"In presenting the dissertation as a partial fulfillment of the requirements for an advanced degree from the Georgia Institute of Technology, I agree that the Library of the Institution shall make it available for inspection and circulation in accordance with its regulations governing materials of this type. I agree that permission to copy from, or to publish from, this dissertation may be granted by the professor under whose direction it was written, or such copying or publication is solely for scholarly purposes and does not involve potential financial gain. It is understood that any copying from, or publication of, this dissertation which involves potential financial gain will not be allowed without written permission.

"

# A HIGH VOLTAGE SQUARE WAVE GENERATOR FOR STARK MODULATION

12T. R

A THESIS

Presented to

the Faculty of the Graduate Division

By

James Howard Mauldin

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in the School of Physics

Georgia Institute of Technology

May 1955

A HIGH VOLTAGE SQUARE WAVE

GENERATOR FOR STARK MODULATION

Approved: ______________________

______________________

______________________

Date Approved by Chairman: 4 June 1955

# PREFACE

During the course of the research work going on at the Graduate Laboratory at Georgia Institute of Technology, it became apparent that future work in microwave spectroscopy would be greatly facilitated by the construction of a high voltage square wave generator for Stark modulation. This work has been made possible through the sponsorship extended by the Office of Ordnance Research, United States Army, under Contract Number DA-01-009-ORD-353. The author would like to express his appreciation to Drs. T. L. Weatherly and J. Q. Williams both for suggesting the thesis topic and for supplying many hours of constructive consultation.

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

THESIS ABSTRACT

A HIGH VOLTAGE SQUARE WAVE
GENERATOR FOR STARK MODULATION

( 31 pages )

by

James Howard Mauldin

This thesis describes the construction and use of a high voltage square wave generator for Stark modulation of a microwave spectrograph. Also included is a discussion of the rotational spectrum of a gas with and without an applied electric field.

Microwave spectroscopy is a study of the absorption of electromagnetic energy by a gas in the region extending from about 1 millimeter to 30 centimeters in wavelength. Most of the spectral lines found in this region result from changes in the rotational energy of molecules.

The gas to be studied is introduced into a waveguide through which electromagnetic energy is flowing. This energy is produced by a klystron at one end of the waveguide and is detected by a crystal rectifier at the other end. The absorption of energy by the gas can be observed on an oscilloscope by frequency modulating the klystron in phase with the horizontal deflecting voltage of the oscilloscope and applying the amplified signal from the crystal rectifier to the vertical deflection plates. More sensitive spectrographs employ the principle of Stark effect.

The Stark effect is the splitting of the energy levels of a molecule when an electric field is applied to the gas. This splitting of the

energy levels produces a splitting of the original spectral line into a number of weaker Stark components. Thus, if the klystron is tuned to either the original line frequency or to a Stark component frequency, and the electric field switched on and off, the microwave energy transmitted through the gas will be modulated at the on-off frequency. This electric field can be supplied by a square wave voltage applied between the waveguide and an electrode inside the waveguide. The square wave is zero based so that for a half cycle the electric field between the electrode and the waveguide is zero. Thus, the square wave generator applies an approximately constant electric field for one half a cycle and zero electric field for the remainder of the cycle.

The signal from the crystal rectifier is detected by a narrow-band communications receiver tuned to the square wave frequency. The spectral lines can be observed on an oscilloscope if the output of the receiver is applied to the vertical deflection plates and the klystron is frequency modulated in phase with the horizontal sweep.

The square wave generator consists of a crystal controlled oscillator, pulse formers and amplifiers, and special tubes which charge and discharge the electrode within the waveguide. The oscillator produces an 85 kilocycle sine wave which is then split into two sine waves 180 degrees apart by a transformer. These sine waves are transformed into sharp pulses which have short rise time. The pulses are then applied to the grids of output tubes which alternately charge and discharge the electrode.

The apparatus was used to observe the $J = 1 \rightarrow 2$ transition in carbonyl sulfide. By measuring the frequencies of the Stark components, the dipole moment of the carbonyl sulfide was calculated to be 0.71 debye units as compared with the reported value of 0.709 debye units.

# CHAPTER I

# INTRODUCTION

The square wave generator described in this thesis will be used in conjunction with a microwave spectrograph for the observation of the spectra of gas molecules. The spectrum of a gas molecule is determined by its electronic, vibrational, and rotational energies. To a good approximation these energies are separately quantized. Changes in energy are accompanied by absorption or emission of electromagnetic radiation of a frequency given by the Bohr relation

$$\nu = \frac{\Delta E}{h} \tag{1}$$

where $\nu$ is the frequency of the absorbed or emitted radiation in cycles/second, $\Delta E$ is the energy difference between the initial and the final state in ergs, and h is Planck's constant in erg-seconds. The radiation produced by changes in the electronic energy lies in the visible and ultraviolet part of the spectrum, while that resulting from changes in the vibrational energy fall in the infrared region. Frequencies produced by changes in the rotational energy fall in the microwave frequency region of the spectrum. It is these latter frequencies that are of interest in microwave spectroscopy.

Absorption of electromagnetic energy by a rotating molecule arises from interaction of the molecular dipole moment with the electromagnetic field. Hence, no pure rotation spectrum is observable if the molecule has no permanent dipole moment. Classically, the molecule may rotate with any angular velocity, which would result in a continuous absorption spectrum; however, discrete spectral lines are observed. This indicates that only certain rotational energies are allowed - a well known result predicted by wave mechanics. Although classical mechanics does not always lead to the correct results, it gives useful pictures of the molecular motions. In the final analysis, the use of wave mechanics becomes necessary for the correct interpretation of the spectrum.

For the rotational energy of a rigid linear molecule, the quantum mechanical wave equation in polar coordinates is

$$\frac{1}{\sin\theta}\frac{\partial}{\partial\theta}\left(\sin\theta\,\frac{\partial\Psi}{\partial\theta}\right)+\frac{1}{\sin^2\theta}\,\frac{\partial^2\Psi}{\partial\phi^2}+\frac{8\pi^2 IE}{h^2}\,\Psi=0 \qquad (2)$$

where $\theta$ is the polar angle of the molecular axis with respect to a fixed direction in space, and $\phi$ is the azimuthal angle. Physically significant solutions of this equation are possible for certain discrete values of $E = E_J$ only. Quantum mechanics text (1) give the solution

$$E_J=\frac{h^2}{8\pi^2 I}\,J\left(J+1\right) \qquad (3)$$

where h is Planck's constant and I is the moment of inertia of the molecule, defined by

$$I=\sum_i m_i r_i^2 \qquad (4)$$

where $m_i$ is the mass and $r_i$ is the distance from the center of mass to the $i$-th nucleus. The rotational quantum number J may take any positive integral value. For transitions induced by electric dipole radiation the selection rules for J are

$$\Delta J = \pm 1 \tag{5}$$

The energy levels and allowed transitions for J = 0, 1, 2 are shown on the left in Figure 1a.

The frequencies corresponding to the above transitions are given by

$$\nu = 2B(J+1) \tag{6}$$

where

$$B = \frac{h}{8\pi^2 I} \tag{7}$$

Thus, by measuring the frequencies at which a certain gas will absorb microwave energy, it is possible to calculate the moment of inertia of the molecule. For a diatomic molecule it is possible to determine the inter-nuclear distances from the moment of inertia. For a molecule containing more than two atoms the absorption frequencies of several isotopic forms must be obtained in order to compute all the intra-atomic distances.

In addition to discrete energy values, equation (1) also predicts discrete values of the total angular momentum P and its z- component $P_z$,

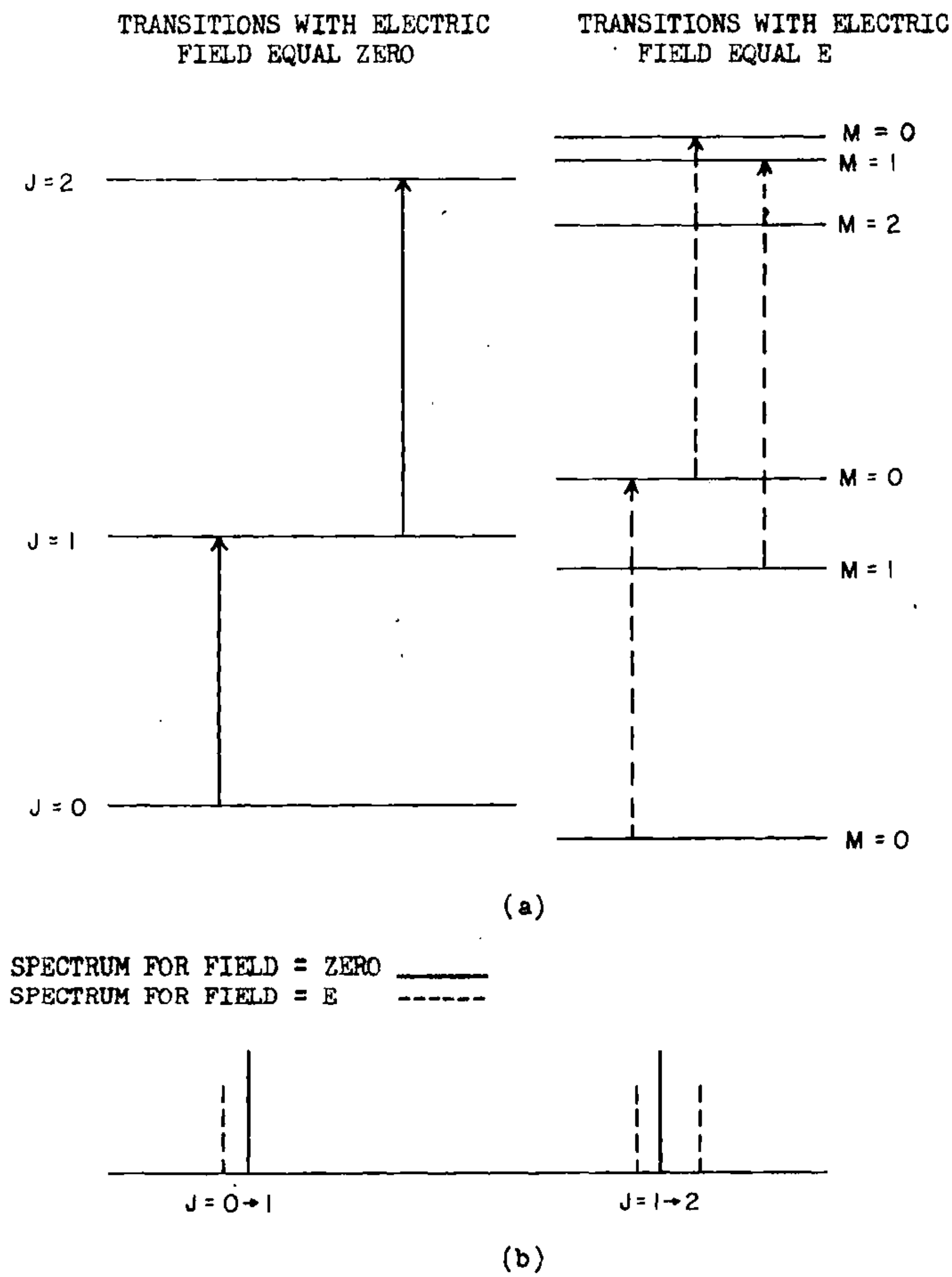


FIGURE 1. (a) PLOT OF ENERGY LEVEL DIAGRAM
(b) PLOT OF ABSORPTION SPECTRUM VERSUS FREQUENCY

which are given by (1)

$$P = \sqrt{J(J+1)}\,\frac{h}{2\pi} \tag{8}$$

$$P_z = M\frac{h}{2\pi} \tag{9}$$

where M may take only the values J, J-1, ..., -J.

The azimuthal quantum number M determines the angle $\alpha$ between the total angular momentum vector $\vec{P}$ and the space fixed z- axis. This angle can be obtained from

$$\cos\alpha = \frac{M}{\sqrt{J(J+1)}} \tag{10}$$

which is a direct result of equations (7) and (8).

When an electric field is applied in the region of space occupied by a rotating gas molecule, the allowed rotational energies are split as a result of the interaction between the electric field and the molecular dipole moment. The magnitude of this energy splitting depends upon the electric field strength $\vec{E}$, the dipole moment $\mu$, the direction of the total angular momentum vector $\vec{P}$ with respect to the molecule, and the angle between $\vec{P}$ and the electric field $\vec{E}$. For an electric field in the z- direction the angle between $\vec{P}$ and $\vec{E}$ is given by equation (9). Therefore, the energy splitting will be a function of the quantum number M. This effect upon the energy levels when an electric field is applied is termed the first-order Stark effect. There also exists a second-order Stark effect which is proportional to $E^2$.

The exact magnitude of this energy splitting is very difficult to calculate. For a linear molecule the first-order Stark effect does not appear. The magnitude of the energy splitting due to the second-order Stark effect is given by (2)

$$W_{JM}^{(2)} = \left[ \frac{4\pi^2 \mu^2 E^2 I}{h^2} \right] \left[ \frac{J(J+1) - 3M^2}{J(J+1)(2J-1)(2J+3)} \right] \tag{11}$$

with

$$W_{00}^{(2)} = - \frac{4\pi^2 I E^2 \mu^2}{3h^2} \tag{12}$$

where E is the strength of the applied electric field, and I is the moment of inertia of the molecule about its center of gravity. Since $W_{JM}^{(2)}$ is a function of $M^2$, and M may take the values -J, -J 1, ..., J, each rotational energy level is split into J + 1 levels when the field E is applied. The splitting of the J = 0, 1, 2 levels of a linear molecule is shown on the right of Figure 1a. When the applied electric field E is parallel to the electric vector of the incident radiation, only those transitions are allowed for which $\Delta M = 0$. Transitions corresponding to this selection rule are shown in Figure 1b. If E is perpendicular to the electric vector of the incident radiation, transitions are allowed for which $\Delta M = \pm 1$.

For the symmetric-top molecule, first-order and second-order Stark effects exist and the magnitude of the energy splitting is given by

$$W_{JMK}^{(1)} = - \frac{\mu E M K}{J(J+1)} \tag{13}$$

$$W_{JMK}^{(2)} = \frac{4\pi^2 I \mu^2 E^2}{h^2} \quad \frac{(J^2 - M^2)(J^2 - K^2)}{J^3(2J-1)(2J+1)} - \frac{[(J+1)^2 - M^2][(J+1)^2 - K^2]}{(J+1)^3(2J+1)(2J+3)} \tag{14}$$

where the selection rules for linear molecules apply, with the additional requirement that $\Delta K = 0$. The solutions for an asymmetric-top molecule are considerably more involved than those for linear and symmetric-top molecules. These solutions are given in the form of algebraic equations which increase in degree as J increases. Hence, it is possible to obtain from them explicit expressions for the energy levels for certain low J values only.

By reference to Figure 1a, one can see that when an electric field is applied, the characteristic absorption frequencies of the gas are shifted. Figure 1b is a plot of the absorption spectrum for a linear molecule. When the electric field is zero, absorption occurs at the frequencies indicated by the solid lines. When an electric field is applied, absorption occurs at the frequencies indicated by the dotted lines. The solid lines will be referred to as the main spectral lines, and the dotted lines will be termed Stark components.

Since the energies of absorption in the presence of an electric field depend upon the dipole moment as well as other variables, it is possible by use of the Stark effect to measure the dipole moments of gases.

# CHAPTER II

## THE MICROWAVE SPECTROGRAPH

The early microwave spectrographs consisted of a klystron oscillator to supply the microwave energy, a waveguide section to contain the gas, a crystal detector to rectify the ultra-high frequency radiation from the klystron, and a low frequency or direct current amplifier to amplify the rectified signal. The energy transmitted through the waveguide was measured as a function of the frequency. Later investigators displayed the amplified signal from the crystal detector on the vertical plates of an oscilloscope while a saw-tooth voltage was applied to the klystron reflector to sweep the tube over a narrow frequency range. The same saw-tooth voltage was used to sweep the oscilloscope horizontally, thereby displaying a plot of power transmitted through the gas versus frequency. If a sufficiently strong and sharp absorption line of the gas occurred in the frequency region being covered, it would be seen as a pip on the oscilloscope trace. This arrangement had the advantage of simplicity but lacked sensitivity.

In 1947 Hughes and Wilson (3) described an ingenious method of increasing the sensitivity of a microwave spectrograph by use of the Stark effect. A block diagram of this apparatus is shown in Figure 2. The basic principle used is the modulation of the absorption of the gas at a low radiofrequency by the application of a square wave voltage to an electrode in the waveguide. The square wave voltage applied to the electrode produces an approximately uniform field in the guide which is

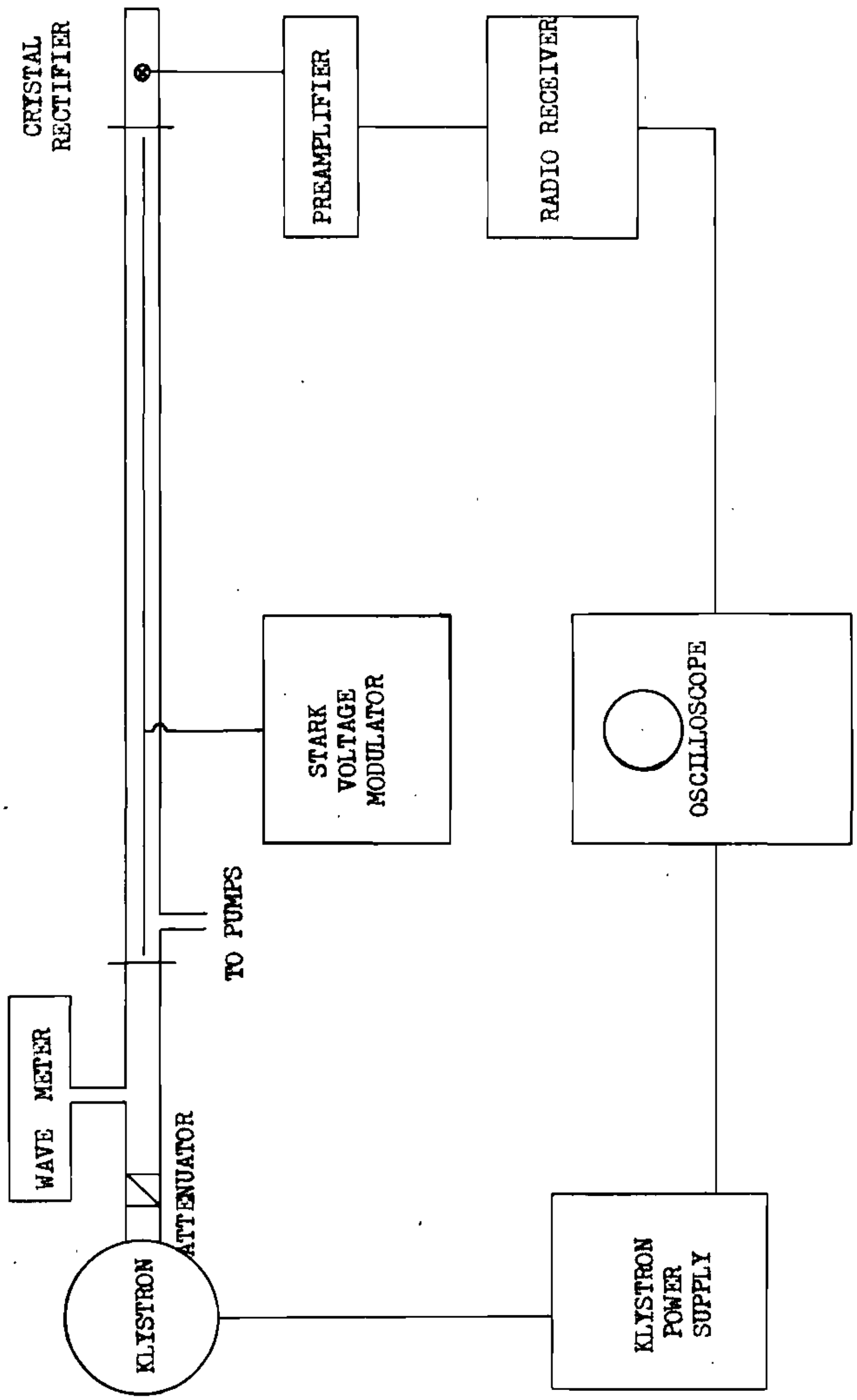


FIGURE 2 - BLOCK DIAGRAM OF THE MICROWAVE SPECTROGRAPH

turned on and off at the square wave frequency. This electrode consists of a metal strip mounted in the middle of the guide and extending the length of the guide. The strip is supported by teflon insulators along each edge. The electrode is mounted so that it is perpendicular to the electric field of the microwave energy. For this type of mounting the electric field distribution of the microwave energy in the gas is not seriously affected by the presence of the central electrode. Also, the inhomogeneity of the radiofrequency field is serious only at the sides of the waveguide, where the microwave field is rather weak.

The square wave is zero based so that half the time the voltage between the electrode and the guide is zero and the other half it is equal to the peak voltage of the square wave. When the klystron frequency coincides with that of a main spectral line, absorption will occur when the applied voltage is zero, and will not occur when the applied voltage is peak value. When the klystron frequency corresponds to that of a Stark component, absorption will occur when the applied voltage is peak value, but will not occur when the voltage is zero. In both cases the microwave power transmitted through the gas will be modulated at the frequency of the square wave voltage. After rectification of the microwave energy by a crystal, the resulting radiofrequency signal is amplified and detected by a narrow-band radio receiver, and applied to the vertical plates of an oscilloscope. The horizontal plates of the oscilloscope are swept by the same saw-tooth voltage applied to the reflector of the klystron. For higher sensitivity a phase sensitive amplifying and detecting system with a very narrow-band width is used together with a pen and ink recorder. In this case, the frequency of the klystron is slowly varied by a mechanical drive while the reflector voltage is held constant.

The spectrum observed using Stark modulation consists of the main spectral line and its Stark components. The pattern of Stark components is necessary for the measurement of dipole moments and is frequently useful for identifying the transition. However, the principal advantage of Stark modulation is the resulting gain in sensitivity. By detecting and amplifying at a radiofrequency, one avoids the lower frequency region where there is high crystal and source noise. In addition, detection of power variations caused by reflections in the waveguide and spurious responses caused by other frequency sensitive devices in the waveguide systems are eliminated.

It is possible to obtain Stark modulation by the application of a zero based sine wave voltage to the Stark electrode. This type of modulation was employed in the Georgia Institute of Technology spectrograph up until the time this project was completed. It was decided to undertake the construction of a square wave modulation system in preference to the sine wave modulation for the following reason. Better resolution and hence more detail is observed when using square wave modulation than is the case when using sine wave modulation. With sine wave modulation the field gradually changes from zero to a maximum and then back to zero. This means that the Stark components will be spread over a wide range of frequencies and will not be individually resolved. With the square wave generator the rise time of the field is short and allows a more constant field both at the maximum voltage and at zero.

It might appear at first glance that the best modulation frequency would be the highest attainable since crystal noise decreases with frequency. Actually there are several factors which place an upper limit on this frequency. The power dissipated in charging and discharging the Stark cell is given by

$$P = \nu C V^2 \tag{15}$$

where $\nu$ is the frequency of the square wave, C is the capacitance of the guide, and V is the peak value of the square wave voltage. Thus, as the frequency increases, so does the power expended. Also, if one uses modulation frequencies higher than about 100 kilocycles, the true absorption line shape becomes seriously broadened. This can be explained by the Heisenberg uncertainty principle which is given by

$$\Delta E \, \Delta t \approx h . \tag{16}$$

In this equation $\Delta E$ is the uncertainty in the energy of a state which exists for a time $\Delta t$ . From the Bohr frequency condition

$$\Delta E = h \, \Delta \nu \tag{17}$$

therefore, the uncertainty in frequency is given by

$$\Delta \nu \approx \frac{1}{\Delta t} . \tag{18}$$

For square wave modulation of frequency f the uninterrupted lifetime of an energy state is

$$\Delta t = \frac{1}{2f} \tag{19}$$

giving

$$\Delta \nu \approx 2f \tag{20}$$

for the uncertainty in frequency associated with each energy state. Thus, for a transition between two such energy states, the resulting line width will be approximately four times the modulation frequency. This means that as the modulation frequency increases, the spectral lines will be broadened. Consideration of these factors thus lead to the adoption of an optimum Stark modulation frequency of about 85 kilocycles.

It is the purpose of this thesis to describe the construction and use of a high voltage square wave generator for Stark modulation. This generator is similar to the ones described by L. C. Hedrick (4) and Walter Gordy (5).

# CHAPTER III

## DESCRIPTION OF EQUIPMENT

The instrument to be described was developed for the purpose of supplying an 85 kilocycle square wave voltage to a load consisting of a 1600 micromicrofarad capacitor. This square wave was required to be zero based and variable in amplitude from approximately 50 to 1000 volts.

Figure 3 is a block diagram of the square wave generator. Figure 4 shows in schematic the pulse generator section of the square wave generator. A schematic diagram of the pulse amplifiers and the switching circuit is shown in Figure 5.

A simple explanation of the operation of the square wave generator can be obtained by reference to Figure 3. The wave form for each block is shown in the diagram. The oscillator is a conventional crystal controlled oscillator. The next stage serves both as an amplifier for the signal and as a buffer for the oscillator. Following the amplifier is a phase splitting transformer. This transformer splits the original signal into two signals which are identical except that one is one-half period behind the other. One of these signals then goes through channel A, while the other travels through channel B. Both channels are similar in that they produce large positive pulses. The first stage of each channel changes the sine wave into small pulses. Notice that the pulse in channel A is ahead of the pulse in channel B by one-half a period. In the next stage of each channel the pulses are sharpened and developed so as to have a very short rise time. This stage is important since these pulses will

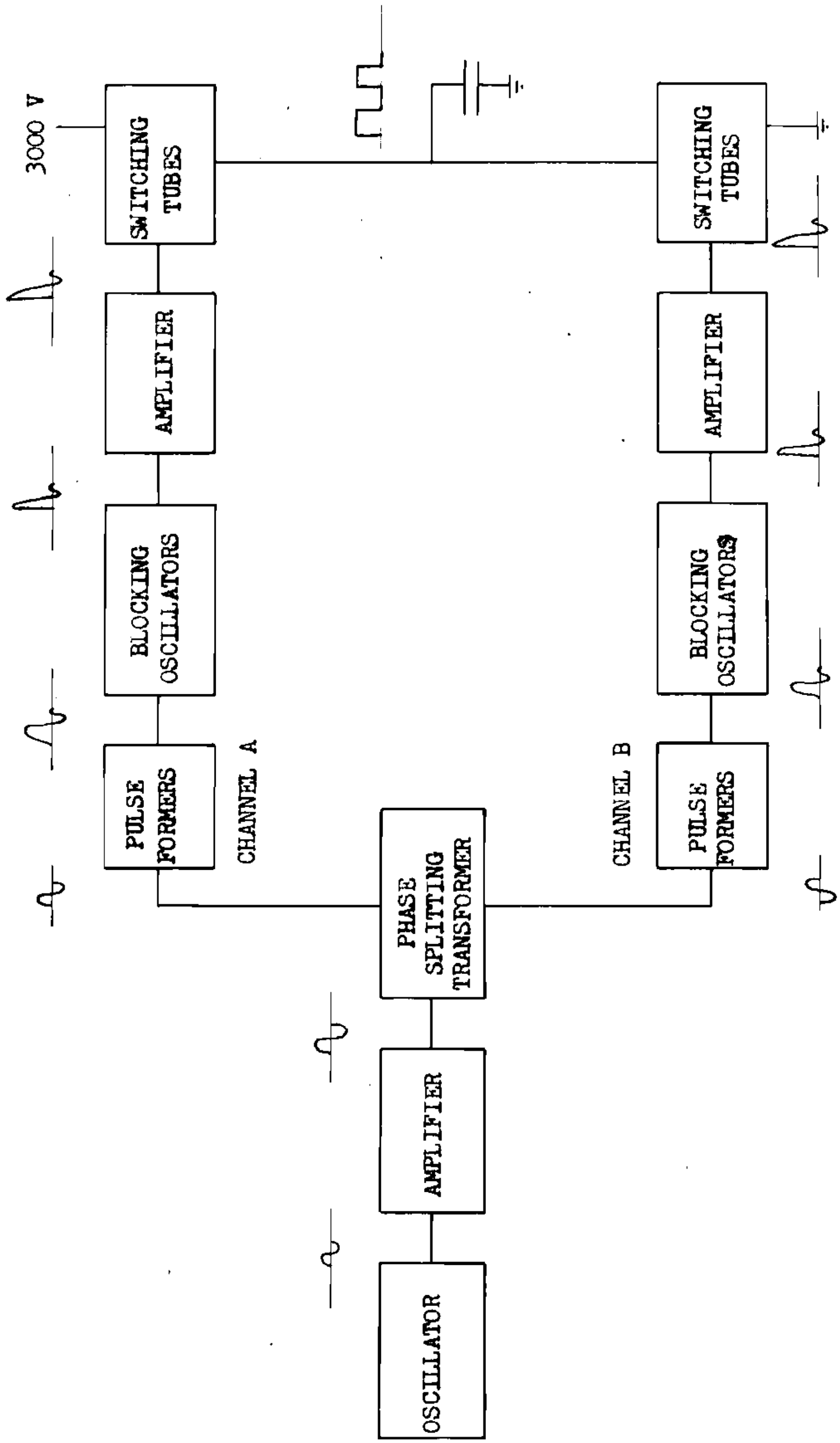


FIGURE 3 - BLOCK DIAGRAM OF SQUARE WAVE GENERATOR

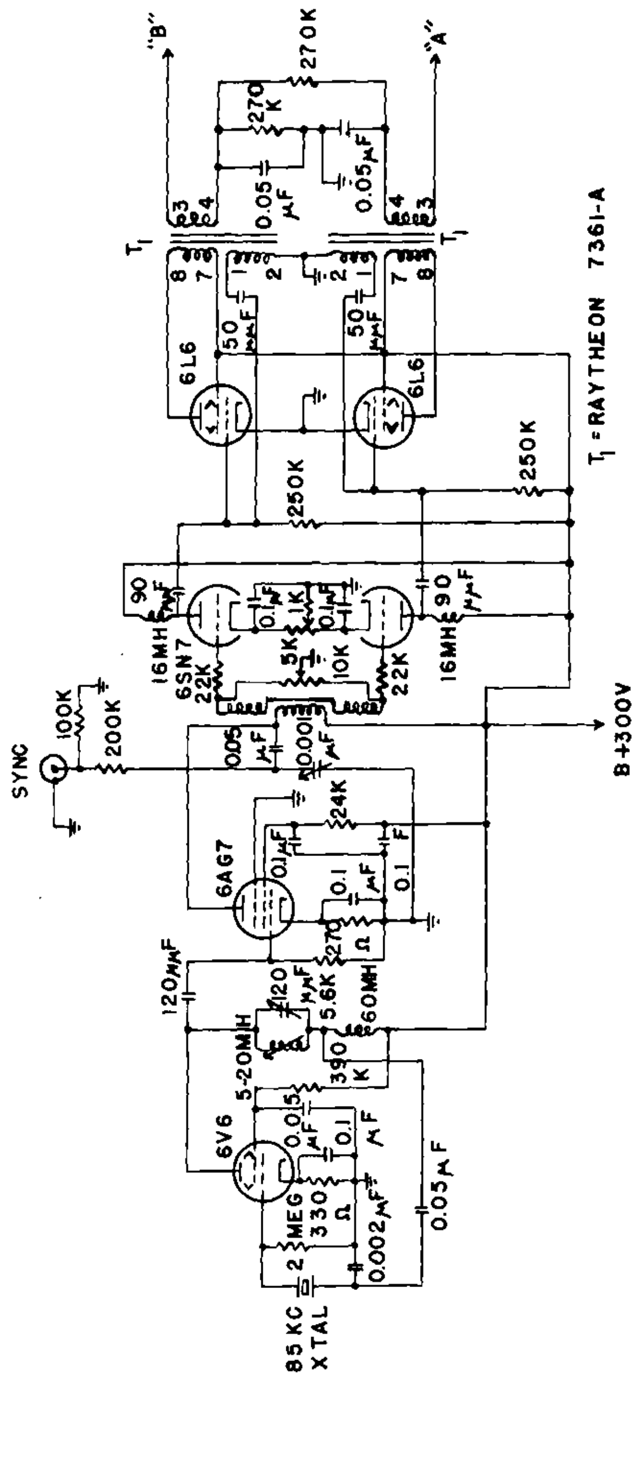


FIGURE 4 - PULSE FORMING SECTION OF GENERATOR

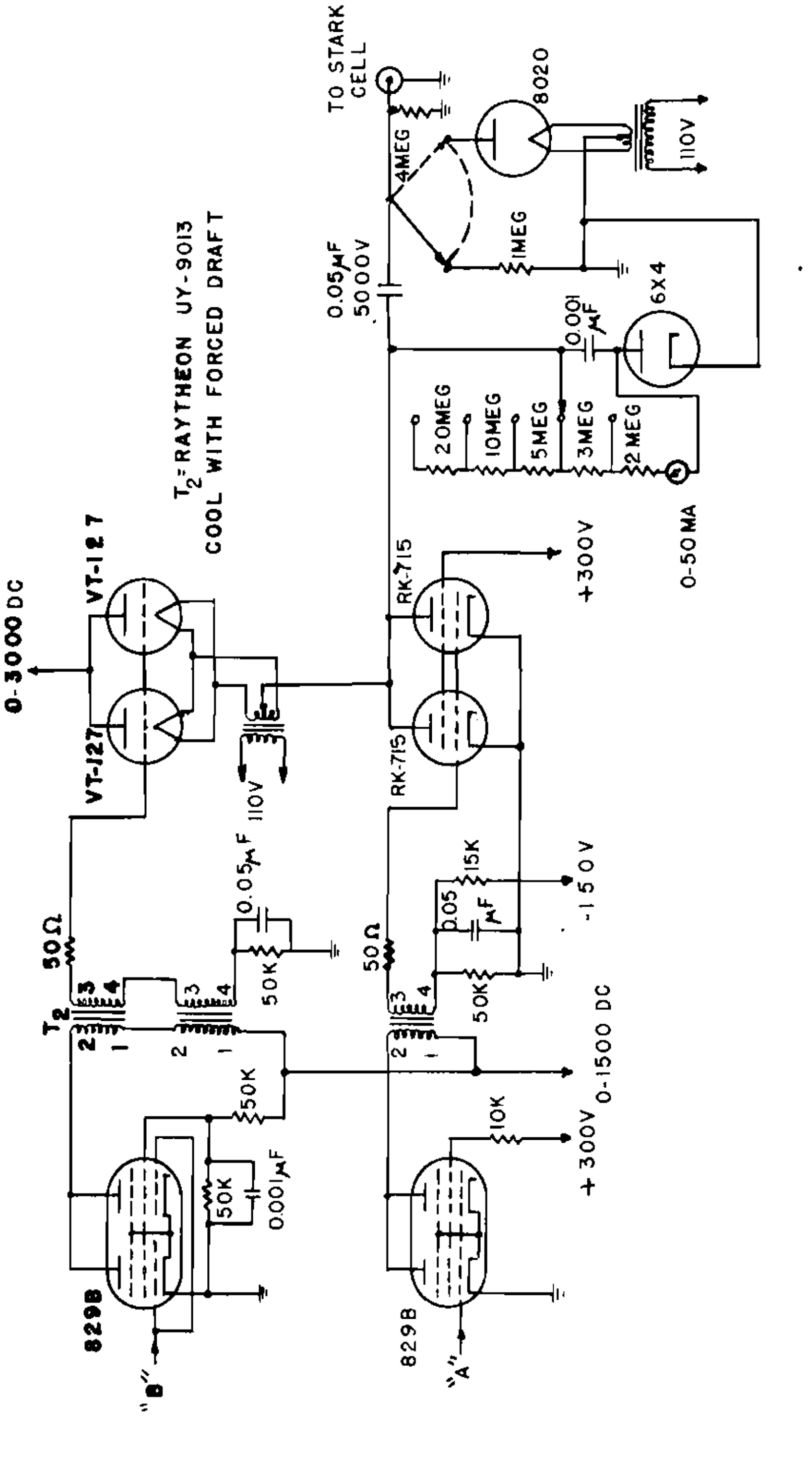


FIGURE 5 - SQUARE WAVE FORMING SECTION OF GENERATOR

determine the squareness of the output voltage. The following stage amplifies the pulse in each channel. Next, the pulse in channel A causes the tubes in the final stage of channel A to conduct heavily, thereby charging the electrode in the waveguide. This electrode and the waveguide form a capacitor, with one side (the waveguide) grounded. One-half cycle later, the pulse in channel B causes the tube in the final stage of channel B to discharge the electrode. Thus, the electrode is alternately charged and discharged very rapidly, producing a square wave voltage across the Stark cell.

The schematic diagrams shown in Figures 4 and 5 lend a more detailed outline of the function of each stage of the generator. The oscillator employs an 85 kilocycle crystal with a 6V6 beam power amplifier tube. A sine wave voltage from the plate of the 6V6 is applied to the control grid of the 6AG7 pentode amplifier tube. After the sine wave is amplified it is applied to the primary of a transformer which has a potentiometer across its secondary with the center tap of the potentiometer connected to ground. This produces two sine wave voltages which differ in phase by 180 degrees, and whose amplitudes may be made equal by adjustment of the center tap. This transformer was made from a choke consisting of two coils of wire. These coils formed the secondary of the transformer and a primary was wound between them.

The two signals from the transformer are formed into pulses by the 6SN7 dual triode. The operation of one section of this tube is as follows. As the grid becomes positive, it draws current. This current flows through the 22000 ohm resistor in the grid circuit and tends to stop the grid from becoming more positive. During the time that a positive signal is applied, the action of the grid is to fix the current in the tube at an almost constant value. Then as the signal applied to the grid begins to go negative, the tube is suddenly cut off. This causes a positive pulse of voltage on the plate of the tube due to the rapid change of current through the choke in the plate circuit. While the grid is negative, the tube is nonconducting. As the grid voltage increases toward zero, plate current will start to flow when cut-off is reached. The plate current increases gradually due to the impedence of the choke in the plate circuit. This produces a negative pulse of voltage which is much smaller in size than the positive pulse.

The effect is similar in the bottom half of the tube which produces a positive pulse one-half cycle later. These two positive pulses are then used as "triggers" for the 6L6 beam power amplifier tubes. These tubes act as blocking oscillators. The action of a blocking oscillator can be explained as follows. Assume that the tube is at cut-off. The positive pulse from the plate of the 6SN7 is applied to the grid. Current begins to flow in the plate circuit, inducing a voltage in the transformer $T_1$ secondary that is between the grid and ground. The polarity of this induced voltage is such as to drive the grid even more positive. The action is cumulative, impulsive and almost instantaneous. The result is a sharp positive increase of plate current, secondary current, secondary and grid voltages all in a very short time. The 50 micromicrofarad grid capacitor begins to charge in such a manner that its negative side is next to the grid. The plate and secondary currents keep on increasing extremely rapidly due to the cumulative action described above until natural limits are reached. In the case of the plate current, the limit is determined either by temperature saturation of the cathode, or simply, by Ohm's law; for if the plate were shorted directly to the cathode, the current could not increase beyond the limit determined by the plate power supply potential and the resistance in the plate circuit external to the tube. As soon as the plate current stops increasing, the voltage it induces in the secondary disappears. As the grid capacitor charges, the secondary current and the grid voltage decrease. This causes a decrease in plate current which induces a voltage in the secondary. Thus, the grid is driven even more negative until the plate current is cut off. The grid is held negative because of the charge accumulated on the grid capacitor. The grid capacitor begins to discharge and the grid potential rises slowly toward cut-off. Before the grid has risen to cut-off, another positive pulse will come along and a new cycle will begin. The results are pulses that have short rise and fall times and are of short duration.

Sharp positive pulses are taken from the pulse transformers, $T_1$, and are applied to the grids of the 829B push-pull beam power amplifier tubes. Here they are further amplified. The pulse transformers in this stage are subjected to high voltages and high plate currents. This considerably overdrives the transformers, and for this reason they must be cooled with forced draft.

The VT-127A and RK-715B switching tubes are normally cut off when no positive voltage is applied to the control grids. The VT-127A tubes are held beyond cut-off by grid leak bias and the RK-715B tubes are held beyond cut-off by the -150 volt bias. A high positive peak voltage is applied to the control grids of the VT-127A tubes. This causes the tubes to conduct heavily, charging the two capacitors in the cathode circuit of the tubes. During this half cycle of operation, the RK-715B's are at cut-off. During the next half cycle a high positive peak voltage is applied to the grids of the RK-715B's. This makes these tubes conduct heavily, discharging the two capacitors. One of these is a 0.05 microfarad 5000 volt capacitor. The other is the Stark cell, which has a capacitance of approximately 1600 micromicrofarads. Thus, the Stark cell is alternately charged and discharged very rapidly, producing a square wave voltage on the Stark cell.

The 8020 diode tube, between the output to the Stark cell and ground, ties the top of the square wave to ground during normal operation. A relay was incorporated to make it possible to switch from the diode to a one megohm resistor at any time. The resistor has the effect of allowing the square wave to go both positive and negative, that is, of clamping the average voltage to ground. Thus, when the resistor is connected, the peak value of the Stark voltage is reduced by a factor of two and there is no interval during which the Stark voltage is zero. This is an aid when searching for a weak absorption line because switching from diode to resistor will cause an absorption line to disappear, but will have no effect on the random noise.

The power supplies for the square wave generator are conventional ones. Figure 6 shows in schematic the high voltage power supplies. The power transformer is a UTC S-50 rated at 3000-2500-0-2500-3000 volts and capable of delivering 300 milliamperes. The filament transformers for the 866 rectifier tubes deliver 2.5 volts. The variac across the primary of the power transformer allows the power supplies to deliver approximately 0-3000 volts and 0-1500 volts with currents of 200 milliamperes and 100 milliamperes respectively.

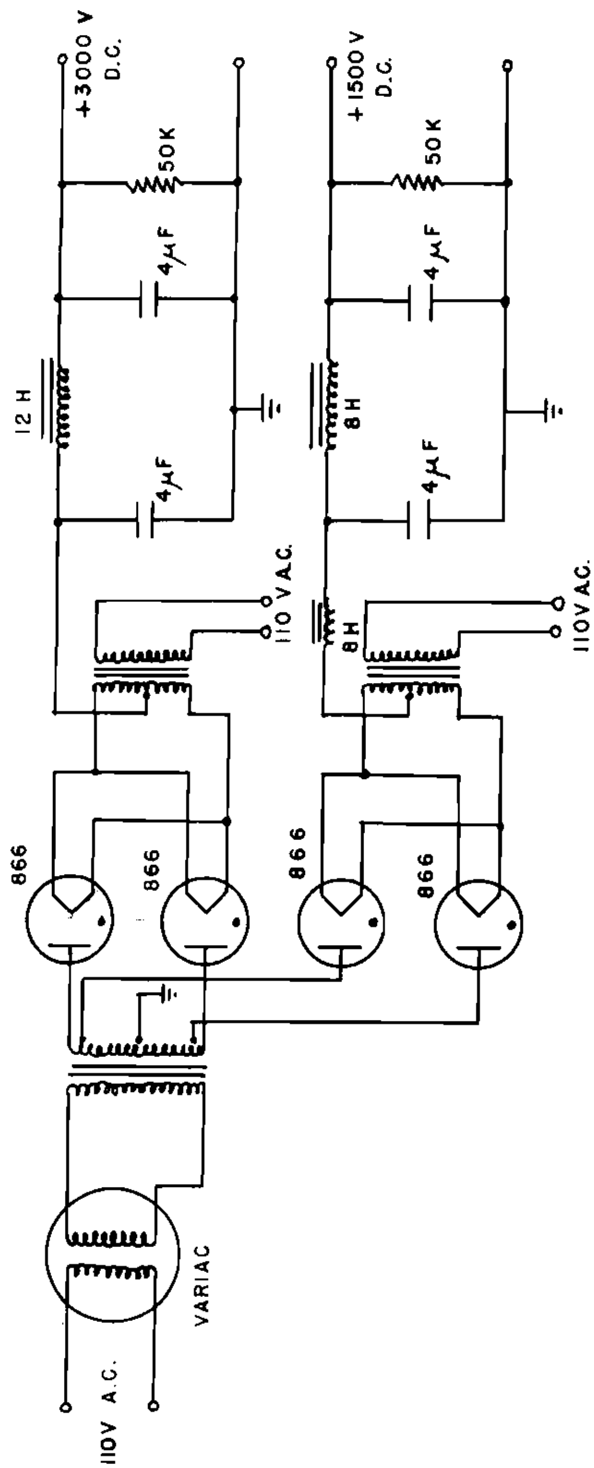


FIGURE 6 - HIGH-VOLTAGE POWER SUPPLIES

Figure 7 shows in schematic the lower voltage power supplies and also the special filament transformers needed. The power transformer is a Thordarson T-22 R07 rated at 350-0-350 volts and capable of delivering 200 milliamperes. The filament transformers for the 83 and 6X5 rectifier tubes deliver 5.0 and 6.3 volts respectively. The 300 volt supply will deliver approximately 200 milliamperes. The -150 volt supply is used for biasing the RK-715B's and therefore furnishes very little current.

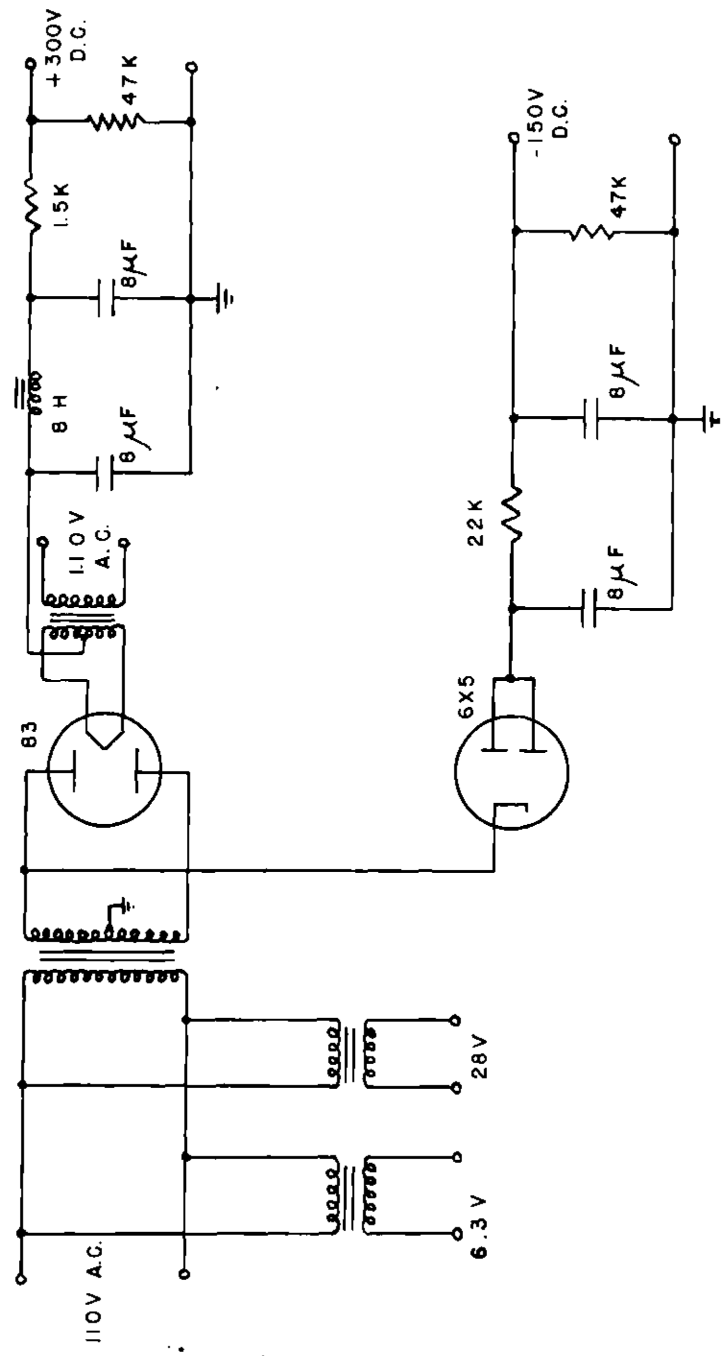


FIGURE 7 - LOW VOLTAGE POWER SUPPLIES

## CHAPTER IV

## OPERATION

The square wave generator is designed for ease of control. The picture of the generator shown in Figure 8 shows the only controls needed for operation. There are two switches, one used to operate the low voltage power supplies, the other used to operate the high voltage power supplies. The tubes in the square wave forming section of the generator need approximately three minutes in order to warm up to the proper temperature. Therefore, the high voltage should not be applied to these tubes until several minutes have elapsed since the filaments were turned on. The filaments for all tubes are controlled by the low voltage power supplies switch. A safety precaution is incorporated into the high voltage supply, in that the switch controlling the high voltage is not energized until the low voltage supplies and filament voltages are turned on.

The output voltages of both the 1500 volt power supply and the 3000 volt power supply is controlled by one variac as shown in Figure 6. Care should be taken to insure that the variac is set on zero before the high voltage power supplies are turned on. A rough estimate of the direct current voltage from the 3000 volt supply can be obtained by multiplying the variac reading by 33.

The high voltage power supply transformer is fused by a 10 ampere fuse mounted on the back of the control panel. This fuse protects this transformer from a possible short circuit in the high voltage supply.

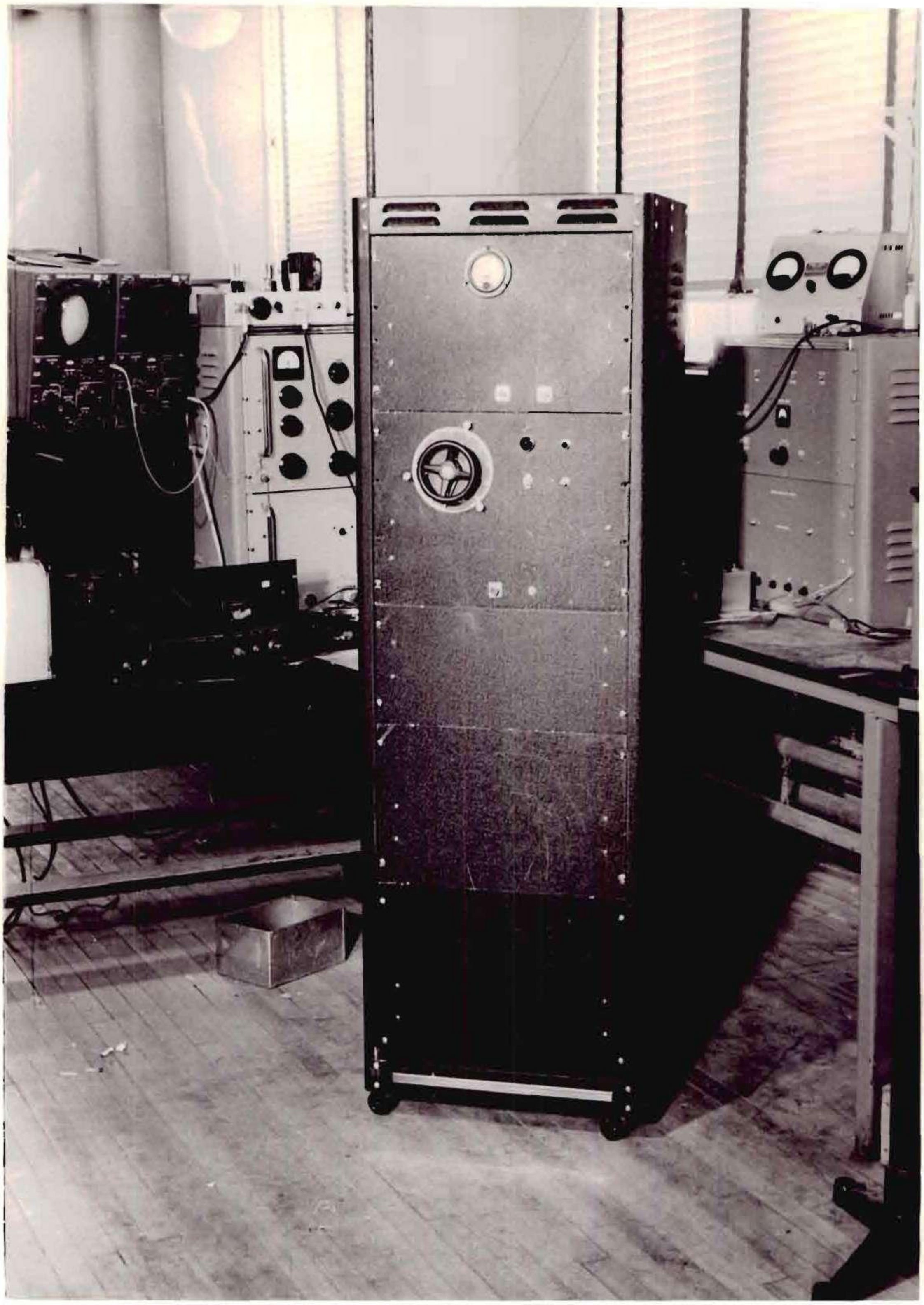

FIGURE 8 - THE SQUARE WAVE GENERATOR

One other adjustment is available on the outside of the equipment. This is the potentiometer that is across the secondary of the phase splitting transformer. The potentiometer balances the signal applied to the grids of the pulse forming tubes and also regulates to some extent the relative widths of the output square wave. Once this potentiometer has been set, it should not require readjustment for normal operation. This potentiometer will also make slight adjustments in the amount of overshoot that occurs at the top and bottom of the square wave.

Figure 9 is an oscilloscope picture of the square wave. There is a slight amount of overshoot at the tops and bottoms of the square wave. This effect is not serious since it lasts for only a small fraction of the half cycle.

The square wave generator was tested by observing the absorption of the $J = 1 \rightarrow 2$ transition of carbonyl sulfide. The equipment performed very well, showing more sensitivity than was previously obtained with a sine wave voltage applied across the Stark cell. The Stark components were well defined and shifted a noticable distance from the main absorption line.

A recording of this transition was made by using a phase sensitive detector along with an Easterline-Angus recorder. The klystron frequency was varied slowly by a mechanical drive. This recording is shown in Figure 10. A phase sensitive detector produces an output voltage which is positive for signals in phase with its reference signal and negative for signals 180 degrees out of phase. For the main spectral line, absorption occurs during that half cycle when the applied electric field is zero. For the Stark components, absorption occurs during that half cycle

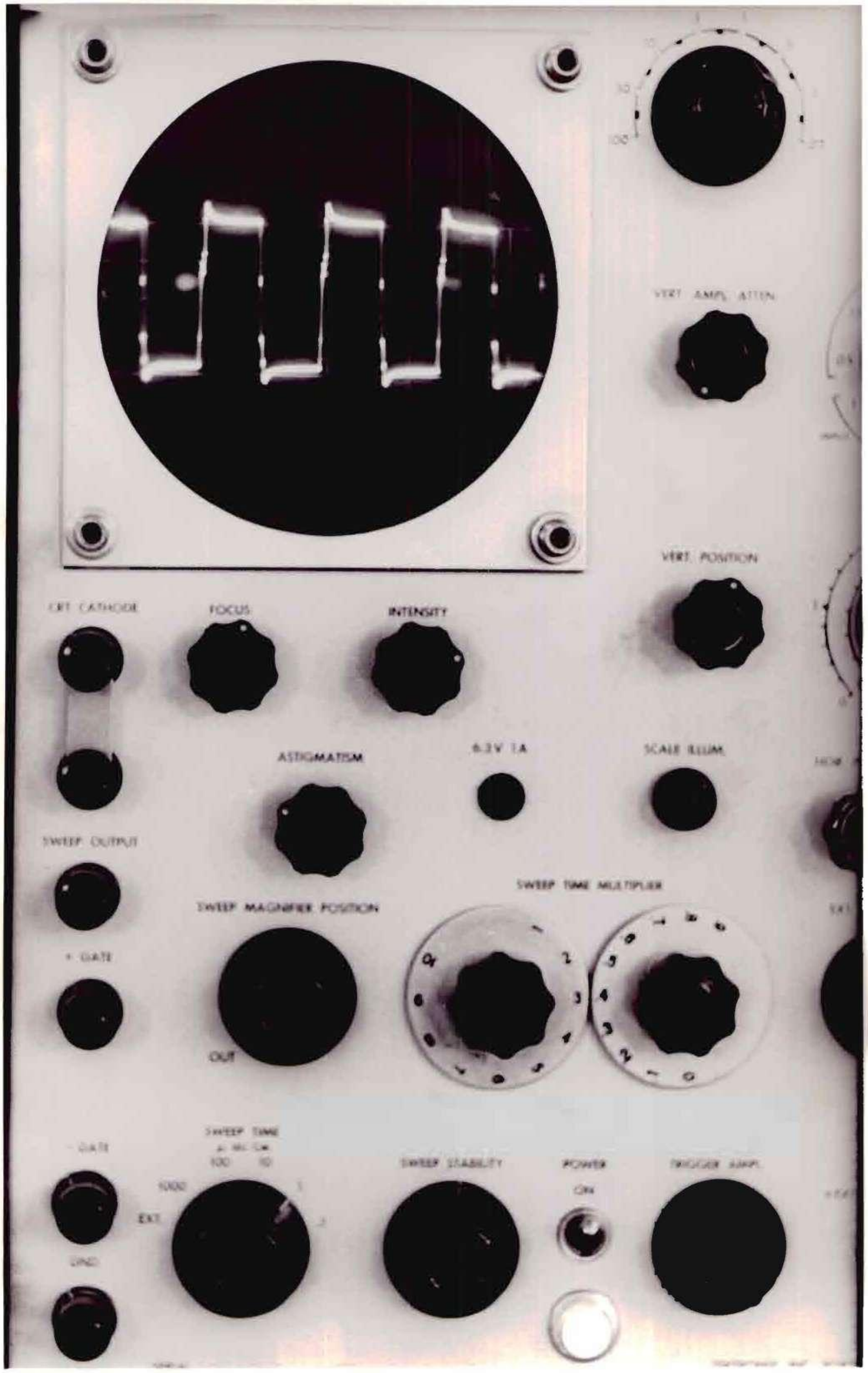


FIGURE 9 - OSCILLOSCOPE PICTURE OF SQUARE WAVE

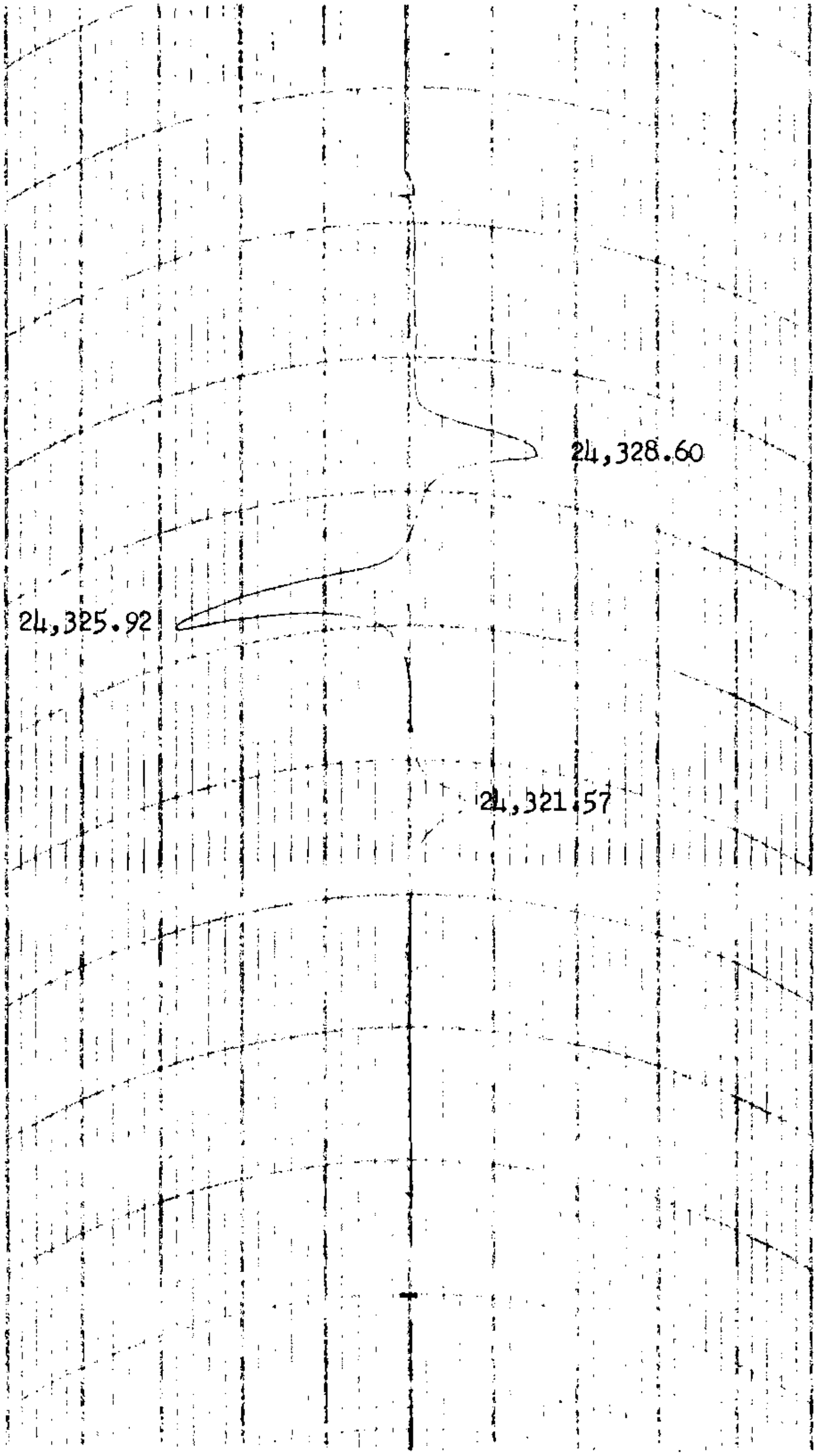


FIGURE 10 - THE J = 1 → 2 TRANSITION OF CARBONYL SULFIDE

when the applied field is different from zero. Thus, for a main line, the radiofrequency signal from the crystal rectifier is 180 degrees out of phase with the square wave voltage, and for a Stark component, the two are in phase. Therefore, using a signal from the plates of the buffer amplifier as a reference signal, the phase sensitive detector recorded the main line as a positive deflection and the Stark components as negative deflections.

The recording in Figure 10 was made using a Stark voltage of 679 volts. The transitions corresponding to these lines are shown in Figure 1. The line at 24,325.92 megacycles is the main absorption line for the $J = 1 \rightarrow 2$, transition of carbonyl sulfide. This transition occurs when the applied electric field is zero. The Stark component at 24,322.57 megacycles results from the transition $J = 1 \rightarrow 2$, $M = 0$, and the Stark component at 24,328.60 megacycles results from the transition $J = 1 \rightarrow 2$, $M = 1$.

From the frequency difference between each Stark component and the main line, the dipole moment of carbonyl sulfide was calculated by the use of equation (11). The average value obtained was 0.71 debye units compared to the value 0.709 debye units reported by R. G. Shulman and C. H. Townes (6).

# BIBLIOGRAPHY

1. Herzberg, Gerhard, Molecular Spectra and Molecular Structure, 2nd ed. New York: D. Van Nostrand Co., Inc., 1950, p. 66-73

2. Gordy, Walter, Smith, William V., Trambarulo, Ralph F., Microwave Spectroscopy, New York: John Wiley & Sons, Inc., 1953, p. 159

3. Hughes, R. H., and Wilson, E. B., The Review of Scientific Instruments, v. 20, (1949) p. 821

4. Hedrick, Langdon C., The Review of Scientific Instruments, v. 20, (1949) p. 781

5. Gordy, Walter, Smith, William V., Trambarulo, Ralph F., Microwave Spectroscopy, New York: John Wiley & Sons, Inc., 1953, p. 5-81

6. Shulman, R. G., and Townes, C. H., Physical Review, v. 77, (1950) p. 520