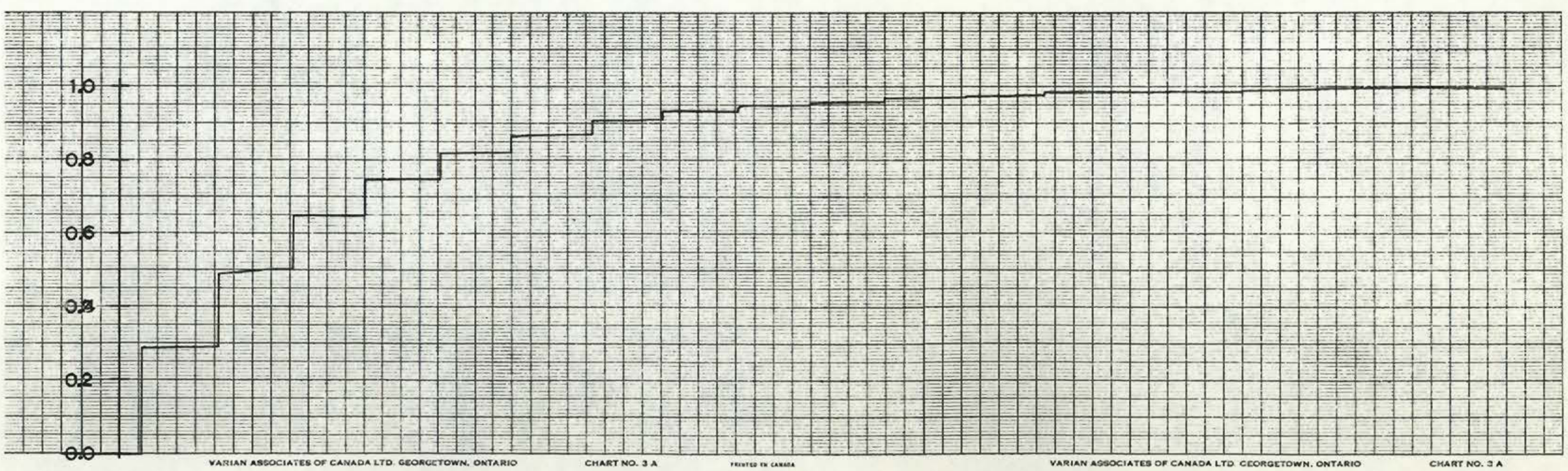


Fig. 5.4.2. TRANSLATING SYSTEM CALIBRATION (RELATIVE FIELD STRENGTH).

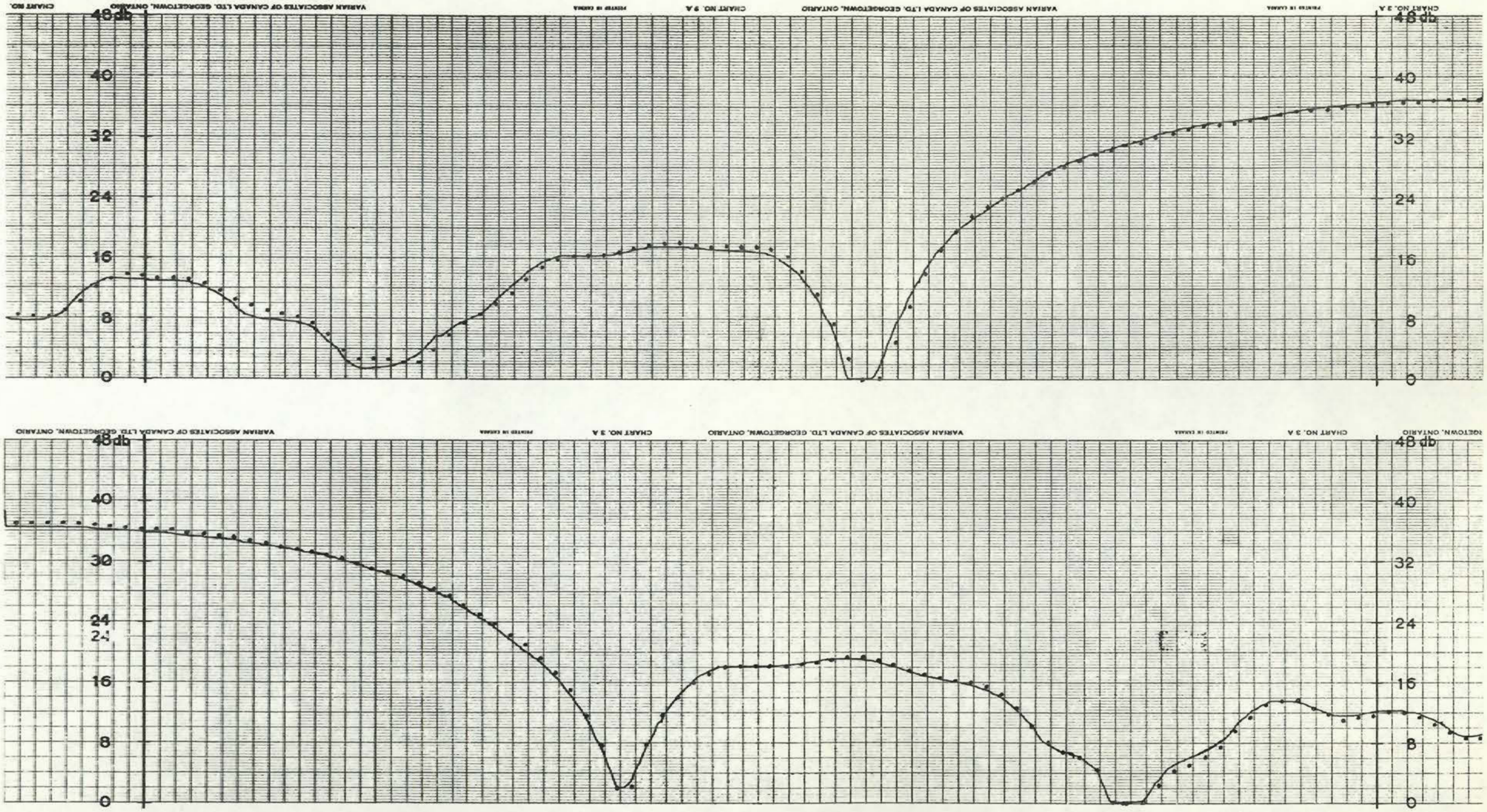


Fig. 5.5. AUTOMATIC SCAN RECORD
(LOGARITHMIC).

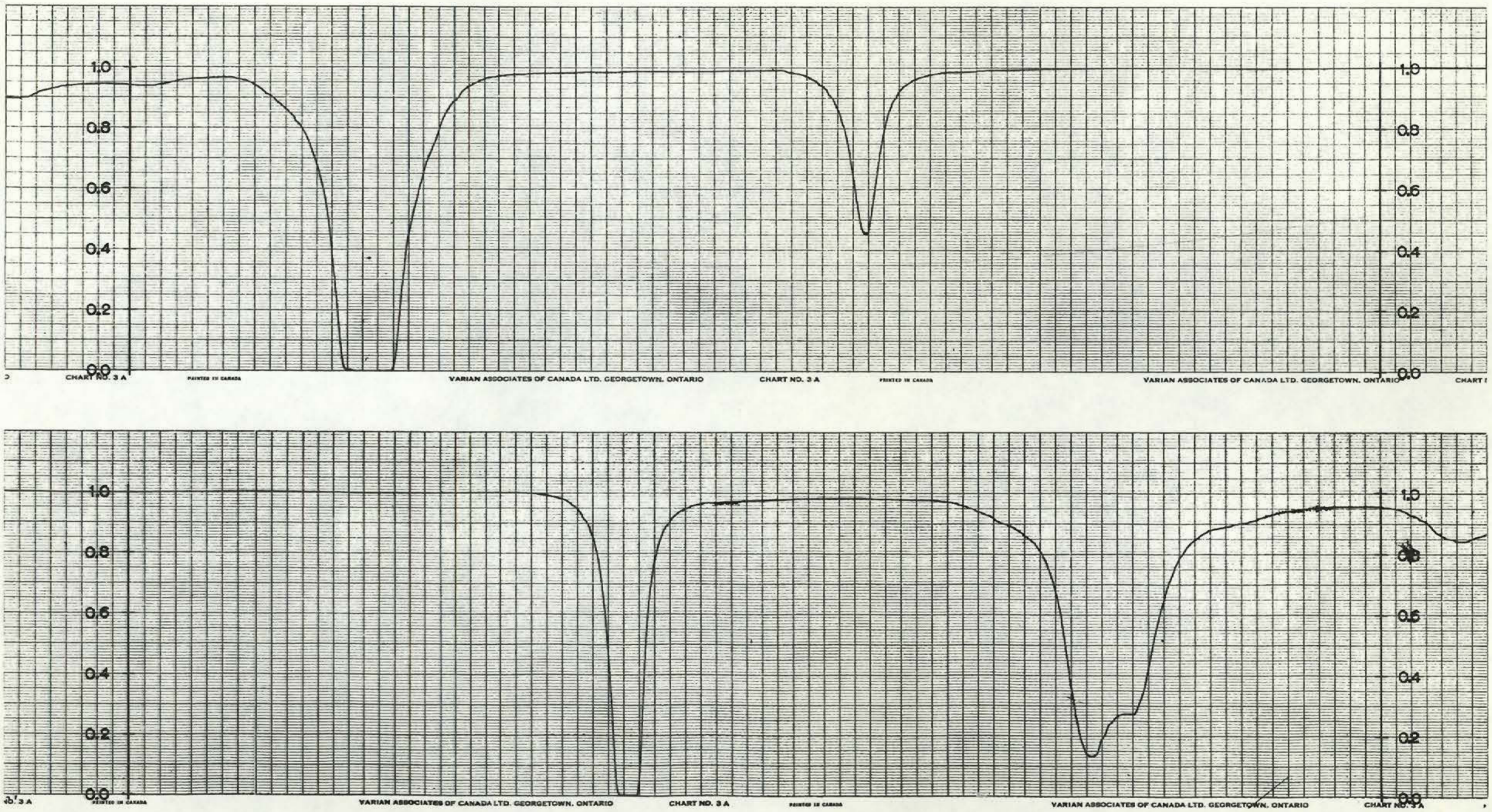


Fig. 5.6. AUTOMATIC SCAN RECORD (RELATIVE POWER).

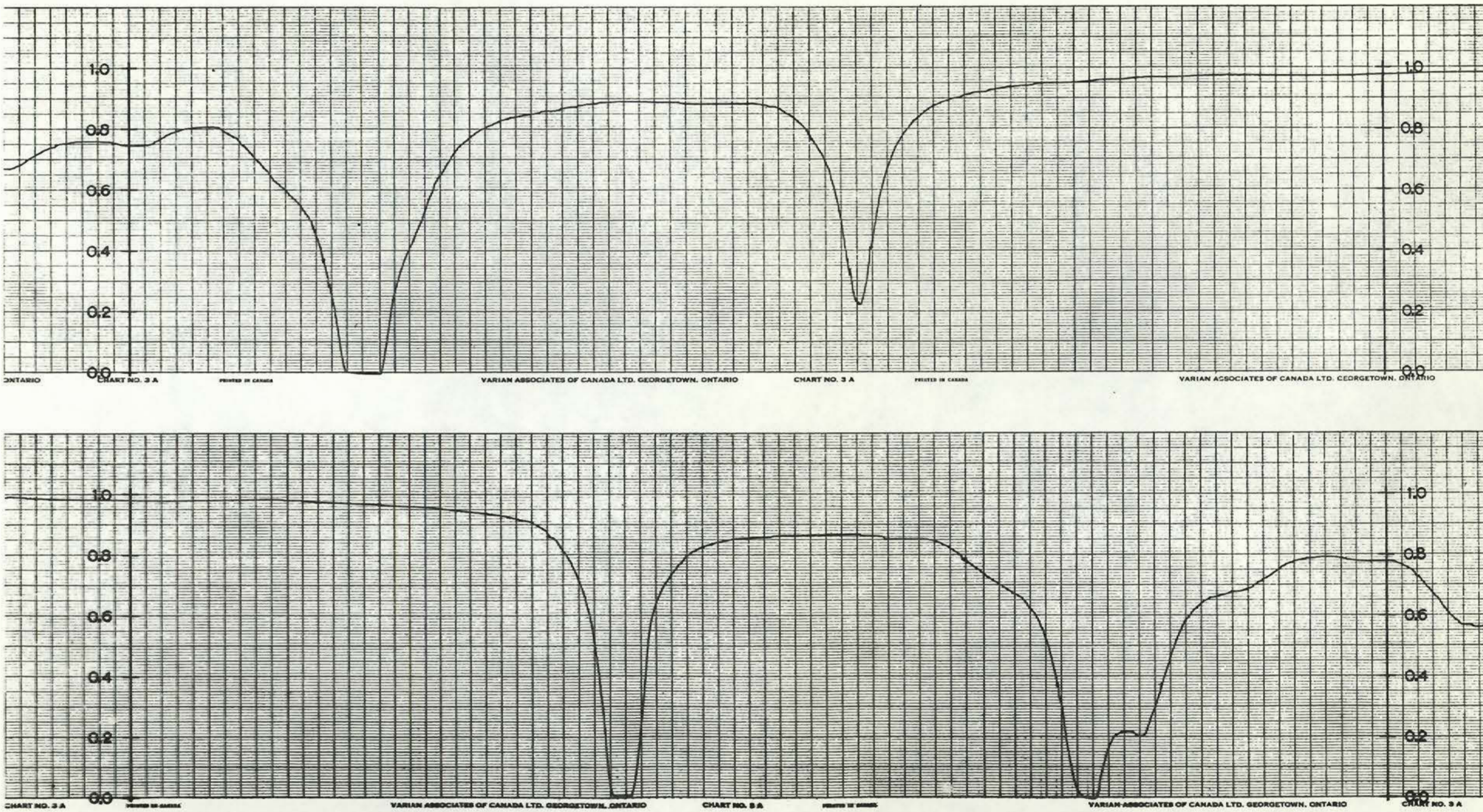


Fig. 5.7. AUTOMATIC SCAN RECORD
(RELATIVE FIELD STRENGTH).

CHAPTER 6.

CONCLUSIONS.

The properties of microwave detectors have been examined and summarized. It has been found that they suffer a number of disadvantages. The most important of these in the case of crystals is the deviation from the square law characteristics when operated over a wide range of r.f. power. The main disadvantages in the case of bolometers are their lower sensitivity and their susceptibility to burn-out.

The principal purpose of this project has been to investigate the possibility of developing a device for measuring and recording automatically the intensity distribution of a microwave field, which incorporates the high sensitivity of the crystal detector, but is independent of its characteristics. The r.f. substitution method has been applied here, and it has been found quite adaptable to automatic operation. This was confirmed by the performance tests made on the system.

Significant features in this device are the following. The r.f. power level at the detector is kept constant during the operation thus making the measurement independent of the detector law. This is a direct consequence of the r.f. substitution method adopted in this device. It incorporates a compensating feature for changes in absolute power level at the r.f. source. There is provision in the system to record field intensities in the 3 different units of measurement.

Some improvements may be worth considering as a result of experience in the development of this system.

An obvious simplification now that feasibility has been demonstrated is to replace the function generator by nonlinear potentiometers, viz. Appendix.

As the measurement of intensity is more concerned with gradual changes rather than step type ones the servomechanism should be optimized for ramp or triangle wave type of error inputs. Incorporation of integral control into the system should be considered. Uniform response speed over the range of the attenuator may be achieved by using some function of nonlinear optimization such as for example an a.g.c.

Some control of the scanning speed with respect to field intensity level, i.e. attenuator position, should also be taken into consideration.

A logical improvement in the automatic system is the increase of the scanning speed. An all electrical system should probably be looked into, possibly by using ferrite attenuators or electrically controllable power dividers, in the place of the rotary attenuator.

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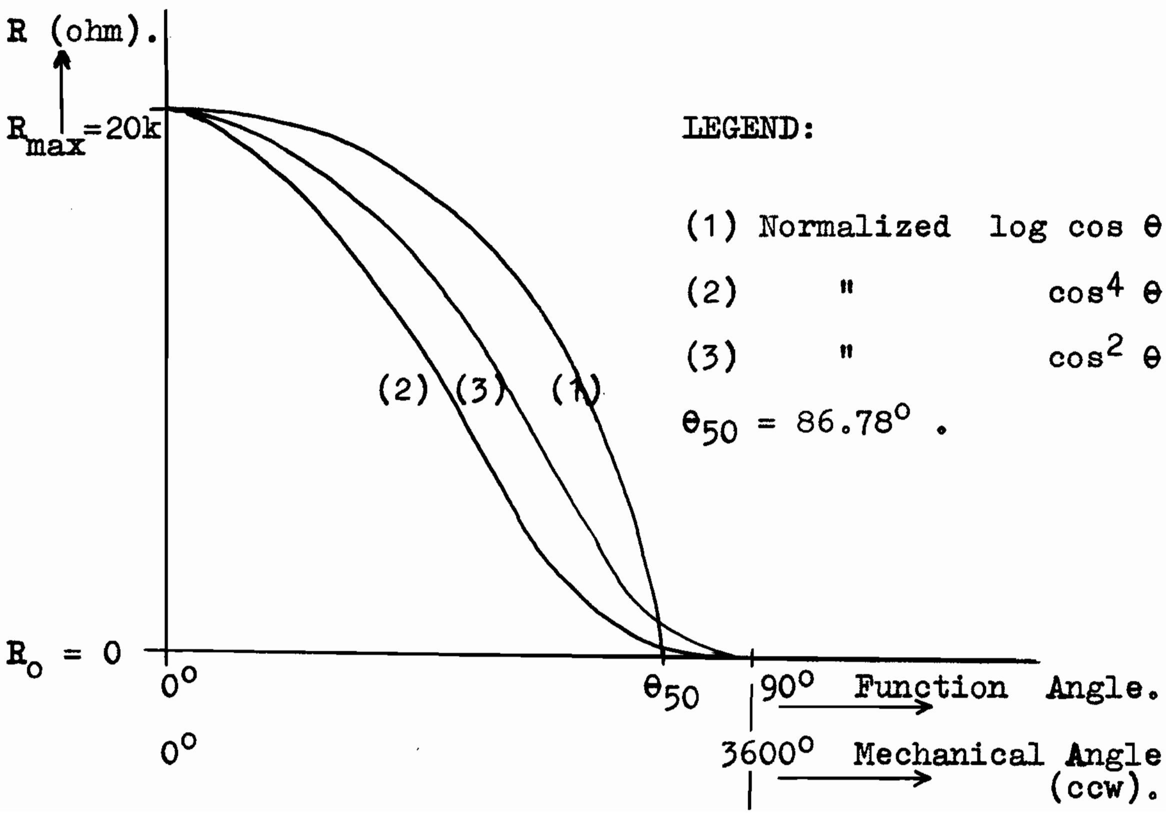
APPENDIX.

FUNCTION POTENTIOMETERS.

This appendix deals with the specifications of the potentiometers, which could be used for the attenuation translators in the place of the curve follower.

With the feasibility of the system shown the curve follower is to be replaced by one or all of these potentiometers as required. Ganged mounting simplifies the coupling of the potentiometers if all are required.

The figure below shows the curves of the different functions with their significant values.



Potentiometer Specifications.

Logarithmic Function.

Resistance function	$R = R_{max}$ (1.25 + log cos θ)/1.25		
R_{max}	20k ± 1%		
R_o	0 ohm @ $\theta_{50} = 86.78^o$		
Deviation tolerance	½%		
Mechanical rotation	3600^o	$+ 2^o$	$- 0^o$
Function angle	90^o	+ 3'	$- 0^o$

Relative Power Function.

Resistance function	$R = R_{max} \cos^4 \theta$		
R_{max}	20k ± 1%		
R_o	0 ohm @ $\theta = 90^o$		
Deviation tolerance	½%		
Mechanical rotation	3600^o	$+ 2^o$	$- 0^o$
Function angle	90^o	+ 3'	$- 0^o$

Relative Field Strength Function.

Resistance function	$R = R_{max} \cos^2 \theta$		
R_{max}	20k ± 1%		
R_o	0 ohm @ $\theta = 90^o$		
Deviation tolerance	½%		
Mechanical rotation	3600^o	$+ 2^o$	$- 0^o$
Function angle	90^o	+ 3'	$- 0^o$