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A MULTICHANNEL ELECTRON DETECTION SYSTEM FOR USE IN A STABILIZED MAGNETIC SPECTROMETER

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Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
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ABSTRACT

Multichannel counting systems facilitate the determination of differential cross sections in electron scattering experiments. The need for a high resolution counting system capable of handling fast counting rates has led to the construction of a transistorized, multichannel system for use with the 100 Mev linear electron accelerator being constructed at the U. S. Naval Postgraduate School. Design and operation of the counting system are discussed, and testing procedures are described.

Since accurate measurement and stability of the spectrometer magnetic field is of fundamental importance in the operation of the multichannel detector, an accurate rotating coil fluxmeter for measuring and regulating the spectrometer magnetic field has also been built and is described. More familiar techniques of magnetic field measurement are not suitable for this application. Measurement of magnet current does not yield sufficient accuracy due to variations in field strength not linearly related to magnet current, and nuclear-magnetic resonance devices are impractical where there is an inhomogeneous field such as exists in a double focusing spectrometer magnet. The fluxmeter measures and regulates field strength to an accuracy of one part in 1000 or one gauss, whichever is greater.

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I. INTRODUCTION

Multichannel and single channel systems have been used for the past ten years in the determination of differential cross sections in electron scattering experiments. A multichannel counting system has been built for use with the 100 Mev linear electron accelerator being constructed at the U. S. Naval Postgraduate School.

The advantages of a multichannel counting system over a single channel system are emphasized by the following brief description of a typical counting experiment. Electrons emerge from an accelerator in a collimated beam with a well defined energy E_i and a very narrow energy spread. The electrons strike some target material and are scattered into a solid angle of 4π steradians, and their resulting energy E_s is no longer well defined. Generally it is desired to plot the relative numbers of scattered electrons as a function of E_s for a fixed E_i and a fixed scattering angle θ. A typical plot is shown in Fig. 1.

In order to obtain such a plot it is necessary first to "look" at the scattered electrons from a certain direction and then to separate them according to their energy. A magnetic spectrometer, which accepts electrons from a specified direction only, focuses the electrons along a focal plane according to their momentum. Because of their relativistic velocity, the electrons have an energy E proportional to their momentum p, i.e., E = cp, where c is the velocity of light. Higher momenta are focused at greater radii than lower

momenta. See Fig. 2.

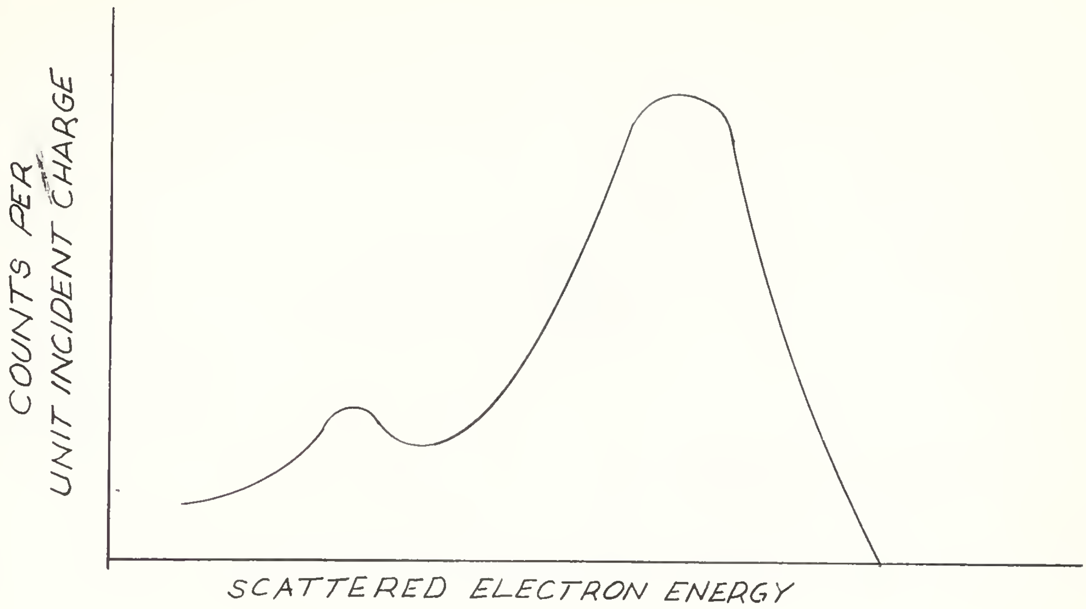

Fig. 1 Typical plot of energy distribution of scattered electrons after passage through a magnetic spectrometer.

In a typical single channel counting system, a detector is placed at point A, and an adjustable slit for defining energy resolution is interposed between the detector and the source. In this manner electrons of a particular momentum and momentum spread are counted. The strength of the magnetic field determines the momentum of electrons focused on the detector, and the slit width determines the momentum spread and, therefore, the resolution. In order to count at a different energy, it is necessary to change the strength of the magnetic field in the magnet, or, for a given angle, the incident electron energy. Thus if it were desired to divide the energy spectrum into 50 increments and record counts in each increment, it would be necessary to take 50 separate

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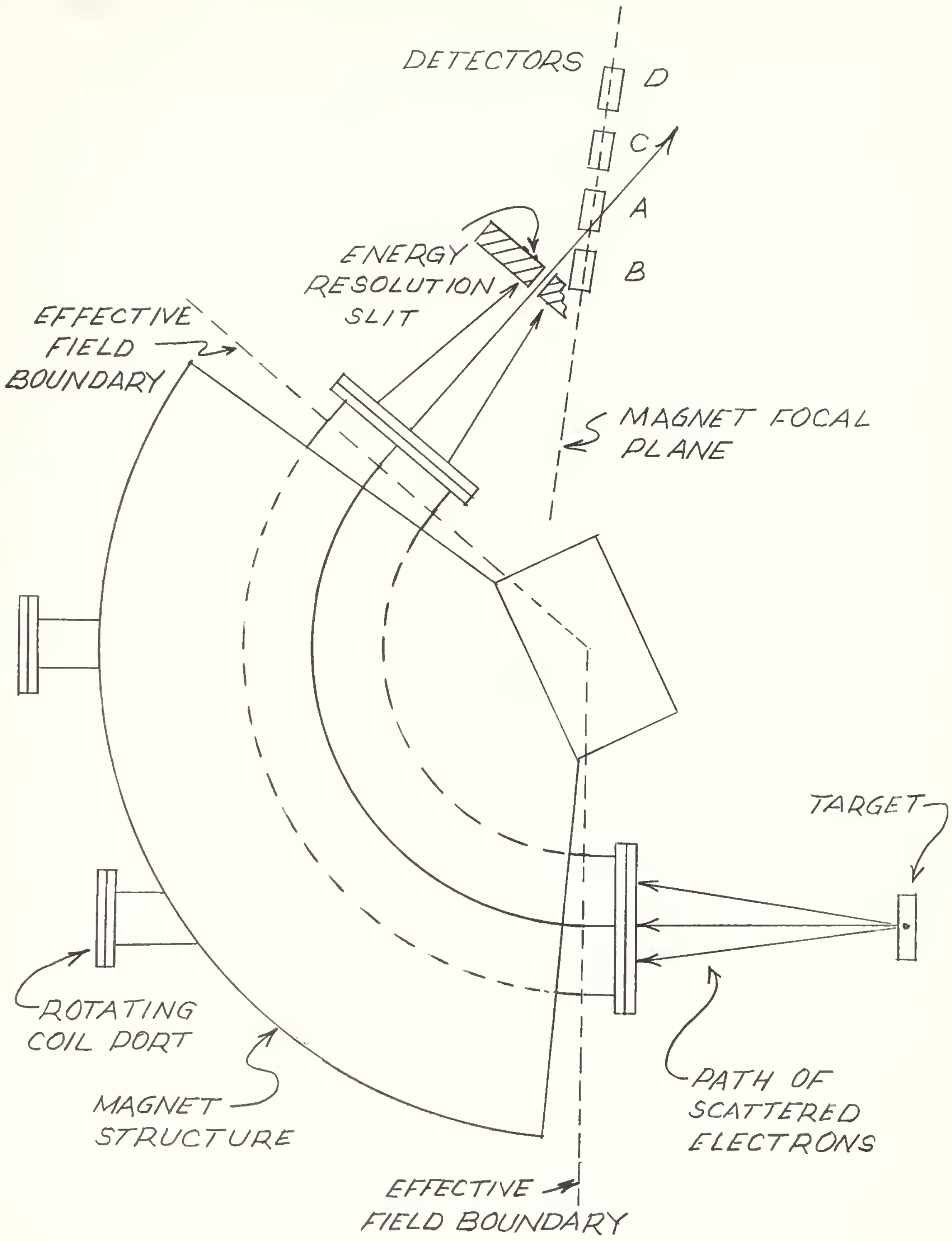


FIG. 2. DIAGRAM OF TYPICAL MAGNETIC SPECTROMETER

data points at 50 different field settings of the magnet.

On the other hand, a multichannel counter with 10 channels utilizes 10 separate detectors situated in the focal plane of the magnet (i.e., at points A, B, C, D, etc.) in such a way that each detector receives electrons in a different momentum range. The momentum spread for a given detector depends on the width of the detector and upon the momentum. No slit is used in such an arrangement. Thus, for a single magnetic field setting, scattered electrons at 10 different energy intervals can be counted simultaneously, and the time required to complete an experiment is reduced by a factor of ten! Actually, since a certain interval overlap is desirable, slightly less time is saved.

In the present installation, the spectrometer magnetic field is measured by an accurate rotating coil fluxmeter and held at a preset value by an associated servomechanism. A rotating coil fluxmeter is required because a nuclear magnetic resonance probe is impractical in measuring the inhomogenous magnetic field in a double focusing spectrometer.

II. THE COUNTING SYSTEM

1. Design Objectives

Before beginning construction of the counting system, it was first necessary to establish performance criteria based on the following objectives:

(1) Initial counting rate of 100 kHz harmonically with the capability of later being increased to 100 mHz

(2) Both visual readout and provision for transmission of data to storage

(3) Reliability

(4) Simplicity of design

(5) Flexibility

(6) Ease of maintenance

(7) Low cost

2. Overall System Design

In order to meet the objectives listed above, the following approach to the system design was adopted: Because of the fast counting rate desired ultimately, fast transistors and solid state devices were chosen. Modular construction was selected because of its great flexibility and ease of maintenance and replacement. All modules are designed to fit into a simple rack with standard 19" panel mountings. To provide for the transmission of data to storage at some future time, Anadex DC-101A scalers were utilized [1]. The 100 kHz counting rate of these scalers may easily be increased to 100 mHz by the addition of suitable pre-scalers. The entire system (except for high voltages to the photo-

multiplier tubes) is designed to operate on only five d.c. voltages: -24 volts, -12 volts, + 3 volts, + 12 volts, and + 250 volts. All outputs and inputs were designed for an impedance match with 50 ohm RG-58C/U or any other 50 ohm cable.

The first element in each channel of the multichannel counting system is a NE102 plastic scintillator [2] attached by a lucite light pipe to a DuMont type 6291 photomultiplier tube. An electron passing into the scintillator produces a flash of light which is transmitted through the light pipe to the face of the photomultiplier tube, thus initiating an electrical pulse which is sent to an amplifier.

The scintillators are situated in a ladder arrangement in the focal plane of the spectrometer as described in Part I. In order to avoid counting stray electrons, backing counters are placed immediately behind the forward counters. Each backing counter will ultimately serve five forward counters. The backing counter uses a plastic scintillator with a light pipe attached to an RCA type 6810A, 14 stage photomultiplier tube. A coincidence circuit in each channel allows a count from one of the forward counters to register only when a pulse received from the corresponding backing counter arrives within the resolving time of the coincidence circuit. This arrangement greatly diminishes the background count, since the probability of stray electrons striking a forward counter and a backing counter in coincidence is very small.

A pulse of about 0.22 volts produced at the anode of the

6291 photomultiplier tube is amplified to 1.4 volts and sent to a discriminator, which has a discriminating level of from 0.5 to 4.8 volts. Thus it is possible to eliminate the smaller pulses originating mainly from photomultiplier noise and gamma rays in the laboratory background.

The output of a forward channel discriminator is a 1.0 volt pulse which is fed to a fanout, where the single pulse is split into three identical 1.0 volt pulses. This provision allows for simultaneous monitoring with an oscilloscope, operation of the coincidence counter, and counting of singles only from the forward counter, if desired. The output from the backing counter photomultiplier tube is a 2.0 volt pulse, sufficiently high to be sent directly to a discriminator without amplification. From this point the pulse goes to a 6-way fanout where it is split and sent to each of the coincidence circuits associated with the corresponding forward counters. If a pulse from the forward counter and a pulse from the backing counter arrive at the coincidence circuit within resolving time, a 1.0 volt pulse is transmitted to a scaler driver which provides a stretched 20 volt pulse for operating the Anadex DC-101A scalers. Provision is incorporated in the scaler driver for a gating pulse to be provided from the accelerator for the purpose of opening the counting circuit only during the duty cycle of the accelerator. In this manner unwanted background is greatly reduced. The circuit providing the gating pulse is not a part of this thesis project.

A block diagram of the system is shown in Fig. 3.

3. Component Analysis

a. High voltage distribution circuit

In order to provide an individually adjustable voltage source for each of the 6291 photomultiplier tubes, a voltage divider with the following characteristics was designed and constructed.

Input:	1800 volts dc
Output:	10 channels separately variable 1000 volts to 1800 vdc at 0.5 ma/channel

The voltage divider is provided with fine and course voltage adjustment for each channel, an output voltmeter, and connections for an external potentiometer. An average current of 0.5 ma was assumed for each of the 6291 photomultiplier tubes. The completed unit was checked with an external potentiometer and found to provide voltage control between 1120 and 1800 vdc at .45 ma/channel.

The unit may be used with any power supply capable of delivering 5 ma at 1800 vdc. The supply used in this project was a Hamner Model N401 High Voltage supply. See schematic diagram Fig. 4.

b. Photomultiplier tube power supply

A chain of resistors composing the base circuit for the 6291 photomultiplier tube was designed to operate with an ambient current of 0.45 ma. It was desirable to keep the current at this low value so that one 5 ma power supply could operate ten tubes. A current much lower than 0.45 ma

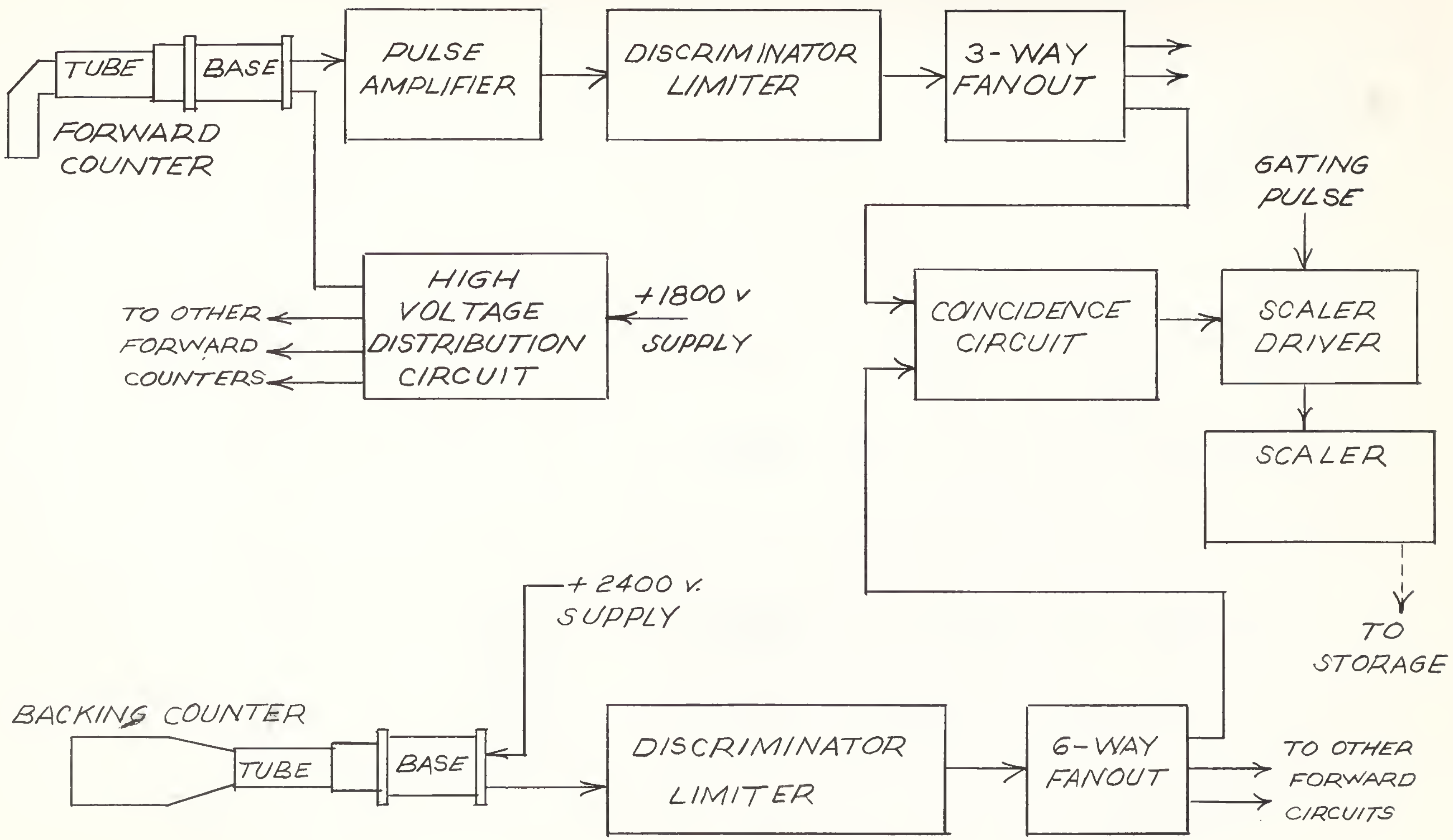


FIG. 3. BLOCK DIAGRAM OF MULTICHANNEL COUNTING SYSTEM

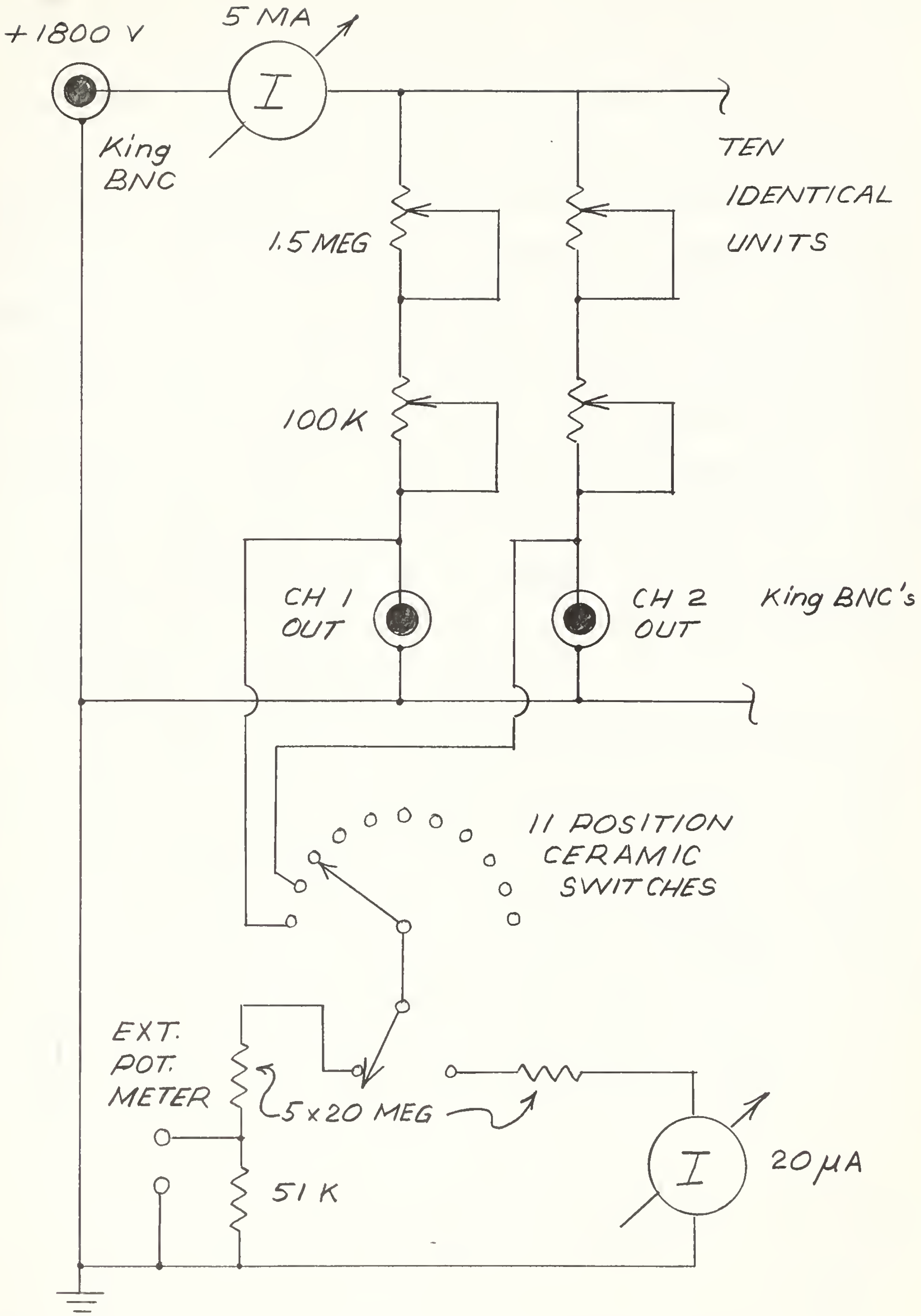


FIG. 4. HIGH VOLTAGE DISTRIBUTION CIRCUIT

would require higher resistance in the chain and thus allow dark currents to cause appreciable voltage variations across the resistors. The base circuit is shown in Fig. 5.

In order to obtain maximum sensitivity and current amplification consistent with the current limitations, the circuit was designed for a 100 volt drop from anode to dynode number 10, 150 volt drop per stage, and 308 volt drop from cathode to dynode number 1. This provides a current amplification of approximately 3×10^7, and a sensitivity of approximately 200 amp/lu. The voltage pulse observed at the anode has a peak value of 0.22 volts. Capacitors were placed in parallel with the last seven stages in order to prevent any appreciable voltage drop across a stage while its associated dynode is supplying electrons.

A 100 kohm resistor was placed between the 1800 volt power supply and the last stage 220 kohm resistor in order to cause a large voltage drop in the event of a short circuit in the chain. Capacitor C_1 shorts any noise to ground. Although the anode current has two paths to ground, 97.5% of the current passes through the 50 ohm input impedance of the anode pulse amplifier; and only 2.5% passes through the 2 kohm anode resistor.

c. Pulse amplifiers

In order to amplify the output pulses of the 6291 photomultiplier tubes from .22 volts to 1.4 volts, ten pulse amplifiers were constructed on a standard 19 x 3-1/2 inch panel.

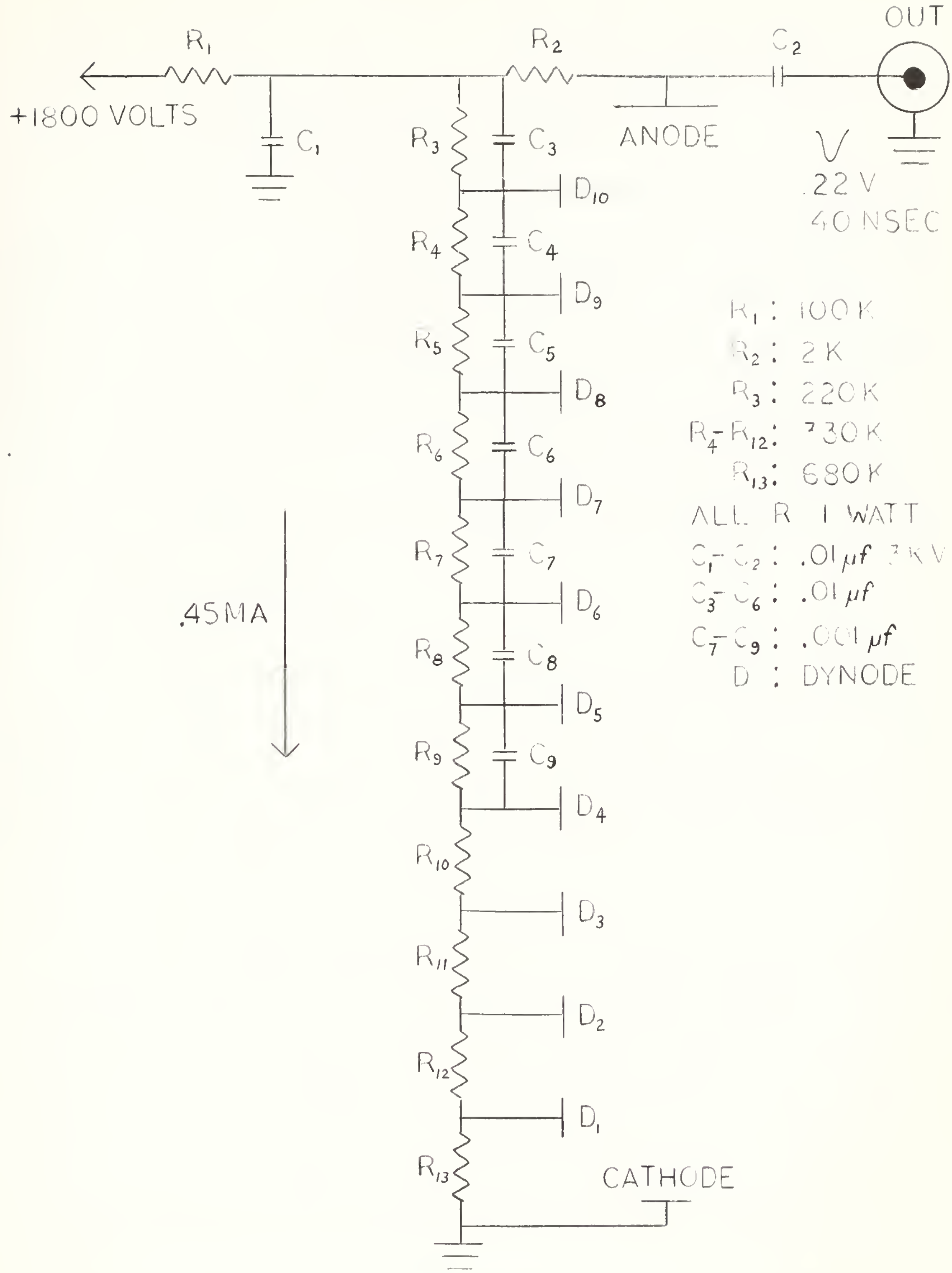


Fig. 5 Photomultiplier Tube Base Circuit

The operating characteristics are as follows:

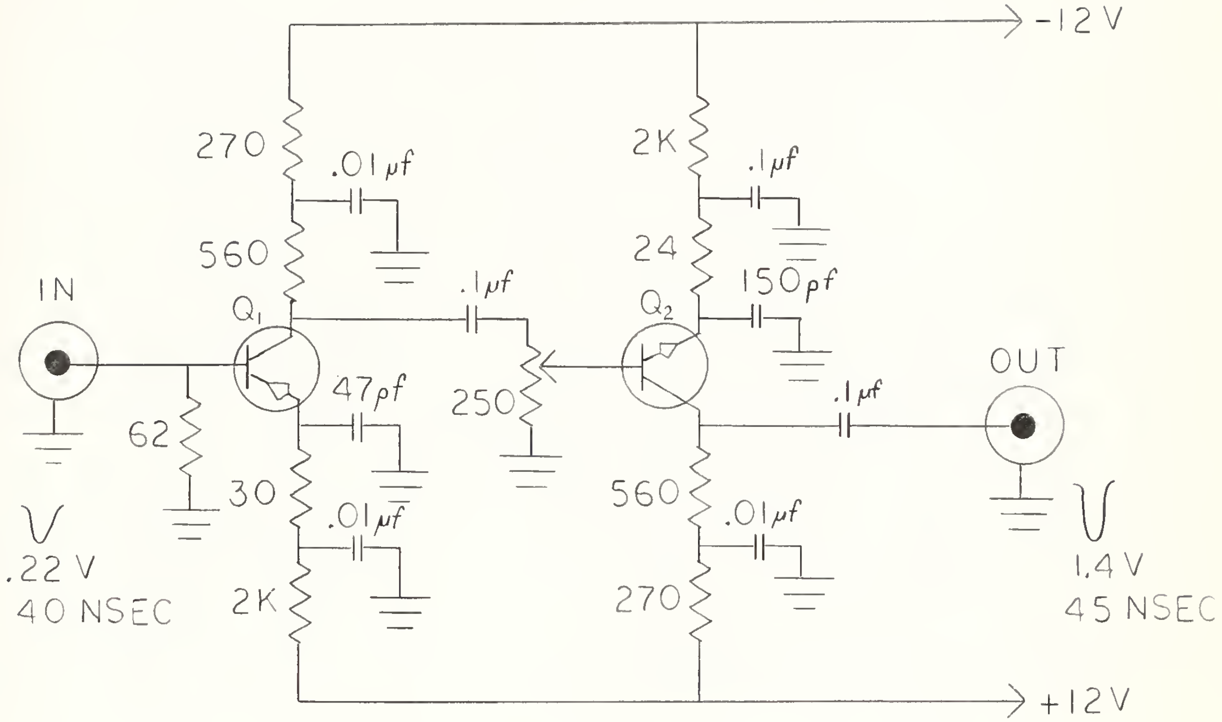
AC input impedance:	50 ohms
Voltage gain:	Variable from 0 to 10
Input and output pulse polarities:	Negative

These characteristics were obtained with the circuit shown in Fig. 6. The 250 ohm potentiometer provides a convenient means of varying gain, and since transistor Q_2 in emitter follower configuration has a very high input impedance, the output impedance of transistor Q_1 is nearly constant regardless of the potentiometer setting. Transistor Q_2 gives the desired negative pulse for transmission to the discriminator circuit.

d. Discriminator-limiter

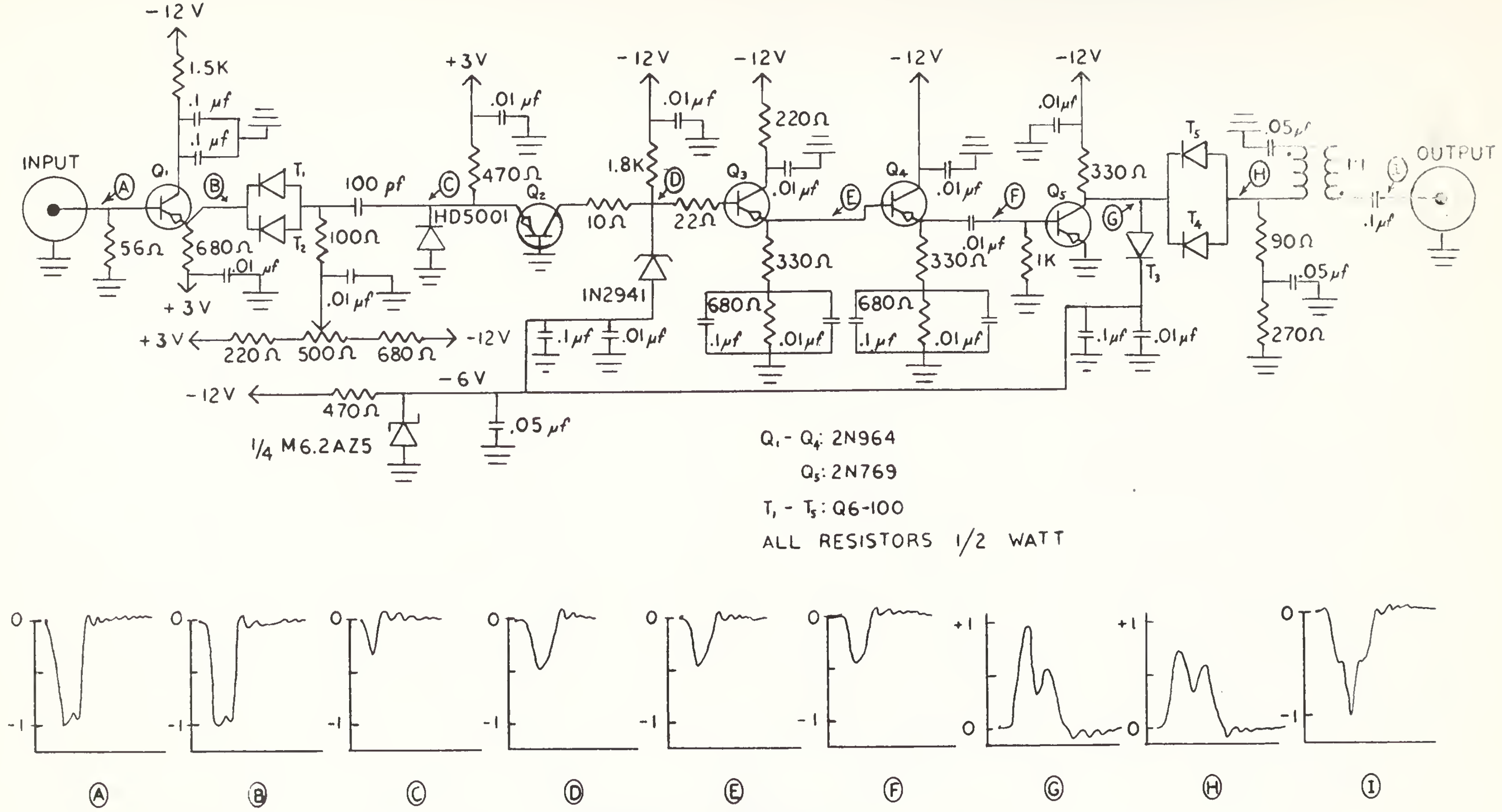
The discriminator has a variable discriminating level between .5 volts and 4.8 volts. The circuit in Fig. 7 was used and will be referred to for the following analysis. Typical pulse shapes at various points in the circuit are also shown in Fig. 7.

Transistor Q_1 insures a nearly constant input impedance of 50 ohms. A pulse is transmitted through diodes T_1 and T_2 only if it is of sufficient negative amplitude to drop the potential at the cathode below the potential at the anode. Thus the discriminating level is determined by adjusting the 500 ohm potentiometer to obtain the proper voltage at the anode.



Q_1: 2N964
Q_2: 2N955
ALL RESISTORS 1/2 WATT

FIG. 6 PULSE AMPLIFIER



TYPICAL PULSES

FIG. 7 DISCRIMINATOR - LIMITER

A pulse arriving at point C is shaped into a pulse of constant magnitude independent of the input. This is done by the 1N2941 tunnel diode driven by transistor Q_2. The pulse at point C changes the current through this transistor and causes the tunnel diode to flip with a voltage change of .5 volts. The circuitry beyond point D is used to amplify and shape the .5 volt negative pulse and to obtain proper impedances.

To stabilize the operation of the tunnel diode, it is necessary to increase the output impedance as seen from point D. To accomplish this, two transistors are used in emitter follower configuration. The pulse is then amplified from -.5 volts at point F to + .9 volts at point G. Diode T_3 with its cathode set at -6 volts keeps the voltage at point G from becoming more positive than -6 volts when a pulse turns transistor Q_6 on.

Diodes T_4 and T_5 prevent reflections from the pulse transformer which would produce a positive spike at the trailing edge of the output pulse. The pulse transformer inverts the pulse and eliminates ringing. A negative 1.0 volt, 10 nsec pulse is produced at point I, the output of the discriminator.

e. Fanout circuits

Each forward channel employs a 3-way fanout; and each backing counter, a 6-way fanout. The 3-way and 6-way fanouts are identical in design except for the number of outputs incorporated. The circuit consists of a single 2N964 trans-

istor emitter-follower configuration to provide current amplification and proper input impedance followed by another 2N964 in the same configuration for each output. The circuit is designed to provide a negative 2.0 volt pulse at each output when a negative 2.0 volt pulse appears across the input.

The completed fanout circuits were tested using square wave input pulses of -2 volts, 30 nanosec, at 720 pulses per sec obtained from a Tektronix type 110 pulse generator. The output of the fanout was first observed with nearly infinite output impedance, and then it was observed with the output loaded by the coincidence circuit as it would be connected in operation. Although there was a 20% loss in voltage when the circuit was loaded, this is not considered to be excessive. Input and output pulse forms are shown in Fig. 8.

f. Coincidence circuit

The simple coincidence circuit utilizes two Q6-100 diodes for double coincidence action and three 2N964 transistors to isolate the coincidence circuit from the inputs and outputs. Two switches are provided to bias the diodes for singles from either channel or for coincidence. The circuit diagram is shown in Fig. 9.

The completed circuit was tested for resolving time in the following way: A cesium-137 gamma ray source was placed on one of the backing counter scintillators. Resulting pulses from the tube were run through the discriminator and then to the fanout, where they were split into three lines. The

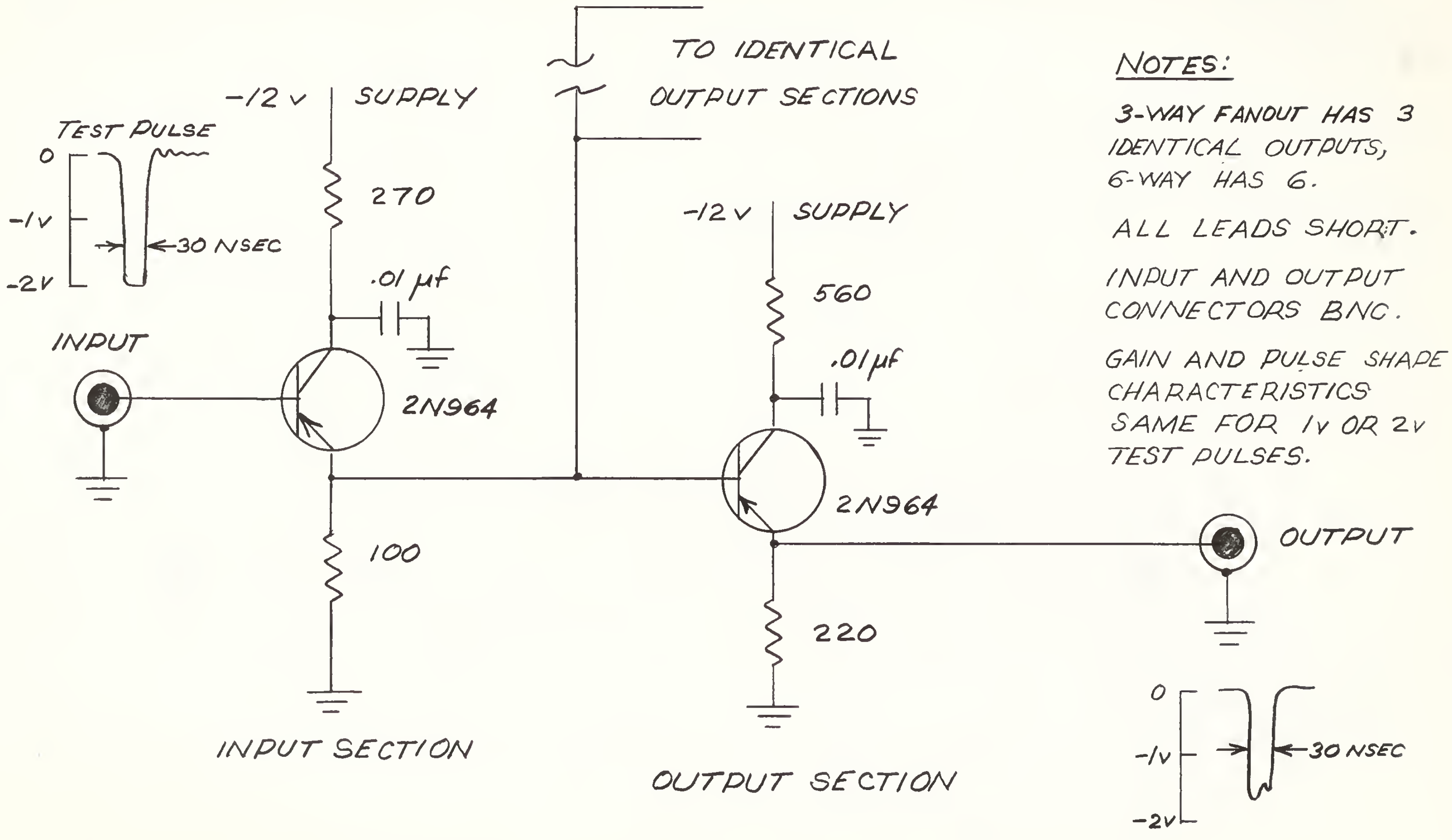


FIG. 8. FANOUT CIRCUITS

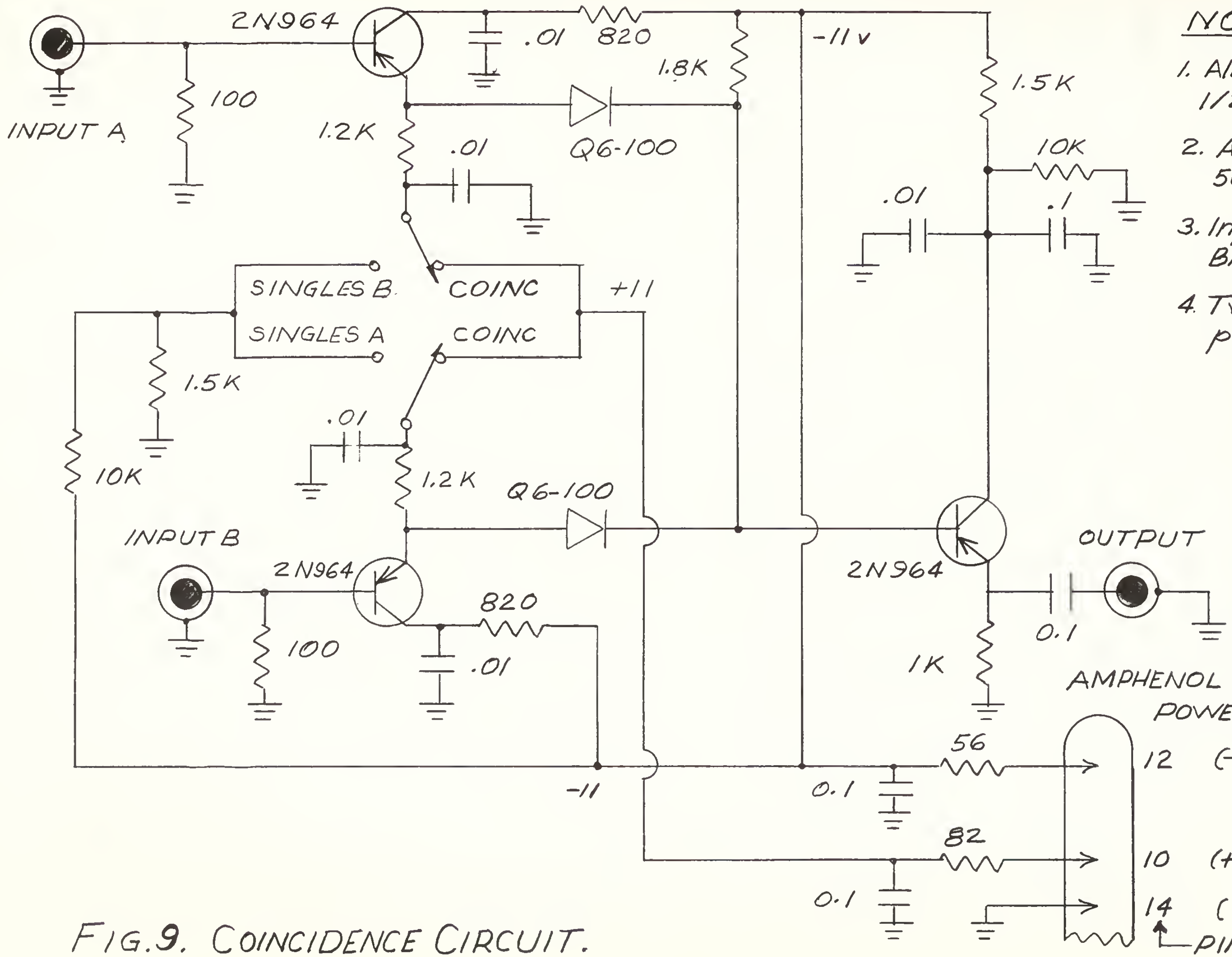


FIG. 9. COINCIDENCE CIRCUIT.

NOTES:

1. All Resistors 1/2 w, 5 %
2. All capacitors in μf, 50 v. ceramic
3. Input-output BNC UG-1094/U
4. Two circuits per module

shortest line was used to trigger a high speed oscilloscope, and the remaining two lines were fed to the coincidence circuit, a variable delay cable being inserted in one of these lines. The two inputs to the coincidence counter were simultaneously observed on the dual trace oscilloscope, and the delay between pulses read directly from the time scale of 10 nanosec/cm. A block diagram of the circuit used for the "cable curve" is shown in Fig. 10.

The test pulses had an amplitude of approximately 1.7 volts and a duration of 20 nanosec at the input of the coincidence counter. A counting rate of about 300 counts/sec is required to produce a trace intense enough to be seen on the oscilloscope. The cable curve obtained is shown in Fig. 11.

g. Scaler driver

The decade scaler driver shown in Fig. 12 was designed to receive negative pulses of amplitude and duration centered about 1 volt and 40 nsec respectively. Transistor Q_1 and Q_2 form a monostable multivibrator which yields an output pulse with size and length independent of the input pulse. Transistors Q_3 and Q_4 constitute an AND gate which permits the system to count only if a gate pulse, supplied by the accelerator trigger, is applied simultaneously with the channel pulse. A switch is provided to disable the gating circuit. The pulse leaving this stage is lengthened and amplified by transistor Q_5 and then sent to a Schmitt trigger, which forms the desired 20 volt, 2 microsec input pulse to the decade scaler.

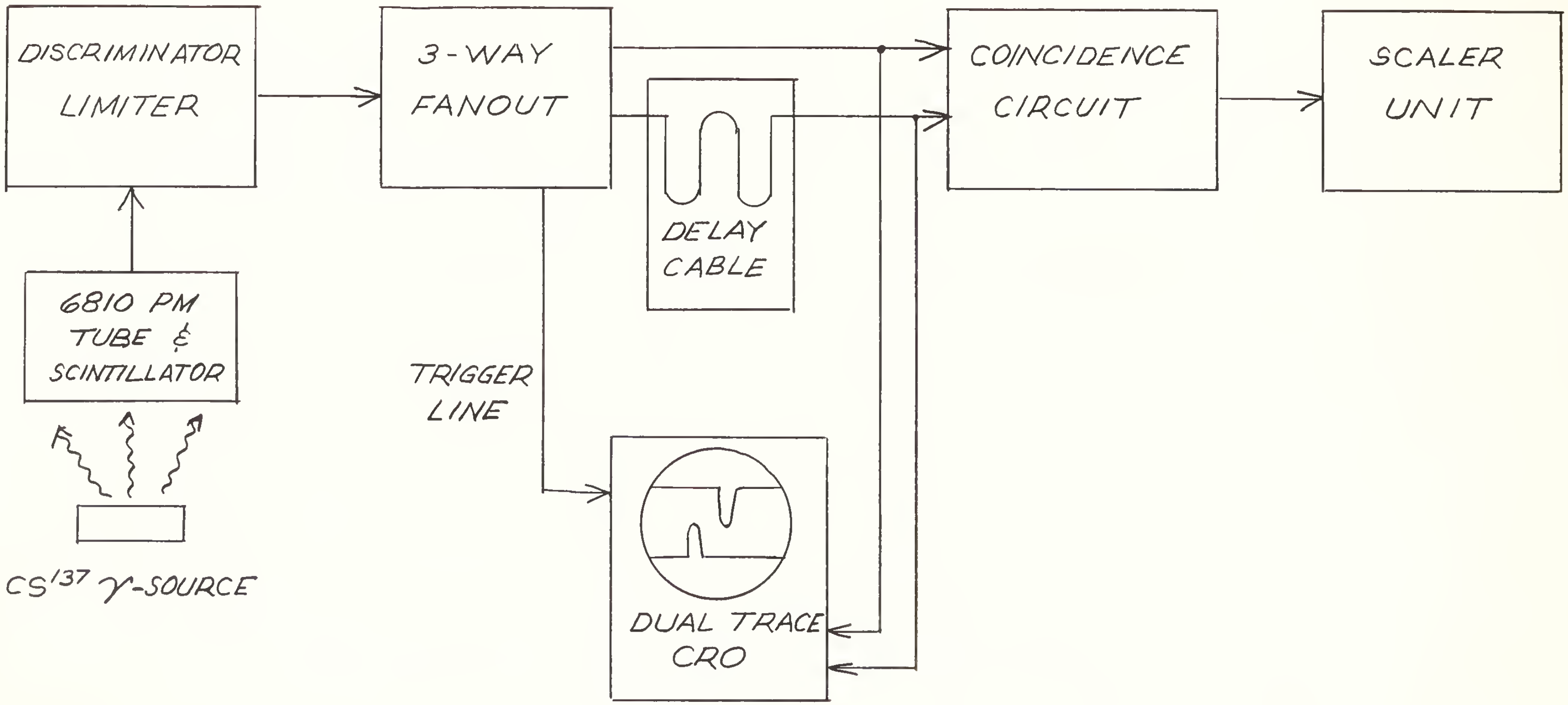


FIG. 10. LAYOUT USED TO OBTAIN RESOLUTION OF COINCIDENCE CIRCUIT

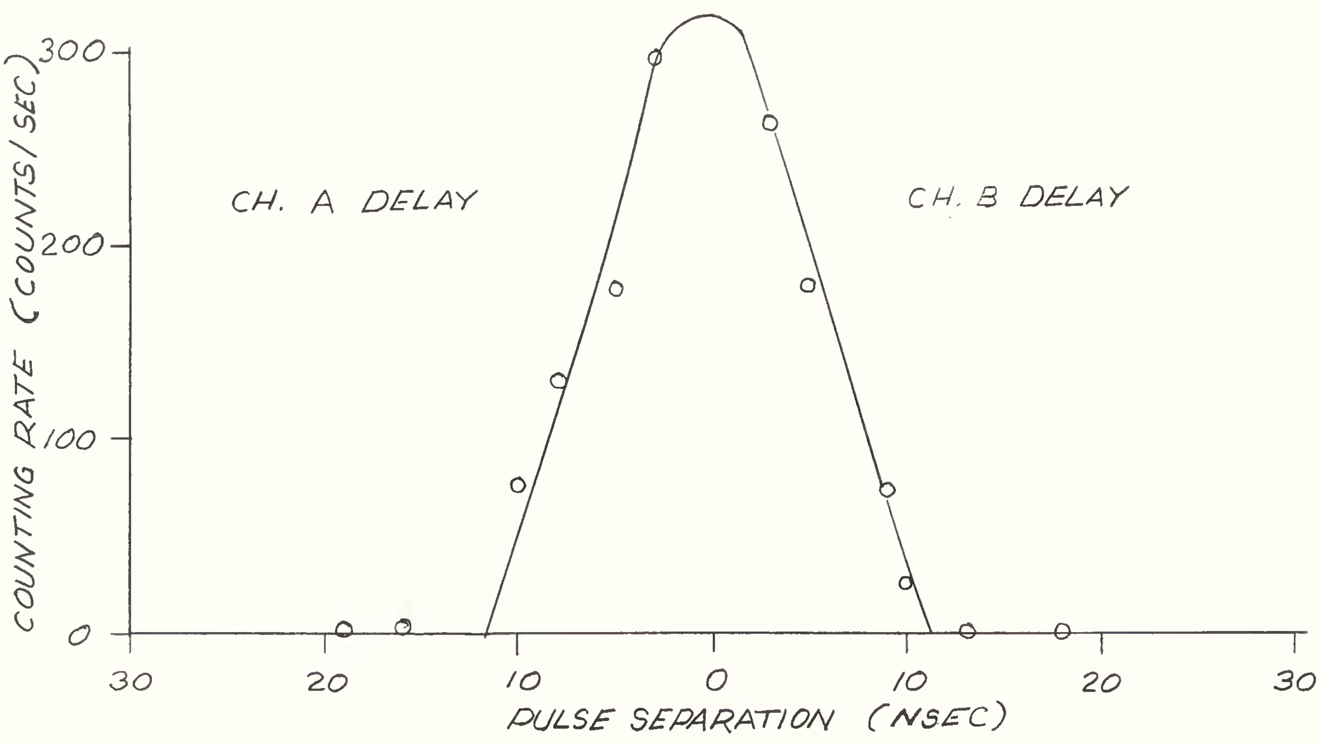
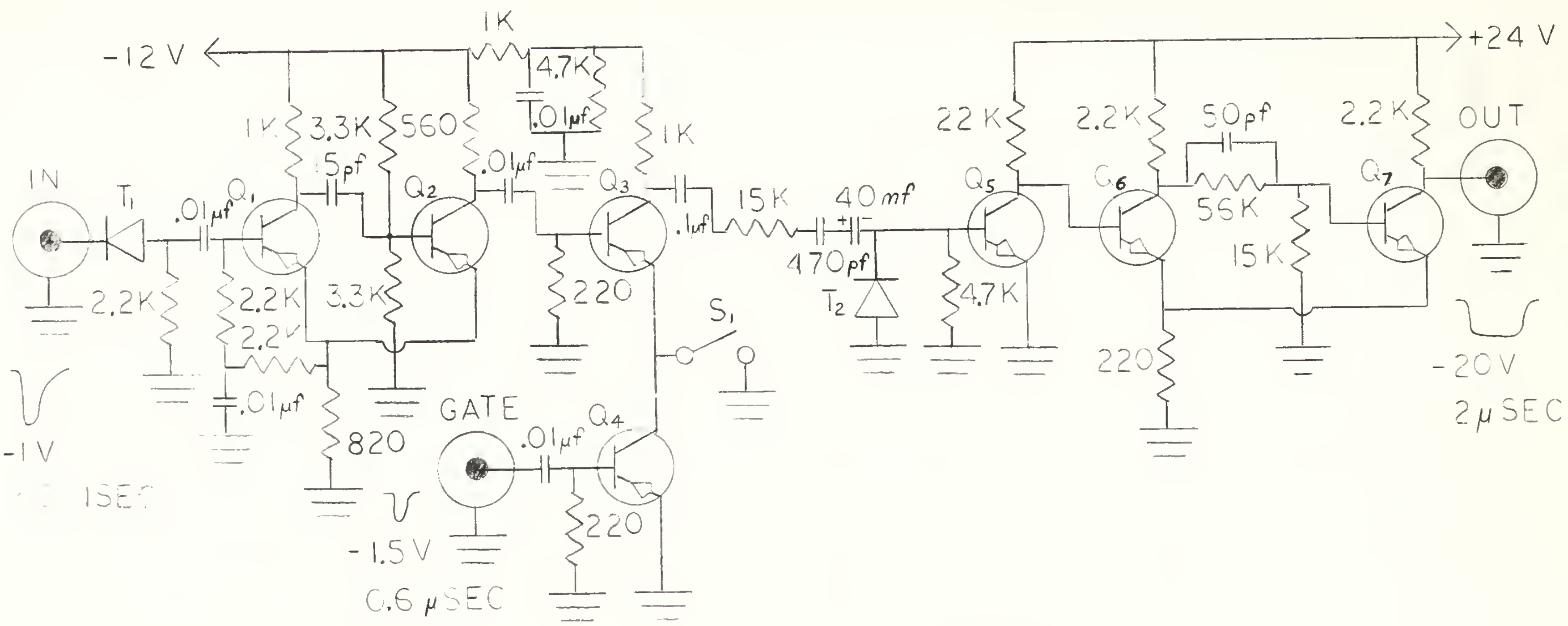


FIG. 11. RESOLUTION CURVE OF COINCIDENCE CIRCUIT



$Q_1 - Q_4$: 2N2048

$Q_5 - Q_7$: 2N1304

ALL RESISTORS 1/2 WATT

T_1: Q6-100

T_2: IN198

S_1: GATE ON OFF CONTROL

FIG. 12 SCALER DRIVER

h. Scaler

Anadex DC-101A decimal scalers are used to register the counts from each channel with four digit readout. Visual display of the readout is accomplished with ultra long life NIXIE tubes. The scalers have provision for decimal electrical readout. They are capable of counting at rates up to 100 kHz.

4. Testing Procedures

A Tektronix 581 oscilloscope with type 82 dual-trace plug in unit and P 6008 probe were used for pulse testing throughout the various circuits of the system. This enabled us to observe the short pulses without causing any appreciable distortion. The rise time of the oscilloscope vertical deflection system when used in conjunction with the type 82 plug in unit is on the order of 1.5 nsec. The dual-trace plug in unit proved to be very convenient for observing the input pulse simultaneously with any other pulse of interest.

As each component of the system was completed it was tested using an input pulse from a Tektronix type 110 pulse generator which is capable of providing pulses with rise times less than .25 nsec and pulse durations of approximately .5 nsec to 40 nsec. The 50 ohm output impedance of the pulse generator is compatible with the input impedances of the various components of the system. It also contains a trigger takeoff system which was normally used to provide the trigger pulse for the oscilloscope.

III. SPECTROMETER FIELD CONTROL

1. General Function of the System

A rotating coil in the field to be measured produces an electromotive force directly proportional to field strength. This signal is put in proper phase relation with, and nulled against, a reference signal. Deviations from null are amplified, rectified, and then fed to a differential amplifier. The differential amplifier output is coupled with adjustable sensitivity to a sensor and regulator which controls spectrometer magnet current. Fig. 13 shows a block diagram of the device.

The entire installation is a closed loop relay servomechanism, the heart of which is the rotating coil fluxmeter. The installation has seven basic components. In general functional order they are:

1) The rotating coil, motor, and signal pick-off device. This unit provides the basic information to be analyzed.

2) Reference voltage unit. The magnitude of the voltage developed in the rotating coil by the spectrometer field could be used to directly measure field strength. However, such measurement would inherently have considerable inaccuracy. Therefore, a reference voltage of the same frequency is generated and made 180° out of phase with the spectrometer voltage. A difference voltage is then obtained which can be measured with the greater inherent accuracy of

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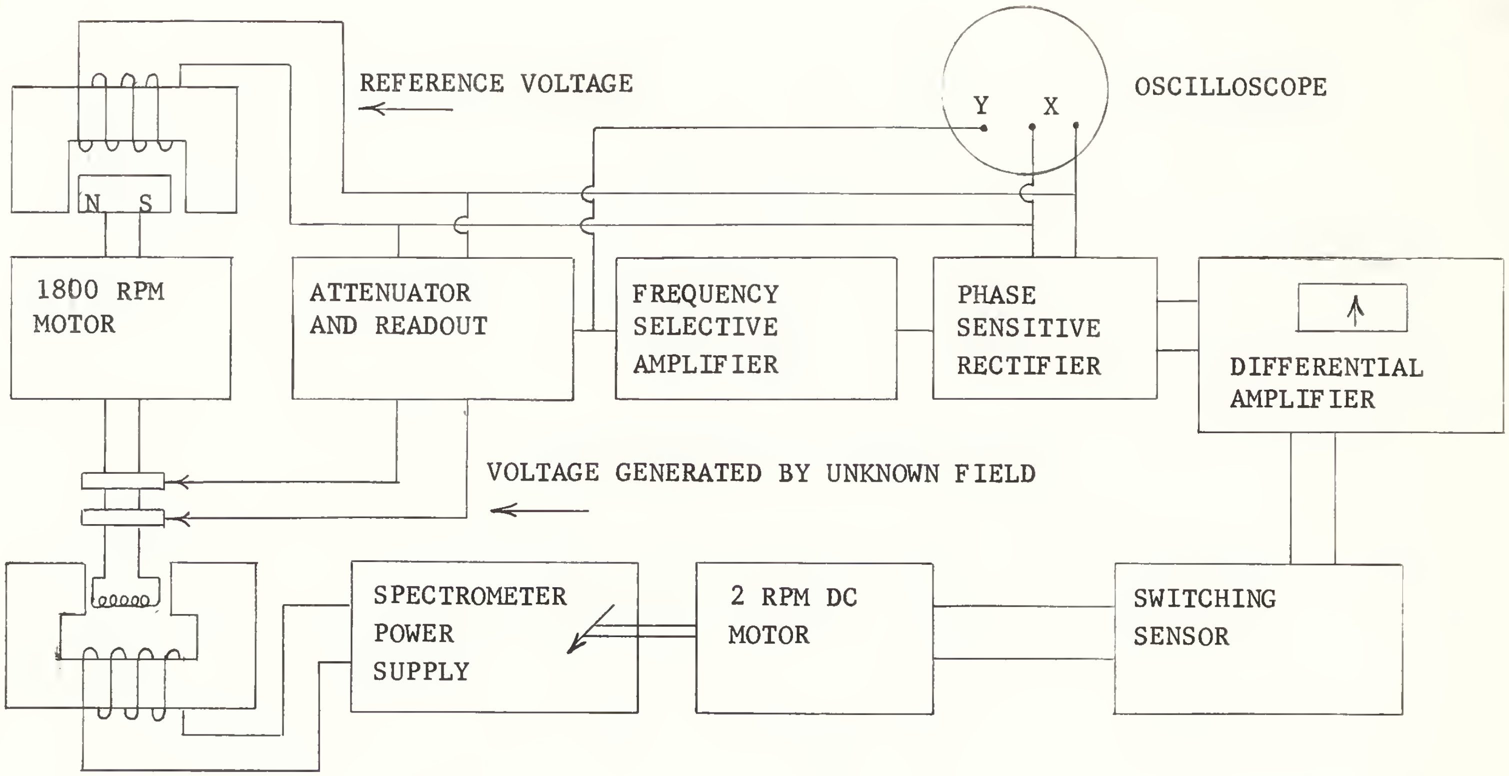

FIG. 13. BLOCK DIAGRAM OF SPECTROMETER FIELD CONTROL

a null method.

3) Nulling device and readout. The reference voltage and spectrometer voltage are coupled through a very accurate resistive divider chain which allows adjusting a portion of the reference voltage to equal the spectrometer voltage by means of a potentiometer. The spectrometer field strength can be read directly from the potentiometer setting.

4) Frequency selective amplifier. A deviation from null voltage is amplified and filtered by a Twin Tee network so as to reject extraneous signals.

5) Phase sensitive rectifier. The ac error signal is rectified in phase relation to the reference voltage. The output is then a dc voltage, the polarity of which reverses when the phase of the error signal reverses. The amplitude of the output depends within limits upon the error signal amplitude.

6) Differential amplifier. This unit amplifies the output of the phase sensitive rectifier and provides sufficient power to drive the null meter and actuate the sensor.

7) Field regulator system. A sensitive transistorized switch with adjustable triggering level actuates one of two relays when the differential amplifier output is non-zero. The actuated relay powers a low rpm dc motor coupled to the spectrometer power supply to accordingly increase or decrease mag-

net current.

2. Description of units

a. Rotating coil unit

The spectrometer voltage and reference voltage generator as an integral unit was available. An 1800 rpm (30 cps) synchronous hysteresis motor rotates both voltage generator units on opposite shaft ends. The voltage from the spectrometer field coil is picked off from two sterling silver slip rings by three equally spaced silver-graphite brushes [3] on each ring. The quality of materials used here and their arrangment made brush noise almost negligible. The reference voltage is generated by a permanent magnet rotating in one leg of a magnetic yoke, where the other leg is wound with sufficient wire to generate a signal of about 2 volts rms.

b. Null unit

A 100 kohm Dekapot [4] attenuator is used as the null device. It has linearity of $\pm .005\%$ and a resolution of .0003%. The calibration voltage divider is a series arrangement of two resistors and a 10 kohm, 10 turn potentiometer (0.1% linearity). This particular arrangement, as shown in Fig. 14, was chosen to extend the attenuator function over the entire spectrometer energy range. At the momenta encountered with the linear accelerator, energy E and momentum p are linearly related by $E = cp$; and, therefore, field and energy are also linearly related. The proper selection of resistors permits energy to be read directly from the

attenuator setting. This advantage of the rotating coil fluxmeter greatly facilitates experimentation.

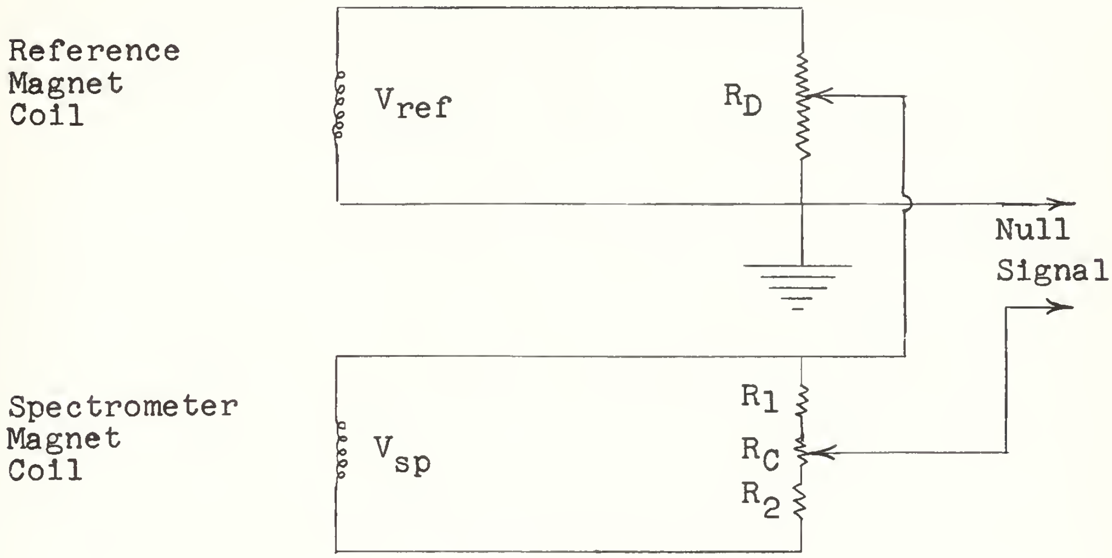

Fig. 14 Null Unit Schematic

Let

$V_{sp(max)}$ = emf generated in spectrometer magnet coil at max electron momentum to be encountered

V_{ref} = reference voltage

R_D = resistance of Dekapot attenuator

R_C = resistance of the calibration helipot

Then two resistors R_1 and R_2 are chosen such that

$$\frac{R_1}{R_1 + R_2 + R_C} = \frac{V_{ref}}{V_{sp(max)}}$$

and $R_1 + R_2 + R_C = R_D = 100$ kohms.

It is seen that various values of R_1 and R_2 could be switched into the circuit to change the range of the attenuator if a very wide range of fields were to be encountered.

The particular arrangement chosen requires that in any case V_{ref} must be less than $V_{sp(max)}$. In some applications then, V_{ref} may have to be stepped down to meet this requirement.

c. Frequency selective amplifier

The frequency selective amplifier shown in Fig. 16 provides four stage amplification, with considerable negative feedback, for a voltage gain of about 300. The Twin Tee device is used as a band-elimination filter, the output of which when fed back yields a band-pass filter network centered at 30 cps. The entire unit then has a half-power bandwidth of 5 cps, and the output is 20 db down at 60 cps for good hum and noise rejection.

The Twin Tee filter has many possible applications as a filter where the signal attenuation and relatively broad bandwidth of the device are acceptable. The unit has considerable advantage in its simplicity and ease of construction, and may be used as either a band-pass or band-elimination filter. The device is shown in Fig. 16, and is discussed in detail by Wallman and Valley [5].

The transfer function of the frequency selective amplifier is shown in Fig. 15.

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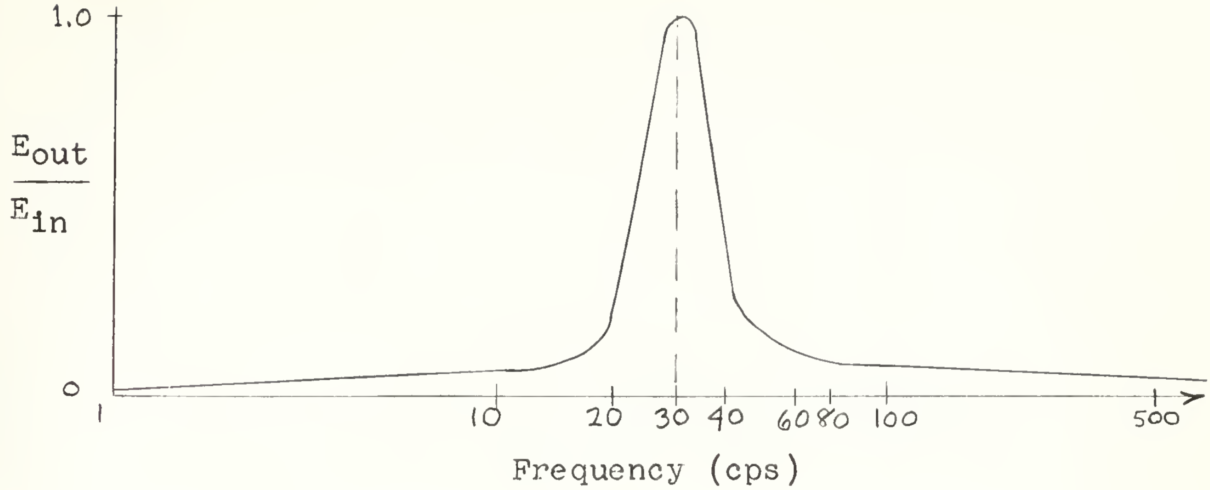


Fig. 15 Frequency Selective Amplifier Transfer Function

While ordinarily the error signal is very close to zero, it is possible that large error signals could be developed during adjustment or while changing field values. Therefore, several of the amplifier stages have reversed parallel diodes shunting grid input. This limits input signal to several millivolts and protects the circuit. The output of the entire unit is further limited by two back-to-back zener diodes which clip the output at plus and minus 2.4 volts. It will be seen in the next section that the amplified error voltage to the phase sensitive rectifier must be less than the reference voltage, after the latter is stepped up in the phase sensitive rectifier. If this is not the case, the input to the differential amplifier will have an undesirable ac component. The limiter prevents this condition.

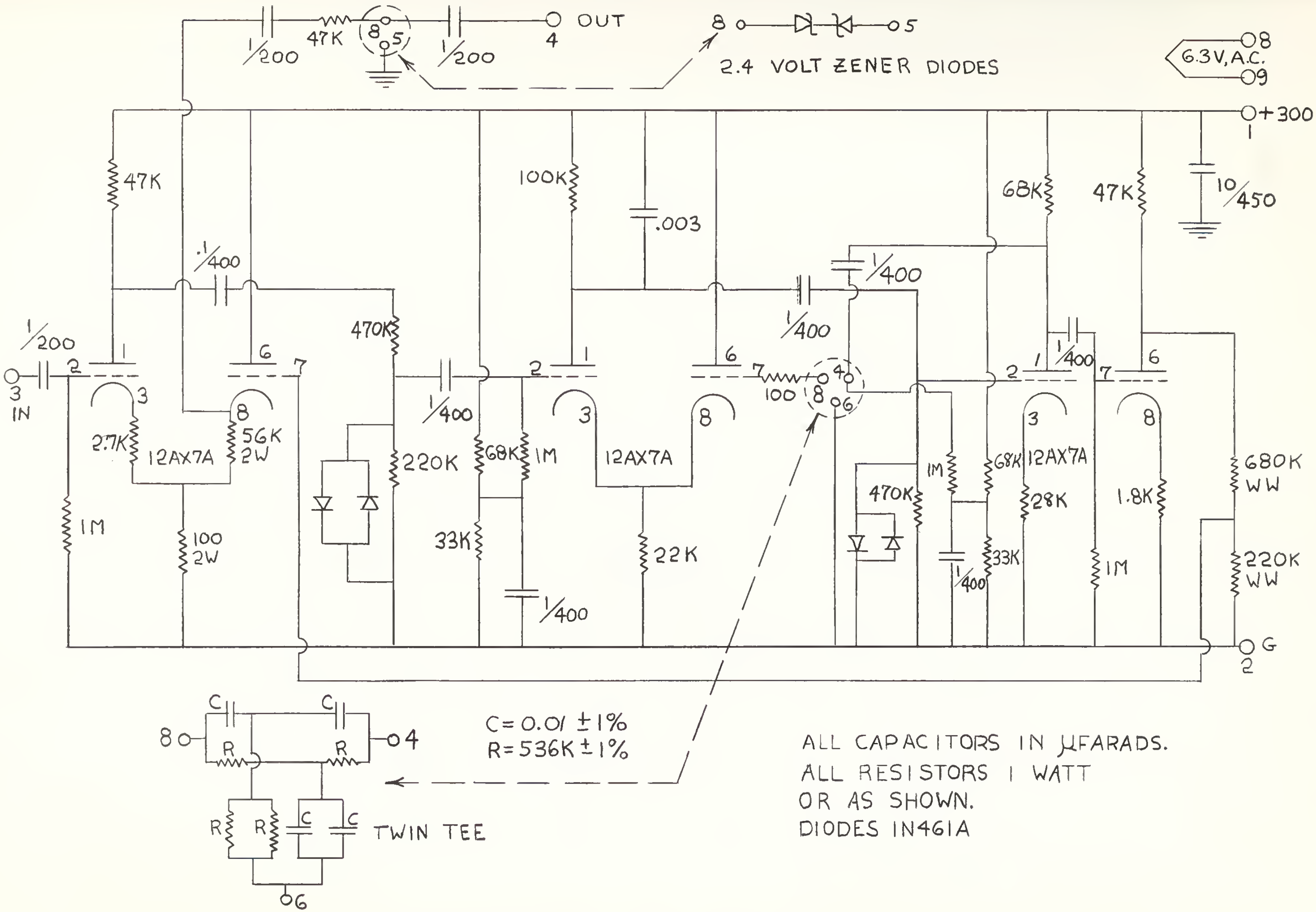
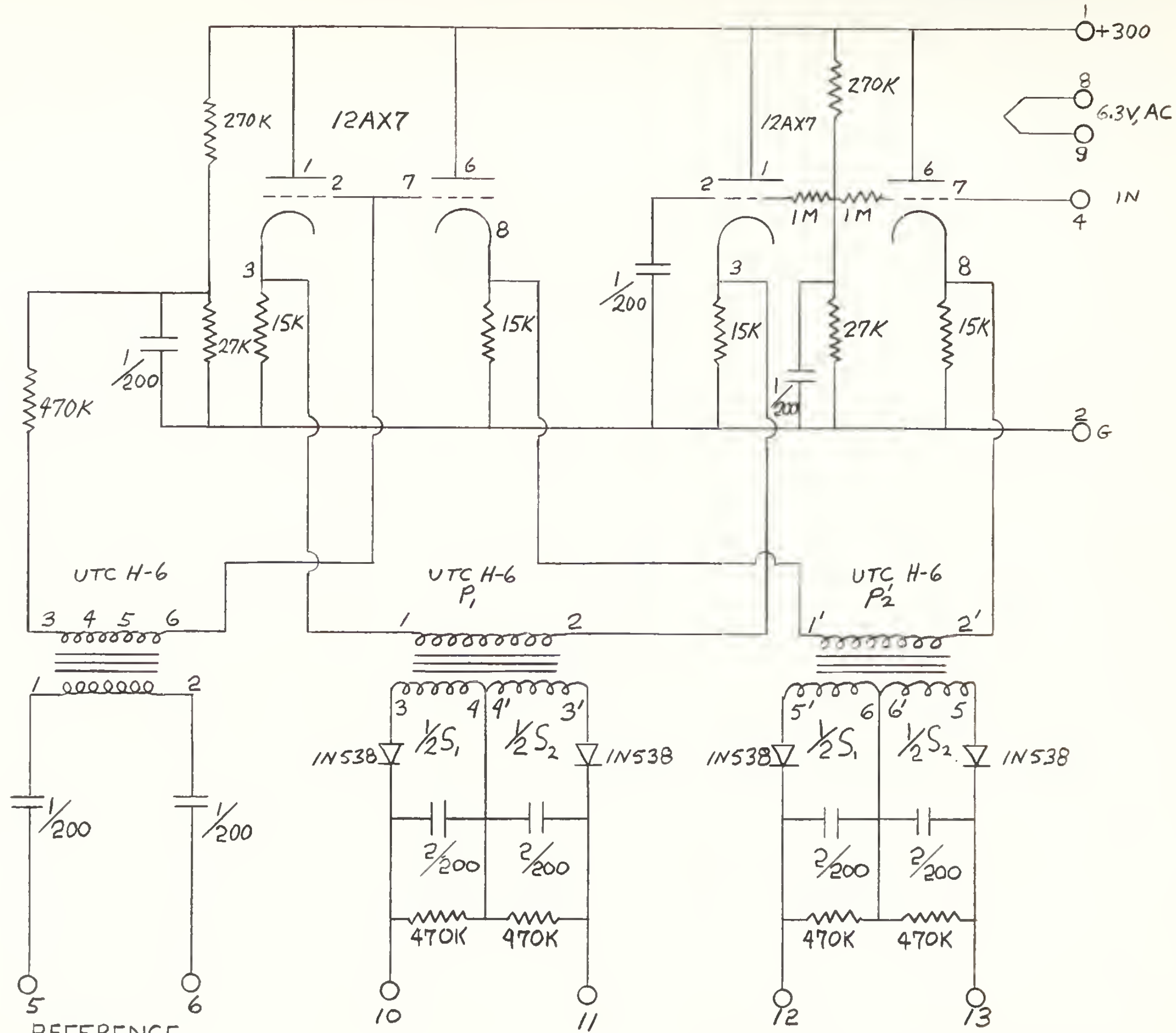


FIG. 16. FREQUENCY SELECTIVE AMPLIFIER AND TWIN TEE



ALL CAPACITORS IN µFARADS
ALL RESISTORS 1 WATT

FIG. 17. PHASE SENSITIVE RECTIFIER

d. Phase sensitive rectifier

The phase sensitive rectifier shown in Fig. 17 has critical limitations which may be encountered in this application. Consider the simplified schematic shown in Fig. 18.

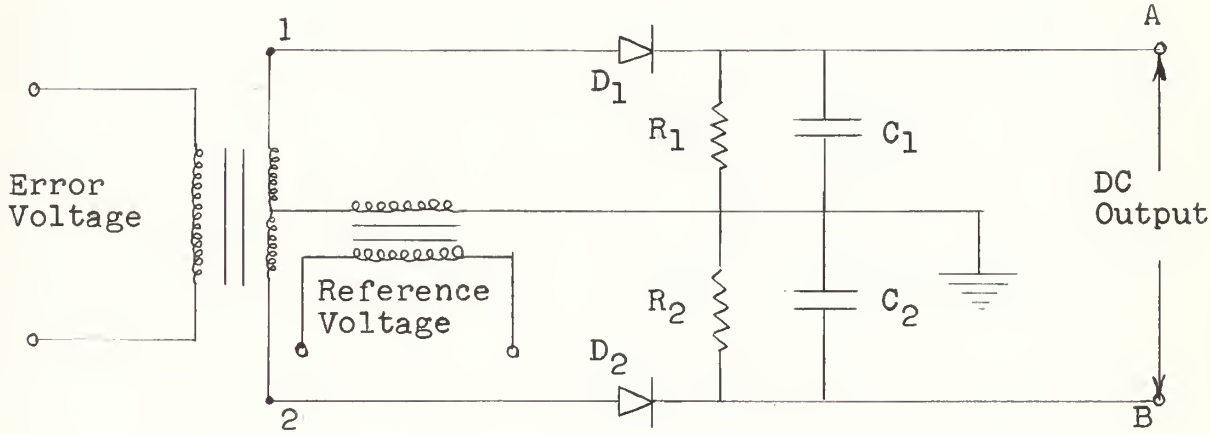


Fig. 18 Simplified Diagram of Phase Sensitive Rectifier

It is seen that both diodes will simultaneously conduct only when the reference voltage is in the negative half-cycle with respect to ground, assuming the reference voltage is greater than the error voltage. In the actual circuit the reference voltage is coupled in through a step-up transformer. The error voltage at each diode is either in or 180° out of phase with the reference voltage. Assume the error voltage at point 1 is out of phase with the reference voltage. Then, during the negative half-cycle of the reference voltage, the current in R_1 will be greater than that in R_2. Therefore, point A will be more positive with respect to ground than point B, and there will be a net dc voltage across

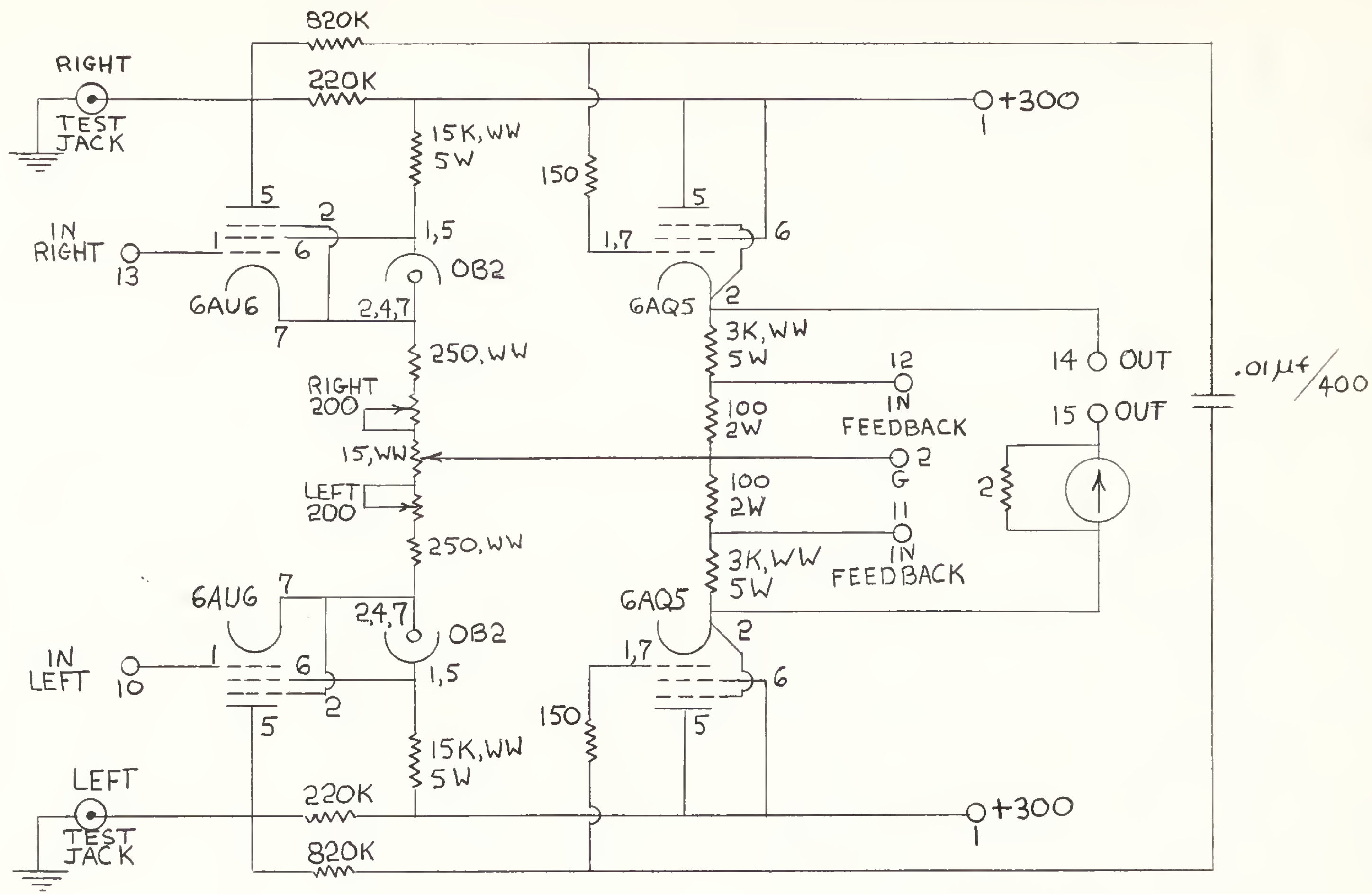
the output due to the smoothing function of the resistive-capacitive network associated with each diode. When the error signal is zero, each capacitor will charge to approximately the same peak value of stepped-up reference voltage and the voltage difference at the output will be zero.

It is important that the reference signal and the spectrometer signal be good sinusoids with little distortion. Distortion limits the ability of the phase sensitive rectifier to sense phase reversals, and consequently distortion lowers the sensitivity of the entire unit. If the waveforms are too distorted, the rectifier cannot distinguish phase reversal at all. Therefore, for large distortions rectification would occur in only one direction, and the output would not change polarity for phase reversal, but only come to some minimum unidirectional value.

Ideally, the output of this unit is a dc signal which varies in amplitude with error voltage and with phase relation between spectrometer and reference signal and has no ac fluctuations. The resistive-capacitive networks across the output are designed for smoothing, and ideally should have a very long time constant. The value of the time constants of the smoothing units must compromise between long time constants for greater smoothing and short time constants to allow the output to follow the error signal sufficiently fast in time.

e. Differential amplifier

The differential amplifier shown in Fig. 19 is designed



METER 50-0-50 μAMP
ALL RESISTORS 1 WATT OR AS SHOWN

FIG. 19. DIFFERENTIAL AMPLIFIER

for large power gain. The output is sufficient to power a variety of regulating systems other than the one used in this application. The two inputs of this unit are capacitively coupled. The proper value of the coupling capacitor can be easily chosen by observing the output for different values of capacitance. Optimum capacitor value will yield rapid response to error signal with minimum overshoot and effective damping. This does not necessarily imply critical damping, since the non-linear relay servomechanism can yield much faster response times than is possible with critical damping and still have negligible overshoot and hunting [6].

It is seen that part of the grid biasing network for the input of this unit is coupled through the output of the phase sensitive rectifier. In addition to the stabilizing effect of negative feedback, this allows balancing component differences in the phase sensitive rectifier. That is, balancing the differential amplifier also balances the phase sensitive rectifier.

In view of recent improvements in techniques for stabilizing transistor differential amplifiers [7], it is planned to transistorize this unit in the near future.

f. Sensor and regulator

The sensor elements and relay switches, as shown in Fig. 20, are of straightforward design. The unit assures rapid and sure switching at a predetermined signal level with minimum relay chatter.

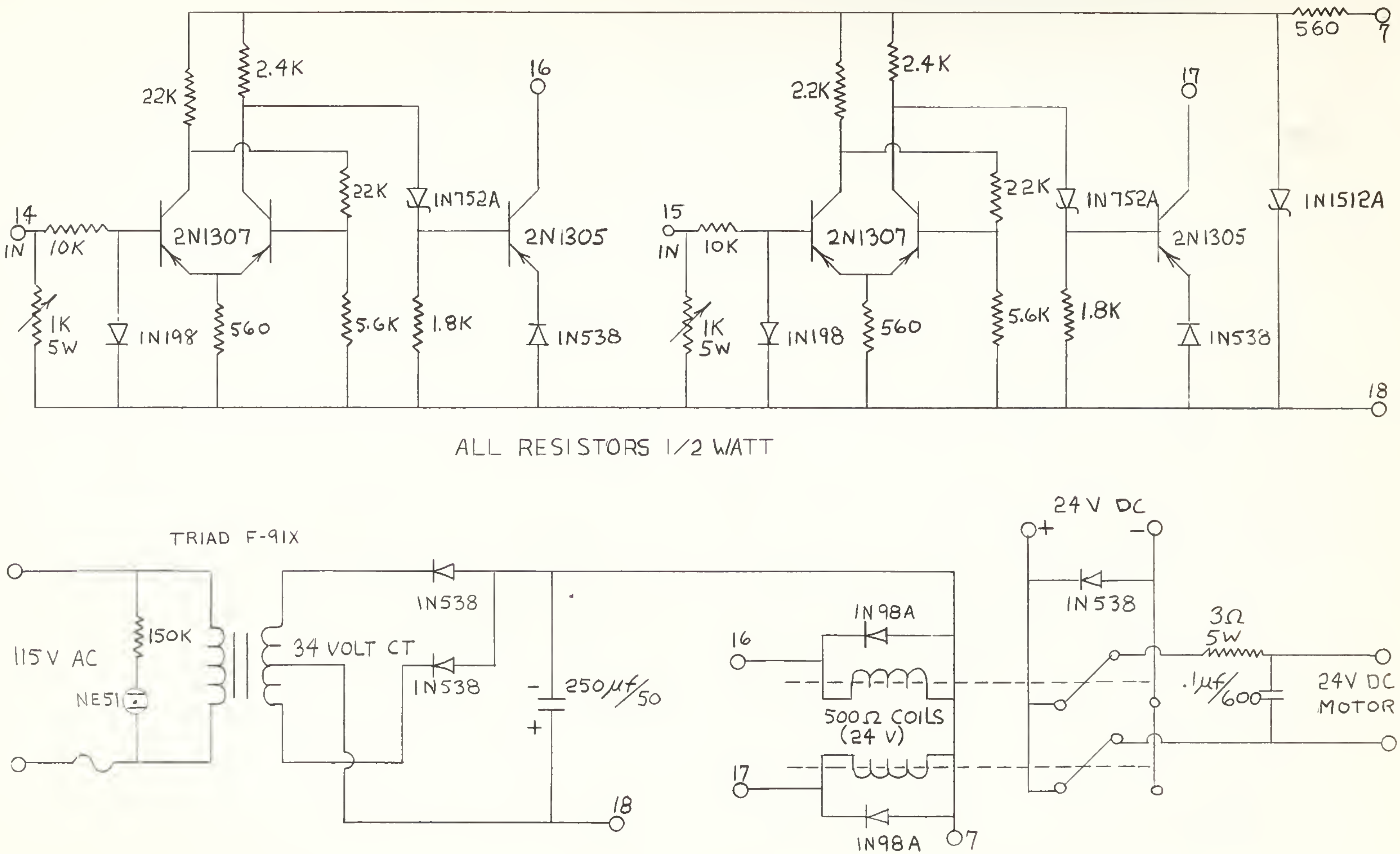


FIG. 20. SENSOR AND REGULATOR

The dc motor is directly coupled to the potentiometer adjusting the current in the spectrometer power supply. It is apparent that the response time of the entire system is directly proportional to the ratio of magnetic field change versus motor rpm. This ratio is again a compromise between rapid response and insufficient damping.

3. Initial Set-up and Operating Procedure

The entire device, except for the sensor and relays, should be turned on and allowed to warm up 15 minutes before adjustments are made. The relays may be de-energized by setting SENSITIVITY to zero. Calibration equipment required are an oscilloscope (CRO), a voltmeter (VOM), and a known magnetic field.

The differential amplifier is first balanced. Insure that reference voltage is being generated and is connected so as to concurrently balance component differences in the phase sensitive rectifier. Set the COARSE-FINE switch to COARSE and center the BALANCE potentiometer; then attach the grounding cap to the Y BNC connector. This simulates zero error signal. With the VOM adjust R and L potentiometers until both sides read 75 volts at the test jacks. The balance meter should also now be centered. Adjusting both sides of the amplifier will not regularly be required, since small deviation from a balanced condition now can be corrected with the BALANCE potentiometer.

Set the magnetic field to a known value and connect the horizontal deflection of the CRO to the X output (reference

voltage). Remove the grounding cap and connect the vertical deflection of the CRO to the Y COARSE output (error voltage before amplification). Set the Dekapot to zero and then rotate the reference coil so as to make the Lissajous figure on the CRO an approximate straight line. If the line slants up on the left (out of phase relation), then the phasing is correct. If the line slants up on the right, then rotate the reference coil 180°. Now set the Dekapot to the value of the known field. The Lissajous figure should now be an approximate horizontal line, assuming the CALIBRATION potentiometer is close to proper value. Switch to Y FINE, or remain in Y COARSE and increase CRO vertical gain, and adjust the reference coil so as to get the best straight line. Adjust the CALIBRATION potentiometer to zero the NULL meter. Repeat reference coil and CALIBRATION adjustments as necessary. The Lissajous figure should now be an approximate horizontal line, the NULL meter should be zeroed, and the value of the calibration field set on the Dekapot.

Increase both SENSITIVITY potentiometers to approximately half value. Small changes (plus or minus one gauss) in the Dekapot setting should now activate the relay servo to bring the field to the new value selected. The relays will normally actuate when the NULL meter is deflected one or two units. The SENSITIVITY is adjusted so as to activate the relays at that minimum NULL meter deflection which can be obtained with no relay chatter. A final test can be made by artificially disturbing the magnetic field, then removing the

disturbance and noting that the field returns to the present value.

4. Performance

The spectrometer magnet was not yet operational when the fluxmeter was completed. Therefore, test facilities were needed to verify performance. Two sets of apparatus were used during performance tests. The first, used to evaluate stability and regulation, was a homogeneous permanent magnet with small correction coils. The correction coils were powered by a small power supply connected to the dc regulation motor. The permanent magnet had a field of about 5400 gauss, and the correction coils could vary this plus or minus 100 gauss. Regulation and stability were then evaluated from 5300 to 5500 gauss. The very stable permanent magnetic field and precise regulation available with this procedure yields data applicable to a much wider range of fields. To test linearity and reproducibility, a six-inch pole face homogeneous electromagnet with regulated power supply was used. Tests were conducted in the range from 5000 to 9500 gauss. All rotating coil field readings were referenced to a nuclear-magnetic-resonance (NMR) device. Both the rotating coil and NMR probes were mounted at various angular positions within the magnetic field but at equal radial distances from the center of the pole faces. One-half inch and three-quarter inch pole gaps were used to reduce fringing and field inhomogeneities. It is expected that linearity and repro-

[illegible]

ducibility data are applicable down to fields of 1000 gauss.

The following data are obtained for fields up to 10,000 gauss where the calibration value is 5,000 gauss.

Linearity and reproducibility:

One part in 1,000 or one gauss, whichever is greater. For each angular positioning of the two probes within the magnetic field, it was found that rotating coil values were consistently greater or less than NMR values. It is therefore probable that the differences in field value were largely attributable to inhomogeneities and fringing in the magnetic field, or to unequal radial positioning of the probes.

Stability:

One part in 2,000 or 2.5 gauss, whichever is greater, over an eight hour period. These values are greatly effected by temperature stability in the voltage generating units and electronics. Only minimal cooling was used during the tests, so these limits should be improved with better cooling.

Regulation:

One gauss over the entire range. Regulation is almost independent of the size of the field being measured; therefore, percentage regulation will, of course, be better for larger fields.

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