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STEP-WISE VARIATION OF SPECTROMETER QUENCH RATES FOR NUCLEAR QUADRUPOLE RESONANCE MEASUREMENTS

By

Curtis M. Wise

A Thesis
Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Physics

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MASTER
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SCIENCE

Art Stege
Dean

Date May 31, 1967

STEP-WISE VARIATION OF SPECTROMETER QUENCH RATES FOR NUCLEAR QUADRUPOLE RESONANCE MEASUREMENTS

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ABSTRACT

In nuclear quadrupole resonance (NQR) it is desirable to better examine the magnitude of the resonance signals. This thesis describes the construction and testing of spectrometer control circuits which enable one to better examine a single resonance signal to the near exclusion of extraneous resonance side band responses and circuit noise in the NQR detection apparatus.

Added to the basic spectrometer circuit is a step-wise varying quench rate control. For each adjustment of this control other control units are activated to keep the chosen NQR signal fixed in position and in magnitude within the spectrometer's span of detected radio frequencies.

The output of the spectrometer may then be summed and averaged by appropriate recording devices. Extraneous signals due to resonance side band responses and circuit noise will have varying positions and magnitudes for the varying quench rates and would consequently average out to have negligible magnitudes, while the chosen NQR signal would remain at the uniform magnitude at which it was detected for each of the quench rate adjustments.

ACKNOWLEDGMENT

I wish to express my sincere appreciation to Dr. Christopher Dean for his valuable help and patient guidance in the course of this project.

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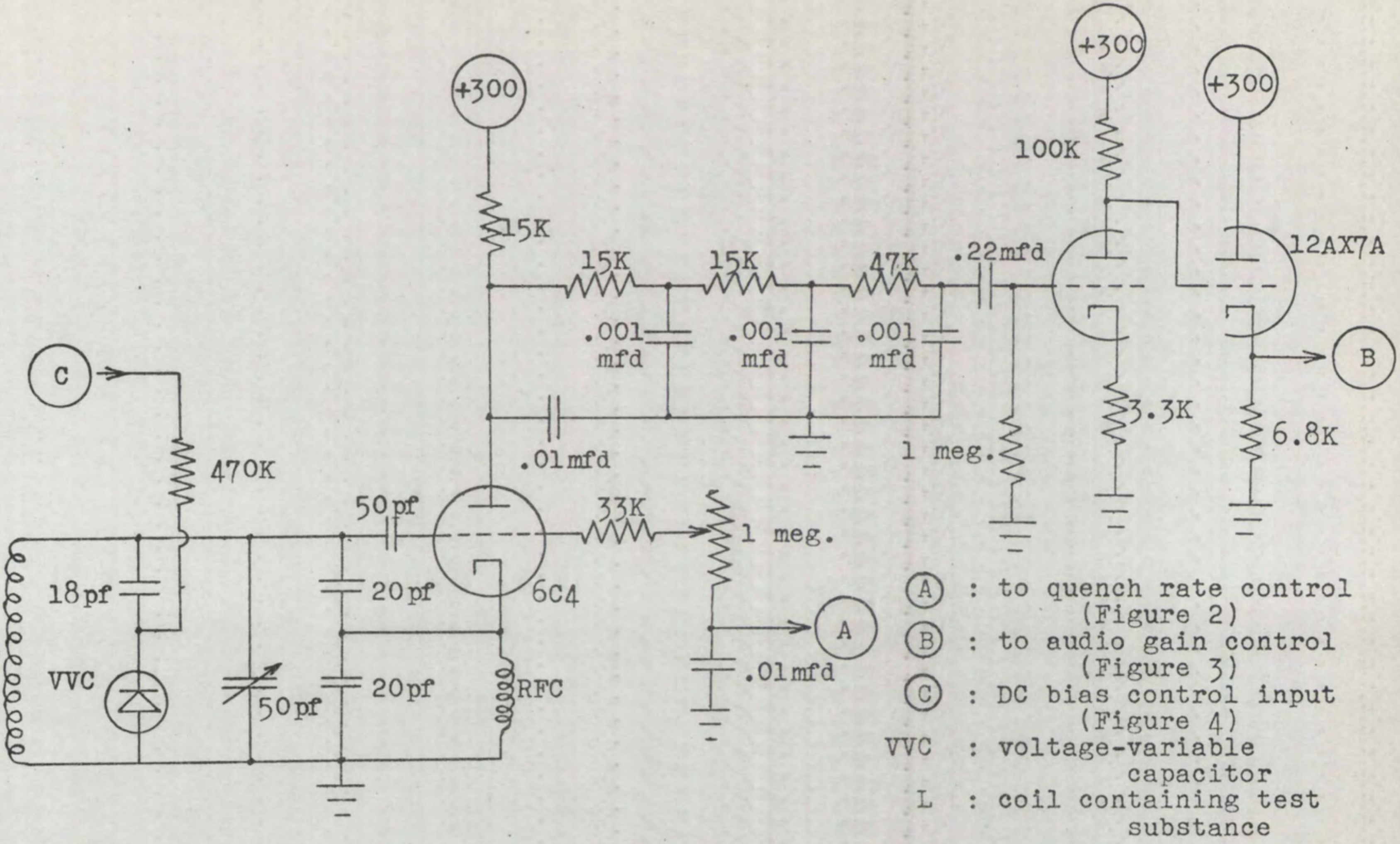
INTRODUCTION

A test material containing atoms whose nuclei exhibit relatively strong nuclear quadrupole resonance (NQR) for the frequency span of the r.f. spectrum over which we operate our spectrometer is placed within the inductance coil of a tank circuit of a pulsed oscillator spectrometer (Figure 1). The tank circuit's capacitance is made to vary periodically so that the natural frequency of the tank circuit will vary over a span of several tens of kilocycles in the r.f. spectrum. This frequency span is made to include the quadrupole resonance frequency of the nuclei of that element in the test material which is under examination.

At quadrupole resonance the tank circuit oscillates at a particular frequency such that the nuclei under examination are excited into higher energy states by accepting quanta of energy from the resulting electromagnetic field generated in the tank circuit's coil. This decrease of energy in the coil's electromagnetic field causes the spectrometer to feed more energy into the tank circuit to restore oscillation, and this action is detected as a momentary extra consumption of power by the tank circuit as it passes through that quadrupole resonance frequency.

For improved detection of the NQR signal the spectrometer utilizes a pulsed oscillator. This oscillator



Ⓐ : to quench rate control (Figure 2)
Ⓑ : to audio gain control (Figure 3)
Ⓒ : DC bias control input (Figure 4)
VVC : voltage-variable capacitor
L : coil containing test substance

Figure 1. Spectrometer Circuit

consists of a vacuum tube to whose grid is connected a resistor in series with a voltage source whose potential is more positive than that of the grid. While the tube conducts its grid captures electrons form the cathode faster than those electrons can leak off to that voltage source. So at some point the grid becomes so negatively charged that the tube shuts off; i.e., the plate current is "quenched." Then the electrons leak off the grid until the tube can conduct again, and the process repeats. The frequency at which the tube is rendered non-conducting is called the quench, or pulse, rate. This pulsed oscillator has the additional effect of introducing side band responses to the main NQR signal. These side band responses are located at multiples of the quench rate away from the main NQR frequency.

We desire to record the main resonance signal, or one of its side bands, to the exclusion of all the other responses, including circuit noise, for more accurate analysis of the chosen signal. To do this the technique of quench rate variation and signal averaging is used. The quench rate is varied by connecting the pulsed oscillator's grid resistor to a step-wise varying voltage source, each step-wise variation being enacted by an individual, transistor-switched quench rate control unit. The more positive the voltage source with respect to the grid, the faster the captured electrons will leak off, and the higher the quench rate will be. This variation of the quench rate causes the side band signals to vary their distances from the chosen response signal. Then, using a recording device, the magnitude of the spectrometer's output can be recorded at a great many frequency positions along the tank circuit's span of the r.f. spectrum for several different quench rate values. The recording device then adds and averages the spectrometer's output for the several quench rates at each of the many frequency positions spanned by the tank circuit. If the signal chosen for analysis has remained at a constant position and with constant magnitude in the spanned frequencies, then the sum and average of its detected magnitudes will be just that magnitude at which it was detected during each quench rate setting. All other resonance responses will have shifted their frequency positions since they are located away from each other at multiples of the quench rate -- which has been varied several times. Hence the averaging of these other signals reduces their magnitudes to just a fraction of their detected values.

The above procedure is satisfactory under ideal circumstances, but in actuality the variation of the quench rate is likely to alter two other signal characteristics: the signal position in the tank circuit's frequency span and the magnitude of the signal chosen for analysis. The first problem is solved by use of a D.C. bias control unit. Such a unit regulates the D.C. bias to a voltage-variable capacitor in the tank circuit. By changing this capacitance with a change in the D.C. bias we can choose the center position of the frequency span on the r.f. spectrum. Consequently, for each quench rate setting, a corresponding D.C. bias control unit shifts the tank circuit's frequency span along the r.f. spectrum until the chosen signal is positioned within the span at the same desired place no matter which quench rate is being used.

The second problem is corrected by means of an audio gain control unit. This type of unit is basically a simple amplifier with which we can change the spectrometer's output to some desired magnitude. For each quench rate setting a corresponding audio gain control unit is adjusted so that the signal chosen for analysis is at a uniform magnitude no matter which quench rate is being used.

This thesis concerns the construction and testing of circuits to control and switch the quench rate, D.C. bias, and audio gain in the desired way. The over-all system is described in the next section, and the subsequent sections describe the circuit details.

GENERAL SYSTEM DESCRIPTION

The equipment used in the system is interconnected as indicated in Figure 2. In operation an audio oscillator delivers a sinusoidal voltage to a wave squarer. This wave squarer consists of two or three inverter units connected in series (the inverter unit is described later in the circuit details of the ring counter and is illustrated in Figure 9). The wave squarer converts the sinusoidal voltage to a square wave voltage and then delivers this square wave voltage to the ring counter. With each square wave cycle of the voltage, the "ON," or active, stage of the ring counter is turned to "OFF," and the next stage in the sequence turns to ON. The output of the ON stage activates its related trigger circuit, and this trigger circuit then relays appropriate "turn on" command signals to its related DC bias, quench rate, and audio gain controls. The spectrometer now operates at a new quench rate, and a new DC bias now acts to position the desired NQR signal within the frequency span over which the spectrometer's tank circuit operates. The resulting spectrometer output is amplified by the audio gain control appropriate for this quench rate so that the desired NQR signal is of some standard magnitude. This standardized signal may finally be displayed on an oscilloscope or on some recording device.

The system uses transistor switches in switching to

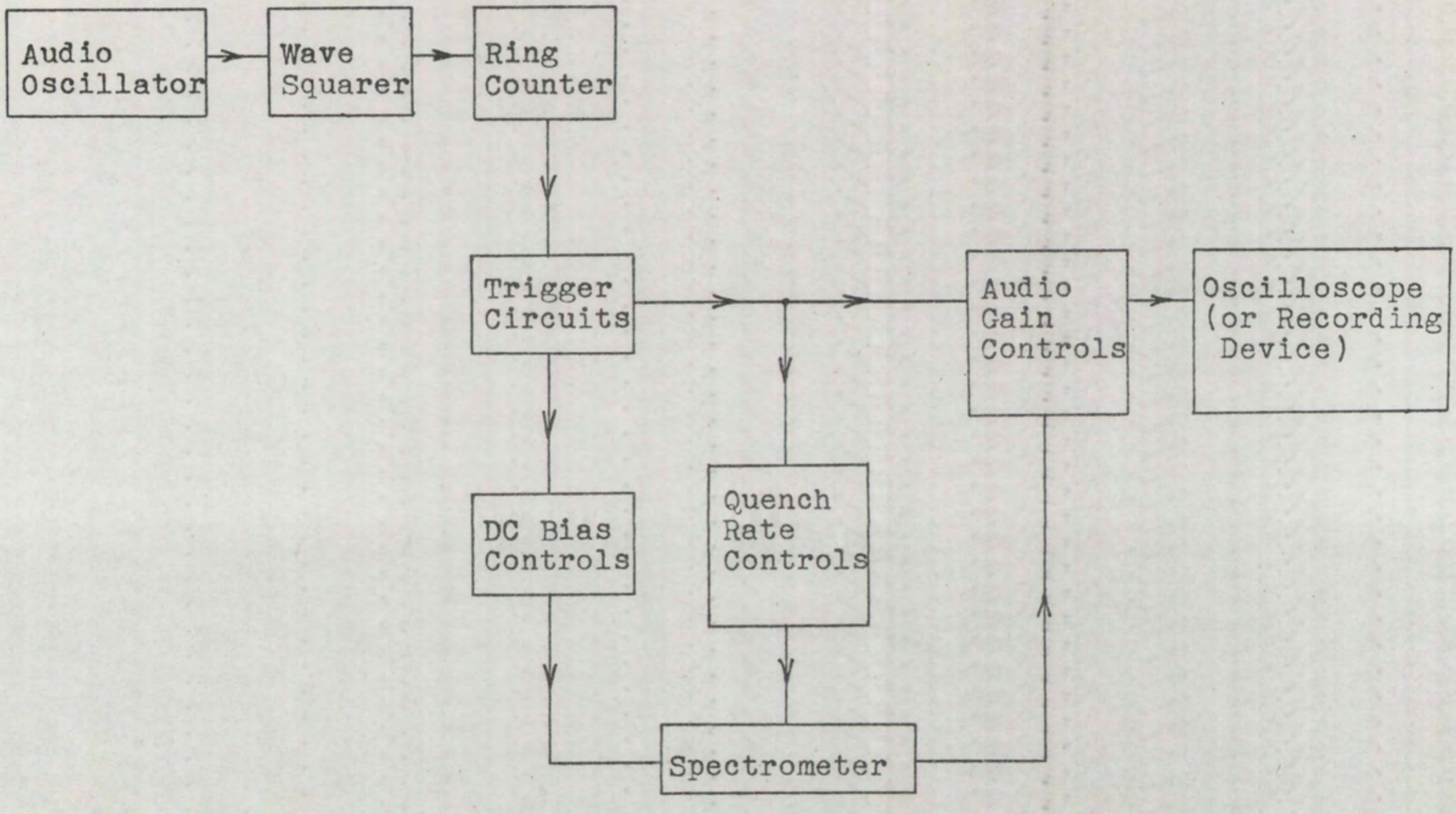


Figure 2. System Flow Chart

and from the control units whose circuit details follow. A transistor is switched into an OFF condition when it is reverse-biased and, consequently, is non-conducting. A transistor is switched into an ON condition when it is forward-biased to such a degree that it is driven into saturation, where it is fully conducting. For a transistor that is switched ON, the emitter-collector resistance is negligible, causing the potential difference across the emitter and collector also to be negligible.

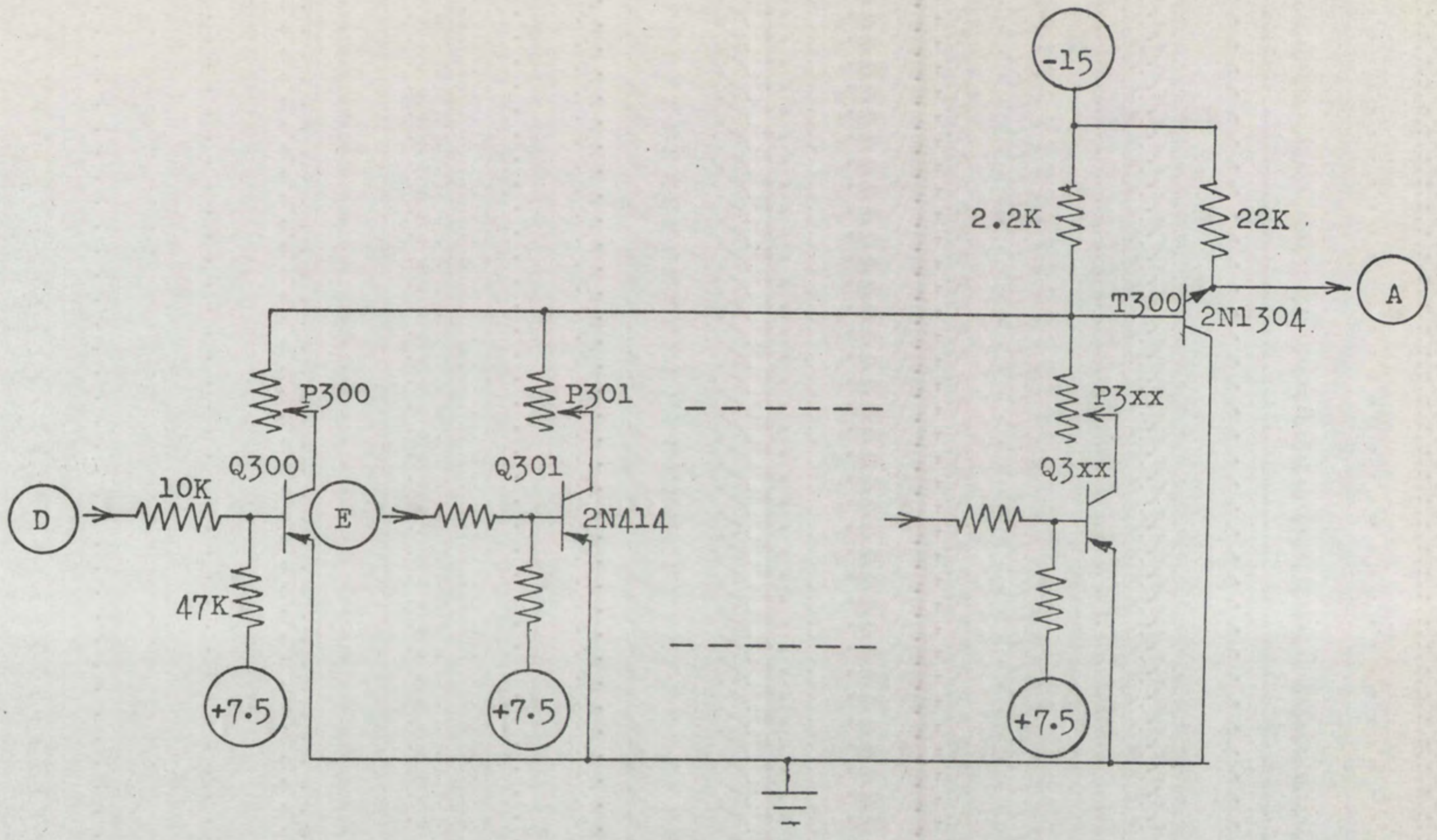
CIRCUIT DETAILS

QUENCH RATE CONTROL

The rate at which the plate current of the pulsed oscillator is quenched is determined by the rate at which the captured electrons are allowed to leak off the grid. This is regulated in two ways: by varying the resistance between the grid and the electron sink (such as ground or some constant potential source which is usually positive with respect to the grid) and by varying the potential into which the electrons leak. In the former case we use a one megohm potentiometer (see Figure 1) for coarse adjustments, and in the latter case we use a voltage divider circuit for fine adjustment.

In describing the fine adjustment quench rate control, we refer to Figure 3. Considering the first control unit as an example, this unit is OFF when a trigger signal of zero volts is entered on the 10K ohm resistor, for then the base of transistor Q300 is reverse-biased, and so Q300 is non-conducting. This unit is switched ON when a trigger signal of -7.5 volts is entered on the 10K ohm resistor, for then, due to the voltage divider configuration of the 10K ohm and 47K ohm resistors, the base of Q300 is forward-biased, and Q300 is switched ON. Then potentiometer P300 and the 2.2K ohm resistor form another voltage divider which can put varying magnitudes of forward bias on the base of transistor T300, depending upon the resistance setting of P300.

The emitter of T300 is connected to the grid of the



Ⓓ : trigger circuit #1 input (Figure 7),
Ⓔ : trigger circuit #2 input (Figure 7),
etc.

Figure 3. Quench Rate Control Units

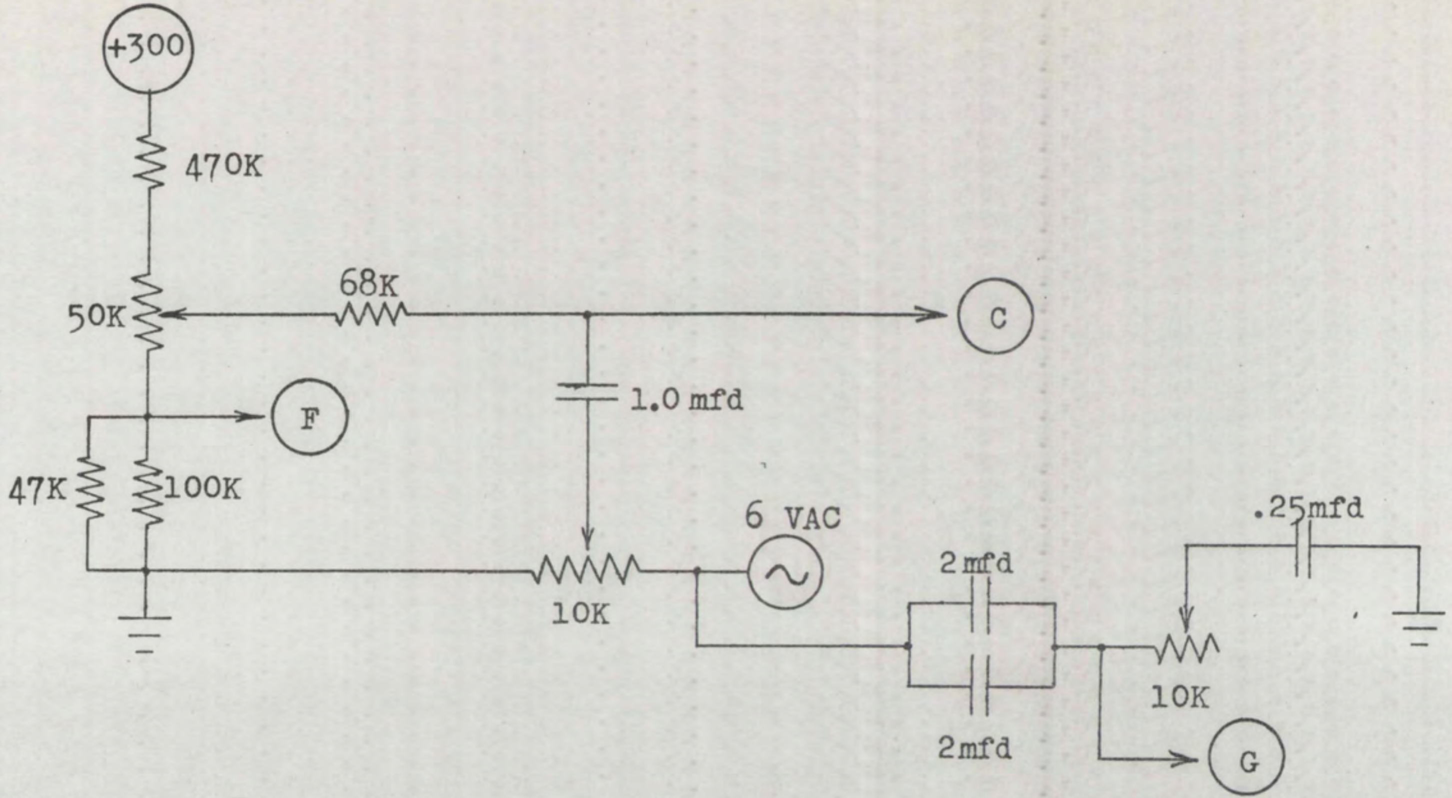
pulsed oscillator tube through two resistances, one of which is the coarse adjustment potentiometer. Since T300 is an NPN transistor used as an emitter follower, the transistor conducts as long as the emitter is biased more negatively than the base; but while T300 conducts, the difference between the emitter and the base potentials is negligible, so whatever potential is on the base of T300 is virtually the same as that on the emitter. Therefore, the more positive the potential on the base of T300, the faster will the electrons leak off the grid of the pulsed oscillator and the higher will be the quench rate.

DC BIAS CONTROL

The spectrometer's tank circuit (Figure 1) oscillates in a frequency range in the neighborhood of 34 megacycles, this frequency range being determined by the capacitance of the network of fixed and variable capacitors in parallel with the substance-containing coil. The "coarse" capacitive adjustment is made by the 50 picofarad, manually-operated variable capacitor. This adjustment roughly locates the frequency range in the r.f. spectrum. The "fine" adjustment is made with a voltage-variable capacitor -- a capacitor whose capacitance is proportional to the potential across its terminals.

The potential applied to the voltage-variable capacitor has both an AC and a DC component: the AC component is determined by a voltage divider consisting of a potentiometer whose fixed resistance is connected across a 6 volt AC source and ground, with the desired AC potential being taken from the potentiometer's brush (see Figure 4). The magnitude of this AC potential determines the span, or range, of the r.f. spectrum surrounding the frequency at which the test substance's nuclei can accept energy from the spectrometer's tank circuit.

The AC potential oscillates about the DC bias which is also acting on the voltage-variable capacitor. This DC bias is also determined by a voltage divider circuit. As shown in Figure 4, the "coarse" DC bias adjustment is made by varying



Ⓒ : to voltage-variable capacitor (Figure 1)
Ⓕ : to DC bias "fine" adjustment control units (Figure 5)
Ⓖ : to horizontal scope sweep

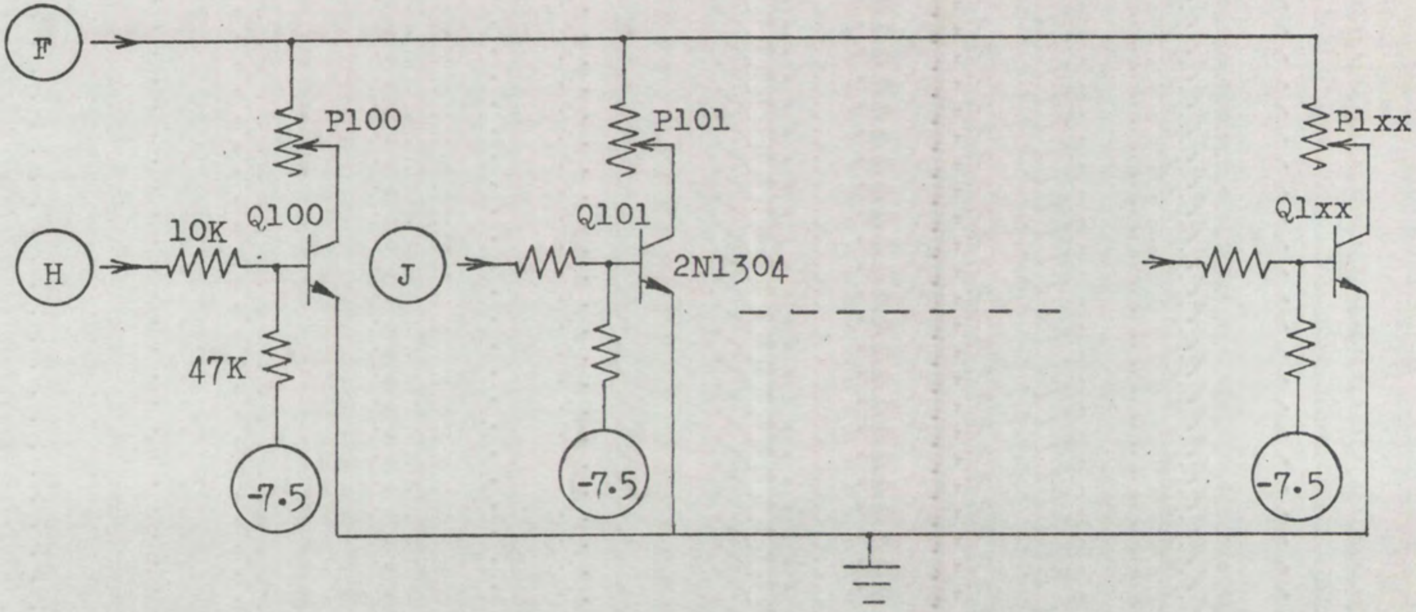
Figure 4. DC Bias "Coarse" Adjustment Control

the position of the brush of the 50K ohm potentiometer connected in series with other resistors between +300 volts and ground. In operation the "coarse" DC bias control is set so that the spectrometer's tank circuit oscillates at a frequency very near the NQR frequency of the substance under test, and then all subsequent adjustments should be made only with the "fine" DC bias controls.

The "fine" DC bias adjustment controls are all connected to the same point (Point D) on the DC voltage divider as shown in Figure 4. The individual "fine" controls are assembled according to Figure 5. Let us assume, for example, that Unit #1 is to be put into operation. When not in use, there is entered at the 10K ohm resistor of Unit #1 a potential of zero volts. By the voltage divider arrangement here, transistor Q100 is reverse-biased and non-conducting, thereby putting this Unit in the OFF condition.

When in use, Unit #1 has a signal of +7.5 volts entered at the 10K ohm resistor; Q100 is then forward-biased and switches to ON. Since the emitter-collector resistance of Q100 is negligible compared to the resistance of potentiometer P100, the "fine" adjustment of the DC bias is determined by the parallel resistance combination of P100 with the 47K ohm and 100K ohm resistors. Consequently, the DC potential at Point C in Figure 4 is also determined.

This "fine" adjustment allows the frequency span "window" to be centered on a particular frequency in the



Ⓕ : input from Figure 4
Ⓗ : trigger circuit #1 input (Figure 7),
Ⓙ : trigger circuit #2 input (figure 7),
etc.

Figure 5. DC Bias "Fine" Adjustment Control Units

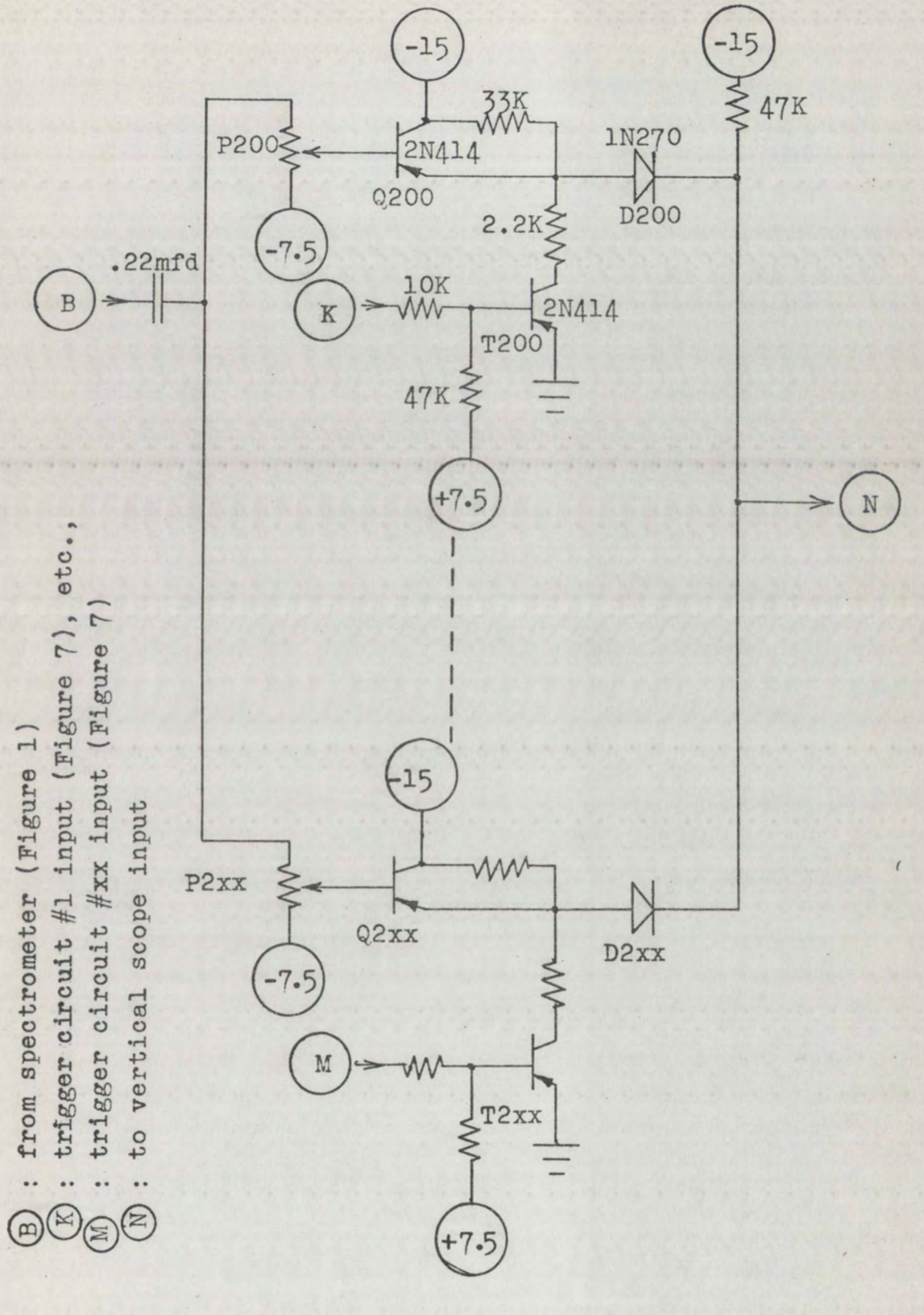
r.f. spectrum -- namely, a resonance or side band response frequency of the substance under test. Thus, no matter which control unit is activated, the response signal under examination remains located at the same place within the "window" -- a condition necessary for averaging out unwanted, position-varying signals detected by the spectrometer.

AUDIO GAIN CONTROL

The audio gain control is pictured in Figure 6. This control is connected to the output of the spectrometer's cathode follower amplifier. The AC signal passed by the capacitor between the cathode follower amplifier and the audio gain control apparatus travels through voltage divider potentiometers (P2xx) which are connected to a potential of -7.5 volts. A uniform amplitude of the AC signal may be obtained from each gain control unit by proper adjustment of each respective potentiometer, the adjustment being determined by whichever quench rate control unit is in operation.

We shall take in illustration the operation of the first audio gain control unit. This first control unit is normally OFF when a trigger potential of zero volts is entered on the 10K ohm resistor. During this time the base of transistor T200 is reverse-biased due to a voltage divider, and T200 is non-conducting. Consequently, the emitter of transistor Q200 is held at -15 volts, and since this emitter is thus negative with respect to the base of Q200, Q200 is also non-conducting. Whether any other audio gain control unit is operating or not, diode D200 will either be reverse-biased or have the same potential on both terminals, respectively, and will therefore be non-conducting while this first control unit is not in operation.

To turn this first control unit ON a trigger potential of -7.5 volts is entered on the 10K ohm resistor, and, due to



Ⓑ : from spectrometer (Figure 1)
Ⓚ : trigger circuit #1 input (Figure 7), etc.,
Ⓜ : trigger circuit #xx input (Figure 7)
Ⓝ : to vertical scope input

Figure 6. Audio Gain Control Units

the voltage divider here, T200 becomes forward-biased and is switched ON. Next, the emitter of Q200 is permitted by the voltage divider arrangement of the 2.2K ohm and 33K ohm resistors to go less negative until the emitter becomes forward-biased (a little less negative than the base of Q200), and Q200 becomes conducting. Then Q200 acts as an emitter follower, the emitter closely following the AC potential on the base. Now diode D200 is forward-biased and therefore conducting, and this resulting output signal is sent to the vertical input of display or recording instruments.

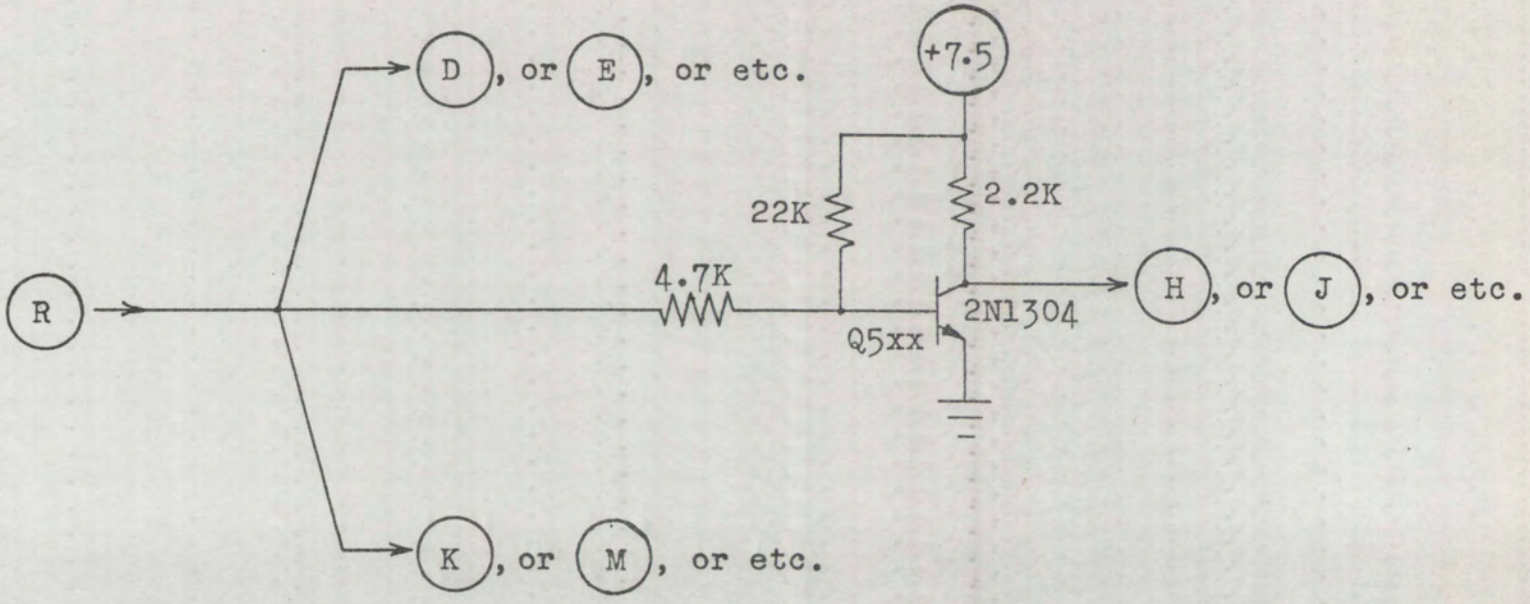
There is a possible mode of behavior of transistor Q2xx that should be mentioned. If the amplitude of the AC potential on the base is too great, the transistor may be reverse-biased and turned off as the base potential approaches its least negative values, or the transistor may be driven into saturation and turned full on as the base potential approaches its furthest negative values, or both conditions may be present. The output signal of such a gain control is "clipped" -- the signal resembles a square wave whose vertical traces are sloping. This feature is generally undesirable because the resulting, clipped signal does not truly describe the shape of the spectrometer's output signal. Consequently, potentiometer P2xx must be adjusted so that the AC potential on the base of Q2xx is kept within desirable bounds.

TRIGGER CIRCUIT

For each quench rate control unit there is associated one specific audio gain control unit and one specific DC bias control unit, and all three of these related units must be activated together in order to make the proper, related changes and corrections in the spectrometer's circuit characteristics. Consequently, the trigger circuit (Figure 7) is used to activate and deactivate each group of control units.

Referring to Figure 7, a group of control units is OFF when a potential of zero volts is entered into the trigger circuit. In this condition a trigger signal of zero volts is transmitted directly to the quench rate and audio gain control units which sets them in the OFF condition. Due to the voltage divider arrangement of the 22K ohm and 4.7K ohm resistors, the base of transistor Q5xx is forward-biased, Q5xx is switched to ON, and the collector goes virtually to ground potential. Since this collector is connected to the DC bias control unit's input, this unit is also set in the OFF condition.

However, when a potential of -7.5 volts is entered into this trigger circuit, this signal is transmitted directly to the quench rate and audio gain control units, and they turn to ON. Due to the previously mentioned voltage divider arrangement, the base of Q5xx becomes reverse-biased, Q5xx switches to OFF, and the collector goes to a potential of



Ⓡ: from some ring counter stage
Ⓓ or Ⓔ, etc.: to appropriate quench rate control unit (Figure 3)
Ⓗ or Ⓙ, etc.: to appropriate DC bias control unit (Figure 5)
Ⓚ or Ⓜ, etc.: to appropriate audio gain control unit (Figure 6)

Figure 7. Typical Trigger Circuit

about +7 volts. This positive potential forward-biases the base of the switching transistor of the appropriate DC bias control unit, so it switches to ON also. Thus all three related control units are simultaneously activated as desired.

RING COUNTER

The ring counter circuit is shown in Figure 8. The counter's basic building block is an "inverter" unit (see Figure 9). In the operation of the inverter, if a logical "1" (-7.5 volts, here) is entered on either or both of its inputs, it will deliver a logical "0" (zero volts) on its lone output. Only if logical "0's" are entered on both of its inputs will the inverter deliver a "1" on its output.

A stage of the ring counter is considered ON when its output to its associated trigger circuit is a logical "1" (-7.5 volts). In operation of the counter, only one stage is ever in the ON condition at any one time; consequently, only one set of the previously described control units is ever in operation at any given time. When a driving impulse is entered into the ring counter, the ON stage is turned to OFF, and the succeeding stage in the ring is turned to ON. Since the "last" stage feeds back into the "first" stage, the location of the ON stage travels in a circle, hence the name of "ring" counter.

For purposes of illustration consider Stage #1 to be initially ON. The driving impulse is a square wave normally at a logical "1" but rising to a "0" for the duration of the impulse. As the leading edge of the driving impulse enters the ring counter, inverters I400 and I406 suddenly have all "0's" on their inputs, and their outputs go from a normal "0" to a "1". Each side of the capacitors

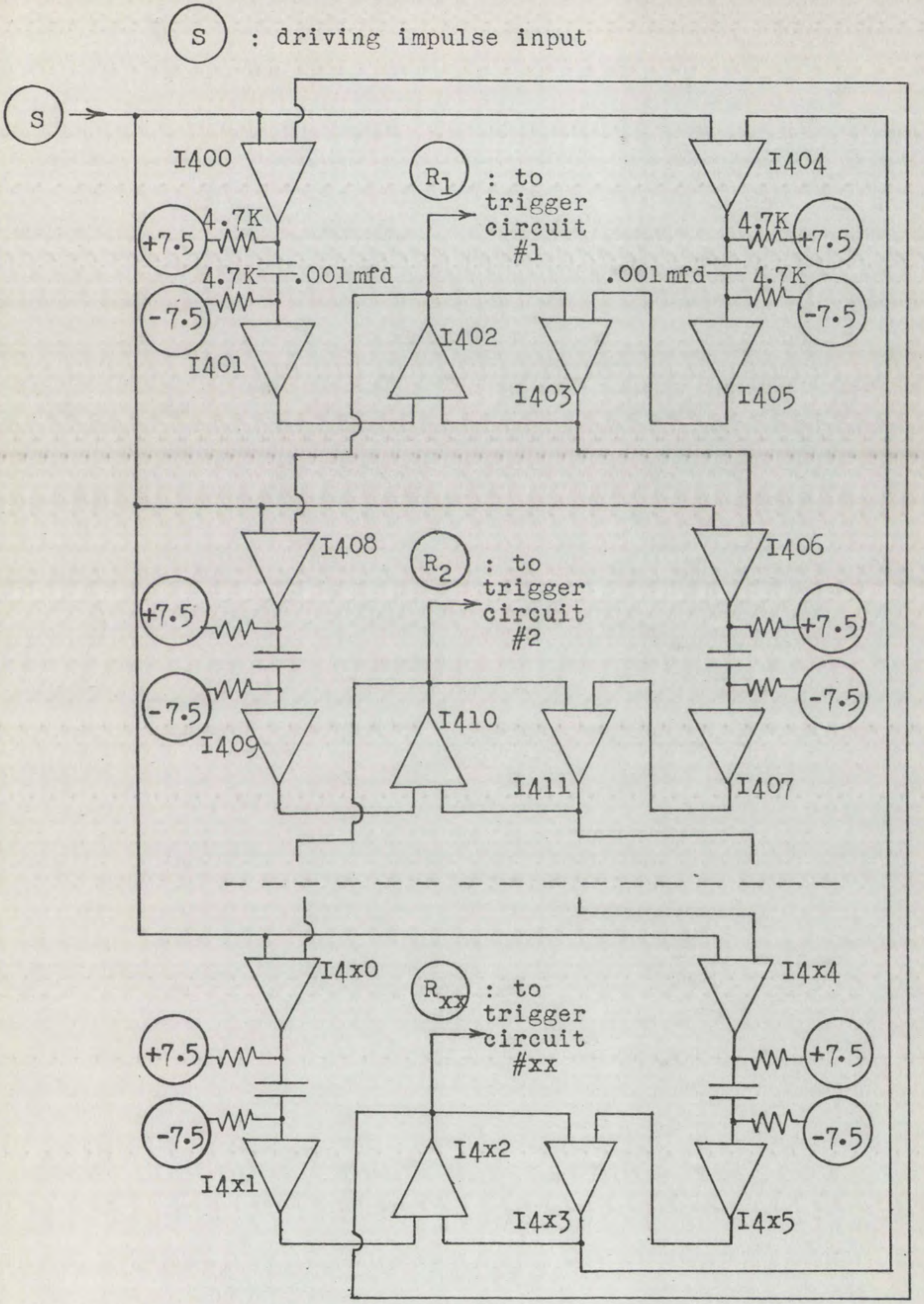
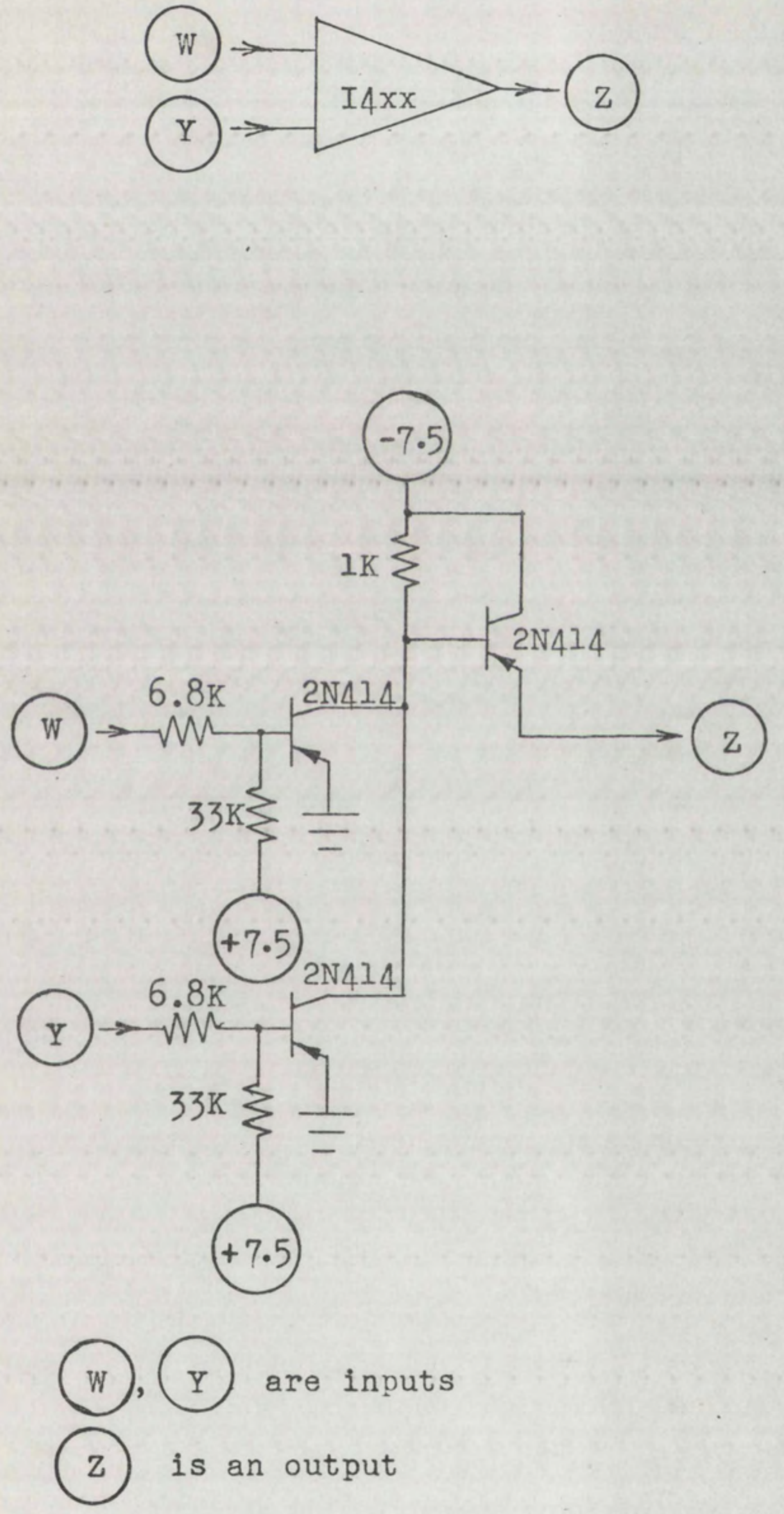


Figure 8. Ring Counter



W, Y are inputs

Z is an output

Figure 9. Inverter Unit

By the same basic sequence of events mentioned above, the OFF condition is relayed from one stage to the next.

CONCLUSIONS

It must be pointed out at this time that no special provision was made for initially clearing the ring counter of all but one ON condition so as to eliminate multiple ON conditions when the power to the apparatus was first turned on. However, no such special provisions were needed since the counter seemed to clear itself automatically of all but one ON condition when the power was initially turned on. The reason for this is not fully understood, but the result is fortunate. Further analysis would be necessary to explain the effect.

Using a signal generator whose output was fed through a series of several inverters (to shape the signal generator's sine wave output into a square wave) and then to the input of the ring counter, it was possible to enter driving impulses into the counter at rates varying from 5 to as much as 60,000 impulses per second. The output of the spectrometer was displayed on an oscilloscope. So far as could be visually observed, the counter and the control units appeared to function very satisfactorily over that range of driving impulse frequencies. However, in practice, the signal generator would be set at no more than 120 cycles per second, for up to that frequency any given set of circuit controls would be in operation for at least one sweep of an oscilloscope trace, and that was what was desired in the first place.

Only six sets of control units were employed in this project. The potentiometers used in the control units were not chosen for accuracy or operating smoothness -- the primary purpose of the project was more to explore the possibility of using this method of circuit parameter variation to obtain useful NQR signal data than to achieve any great degree of accuracy. While it would be possible to select potentiometers of sufficient accuracy to obtain many only-slightly-varying quench rates, the presence of noise in the spectrometer's output signal would make it exceedingly difficult to adjust the control units accurately to the limits of the capabilities of their potentiometers.

Any intentions of using special equipment to sum and average the different spectrometer output signals for the different quench rates were postponed when it was observed on the oscilloscope that an interference signal of considerable size was imposed on the spectrometer's output signals. It is believed that this was a 60 cycle AC signal picked up by the spectrometer from the several power supplies powering the control units or possibly from the power lines of the Physics Building within which the apparatus was located. In any event, the presence of this interference so distorted the desired resonance signals that it was not possible to establish a meaningful reference line on the oscilloscope display from which the magnitude of the desired spectrometer signals could be measured. It is understood that various refinements and revisions of the apparatus could eliminate this problem, but these would be for future projects. However, the operation of the apparatus discussed here seemed to give a sound basis for further work along these lines of NQR signal detection.

BIBLIOGRAPHY

Dean, C., and Pollak, M. "Suppressing Side-Band Interference in Superregenerative rf Spectrometers," The Review of Scientific Instruments, Vol. 29, No. 7 (July, 1958), pp. 630-632.

Dehmelt, H. G. "Nuclear Quadrupole Resonance," American Journal of Physics, Vol. 22 (1954), pp. 110-120.

Rehn, Victor, and Dean, C. "Side-Band Suppression for Self-Quenched Superregenerative Spectrometers," The Review of Scientific Instruments, Vol. 31, No. 1 (January, 1960), pp. 72-73.