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Summary: A basic amplifier circuit and rectifier circuit were designed and built. Each of the two circuits were constructed on plywood panels with the parts laid out in the exact pattern of the schematic diagram. A specific step by step procedure is given so that an inexperienced person could build the units. Parts lists and pictorial diagrams are provided to aid in the acquisition of parts, and to facilitate the construction.

Several experiments are mentioned; among them the detection of a charge of static electricity by the grid of the amplifier, and the substitution of a selenium disc rectifier for the tube in the rectifier circuit. The schematic diagram and parts list for a simple one transistor radio are given. This radio can be used with earphones or played with loudspeaker volume through the amplifier.

The kit was adopted for use by the Travelling Science Teacher Program during the school year of 1960-61.

ADVISER'S APPROVAL James H. Zant

THE DESIGN AND CONSTRUCTION OF AN ELECTRONICS DEMONSTRATION KIT FOR THE TRAVELLING SCIENCE TEACHER PROGRAM

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May, 1960

THE DESIGN AND CONSTRUCTION OF
AN ELECTRONICS DEMONSTRATION
KIT FOR THE TRAVELLING
SCIENCE TEACHER
PROGRAM

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PREFACE

The purpose of this paper is to describe an electronics kit for classroom demonstration, and to give specific details of construction so that a relatively inexperienced person could assemble it. The kit was designed primarily for use by the Travelling Science Teacher Program.

Some of the electronic equipment currently being used by the travelling teachers is bulky and not too well suited for demonstration. Each individual piece is independent of all the others, and part of the apparatus is built into plastic boxes that are unattractive, and very difficult to use in explanation of operating principles.

The kit to be described consists of a rectifier, and an amplifier. Each is built on a plywood panel with the parts laid out in the exact pattern of the schematic diagram. This simplifies explanation and makes the individual components easy to distinguish. The units are light and can be stored in a space no larger than 8" x 10" x 4". They are interrelated, in that the rectifier, after itself serving as a demonstration piece, is used to furnish the direct current required for operation of the amplifier.

Chapters I and II deal with the actual building of the two units and the theory of operation of the circuits. The writer built and tested both circuits from parts ordered from Allied Radio Corporation, 100 N. Western Avenue, Chicago 80, Illinois,[1] and Burstein-Applebee Company,

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[1] _Allied Radio Catalog, Number 190._ (Allied Radio Corporation, Chicago, 1960.)

1012-14 McGee Street, Kansas City 6, Missouri.[1] Tables I and II give parts lists and catalog numbers of the parts.

Some of the measurements given in the construction directions are for the spacing of mounting holes. The measurements were taken from the actual parts used. If other type parts are used, there might be some discrepancies, since two parts with identical characteristics electrically, might not have the same physical dimensions.

Chapter III has several demonstrations described. It also includes specifications for a one tube transistor radio. The circuit was not original with the author: it was, with one modification taken from a transistor manual.[2]

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[1] Burstein-Applebee Catalog, Number 601. (Burstein-Applebee Company, Kansas City, 1960.)

[2] Louis E. Garner, Transistor Circuit Handbook, (Coyne Electrical School, Chicago, 1956), P. 71.

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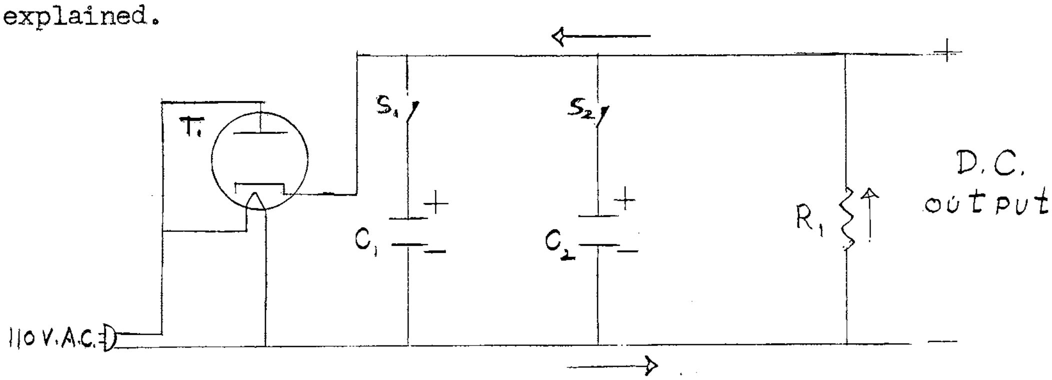
CHAPTER I

THE RECTIFIER

The half wave rectifier to be described is of the so called AC-DC type which does not require a power transformer. The circuit was chosen because its extreme simplicity makes its basic principles very easily explained.



T_1 . . . . 117Z3 half wave rectifier tube

C_1,C_2 . . . . 40 microfarad electrolytic capacitors

S_1,S_2 . . . . Single pole single throw switches

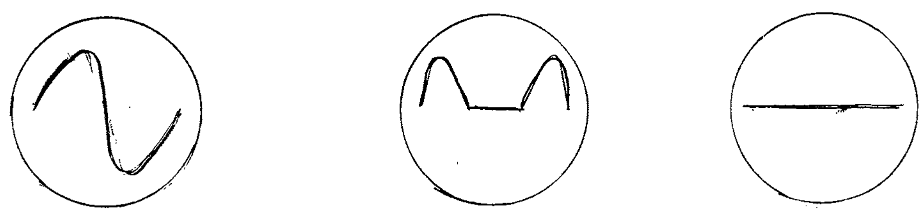
R_1 . . . . 100,000 ohm 1/4 watt carbon resistor

Figure I

Schematic Diagram of the Rectifier

T_1 (Figure I) has a filament which operates directly from 110 V.A.C. making a series dropping resistor unnecessary. Functionally it permits passage of current in only one direction. Since it is connected in series with the A.C. line, current can flow during only one half of the cycle. This current is shown by the arrows. When the potential in the A.C. line reverses, the tube acts as a switch and will not allow the second one half cycle to pass. The result is a pulsating direct current through R_1. For most purposes this pulsating D.C. is useless, so provisions must be made to smooth it out.

C_1 and C_2 do this rather effectively by their charge and discharge action. During the positive cycle, current flows in R_1, and C_1, and C_2 charge with the polarity indicated. During the negative cycle T_1 does not conduct, so C_1, and C_2 discharge through R_1, filling in the gaps between the positive cycles. Figure 2 shows the appearances on an oscilloscope screen of the traces available in the rectifier. (A) shows a normal alternating current cycle. (B) is the rectified, unfiltered pulsating direct current, while (C) is the direct current after C_1 and C_2 are placed in the circuit.



(A) (B) (C)

Figure 2

Oscilloscope Traces in the Rectifier

R_1 has the function of discharging C_1 and C_2 when the instrument is shut off. If this were not done, the capacitors would remain charged for several minutes and an uncomfortable shock would await the unwary.

S_1 and S_2 are included for the purpose of temporarily disconnecting C_1 and C_2 during experiments demonstrating their function.

Construction Procedure for the Rectifier

A step by step procedure should be used in building a piece of equipment. In the instructions that follow, space is provided to check each step as it is completed. When a wire is connected, the symbol (S) means that it should be soldered when connected. The symbol (NS) means that the connection should not be soldered until later because there are other connections to be made to the same post. In electronic work, only rosin core solder can be used. Acid core solder causes corrosion and results in poor connections and ruined parts. Manufacturers of home builders electronic kits immediately void all guarantees when they find that a piece of their merchandise has been subjected to acid core solder.

In the instructions that follow, refer to Figures 3 and 4.

1. ( ) Drill one sixteenth holes a, b, c, d, e, on a line one inch from the bottom of the plywood panel. Space as shown in Figure 3.
2. ( ) Drill one sixteenth holes f, and g on a line one inch from the top of the panel spaced as in Figure 3.
3. ( ) Drill one sixteenth inch holes h, i, j, k, on a line one and one half inches from top of panel spaced as in Figure 3.
4. ( ) Mount the tube socket four and one half inches from the bottom of the panel and one and one half inches from the left end. Measure from center of socket. Mount with pins 5 and 6 toward bottom of panel. Pins number counterclockwise from gap when looking at top of socket.
5. ( ) Drill a one sixteenth hole through the panel as near as possible to pin 3.
6. ( ) Mount slide switches S_1, and S_2 at k, j, h, and i respectively. Mount with soldering post nearest center directed toward bottom of panel.

7. ( ) Use a cable holder to fasten AC cord at a. Allow three inches on end of cord for connections.

8. ( ) Connect one wire of AC cord to pin 5 (NS) of T_1.

9. ( ) Connect a piece of bare wire from pin 4 (S) to pin 5 (S) of T_1.

10. ( ) At b, using bolt and nut, fasten two soldering lugs, one above, and one below the panel. Point the upper lug toward top of panel, and lower lug toward hole at pin 3.

11. ( ) Connect a piece of heavy uninsulated wire from pin 3 (S) through the hole, and to the lower lug at b (S).

12. ( ) Using bolts and nuts, fasten soldering lugs at c, d, and g. Point lugs toward longitudinal centerline of panel.

13. ( ) Connect the remaining wire of the AC cord to b (NS).

14. ( ) Connect C_1 from b (NS) to bottom post of S_1 (S). Be sure that the negative side of C_1 is toward b.

15. ( ) Connect C_2 from c (NS) to bottom post of S_2 (S). Be sure that the negative side of C_2 is toward c.

16. ( ) Shape a piece of heavy copper wire to fit neatly from pin 6 (S) across upper posts of S_1 (S), and S_2 (S) to g (NS).

17. ( ) Connect R_1 from d (NS) to g (NS).

18. ( ) Connect a piece of heavy copper wire from b (S) across c (S) to d (NS).

19. ( ) Connect a thirty six inch length of red flexible lead at g (S).

20. ( ) Connect a thirty six inch length of black flexible lead at d (S).

21. ( ) Fasten flexible leads down with cable holders at e and f.

22. ( ) Connect an alligator clip at the extremety of each flexible lead.

This completes the construction of the rectifier. Check the wiring thoroughly before plugging in. With the tube at operating temperature, and S_1, and S_2 closed, a pop should be heard and a small blue spark seen when the alligator clips are struck together. The clips will tend to stick together when struck. Do not hold the clips together as this will overload the tube and burn it out. They should be in contact only an instant. This is a crude test for function only and tells nothing about the actual purity of the direct current. Purity can be shown visually on the screen of an oscilloscope, or aurally by using the rectifier to power the amplifier.

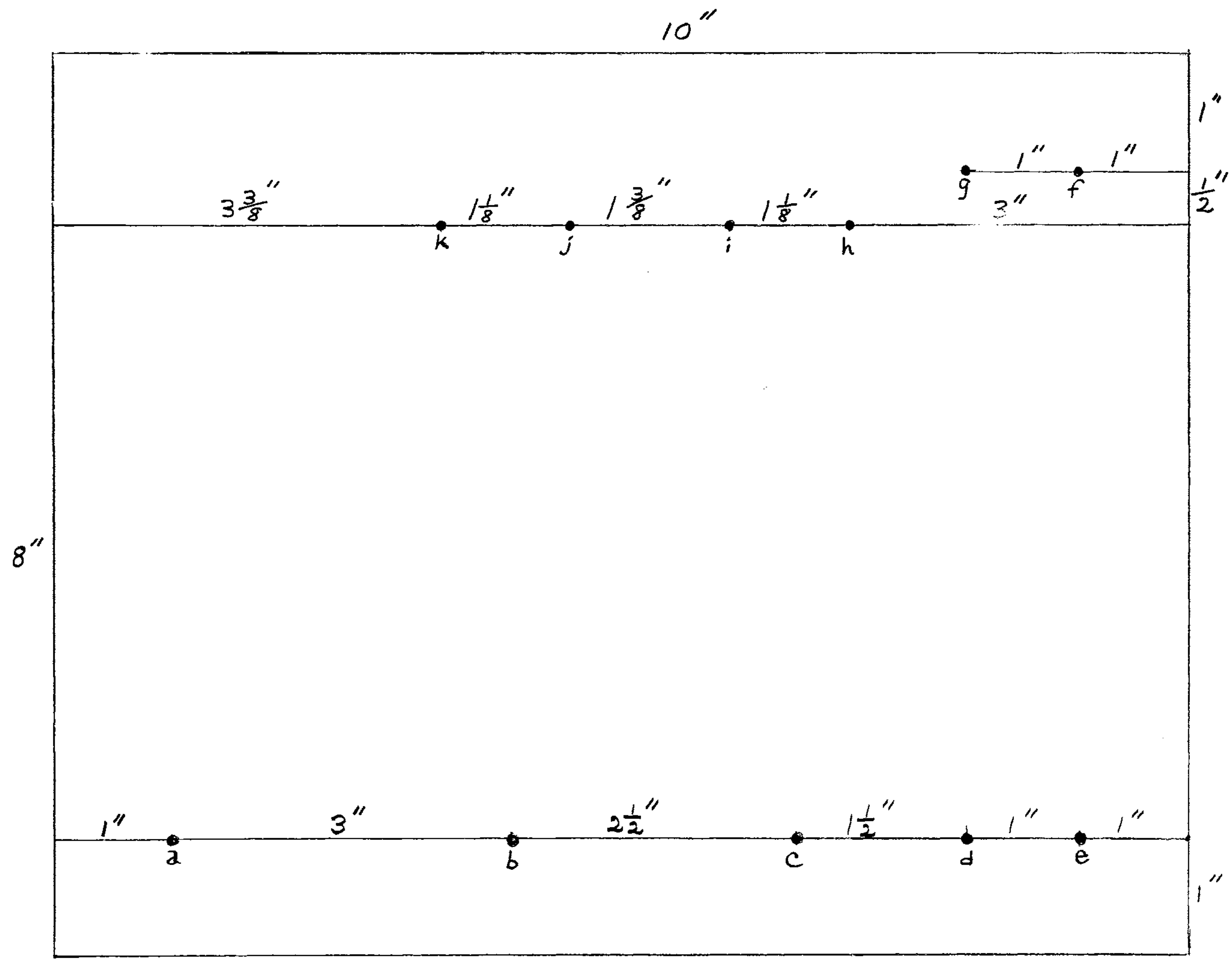


FIGURE 3

Hole Drilling Layout for the Rectifier

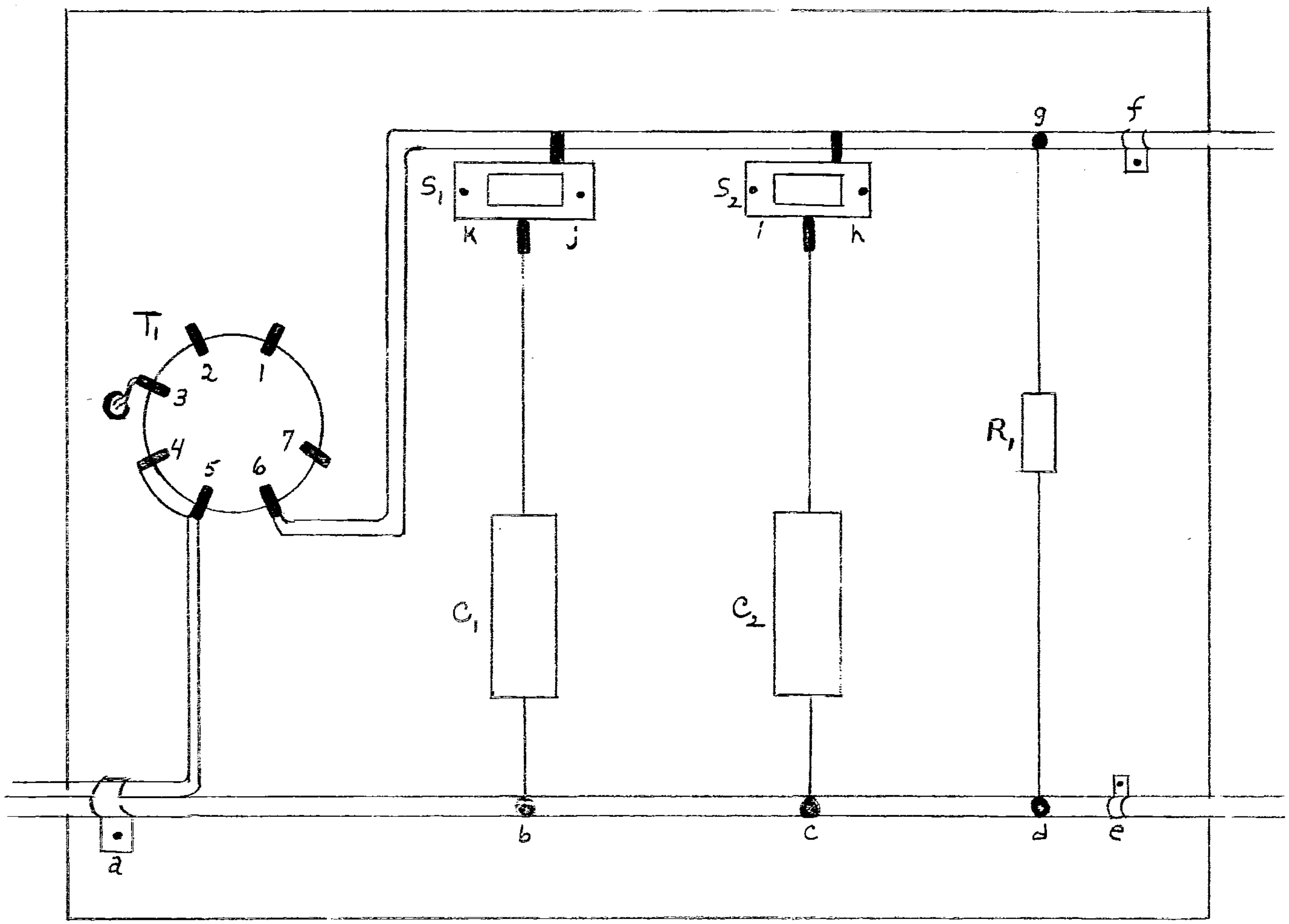


FIGURE 4

Pictorial Diagram of the Rectifier

TABLE I

PARTS LIST FOR THE RECTIFIER

T_1	117Z3 Rectifier tube
R_1	100,000 ohm 1/2 watt carbon resistor
C_1	40 microfarad, 150 volt electrolytic capacitor
C_2	40 microfarad, 150 volt electrolytic capacitor
S_1	SPST switch (Allied Radio Catalog Number 34B422)
S_2	SPST switch (Allied Radio Catalog Number 34B422)
6 foot AC cord	
2 cable holder clamps	(Burstein-Applebee, type 4500 F, catalog number 19B1199.)
5 soldering lugs	(Burstein-Applebee, type C, Catalog number 12A1233.)
2 alligator clips	(Burstein-Applebee, type 60, Catalog number 12B1026.)
7 pin miniature socket	(Burstein-Applebee, type XS7, Catalog number 17B262.)
13 1/16" x 3/4" bolts with nuts	
1 8" x 10" x 1/4" plywood panel	
36" piece of red flexible lead	
36" piece of black flexible lead	

CHAPTER II

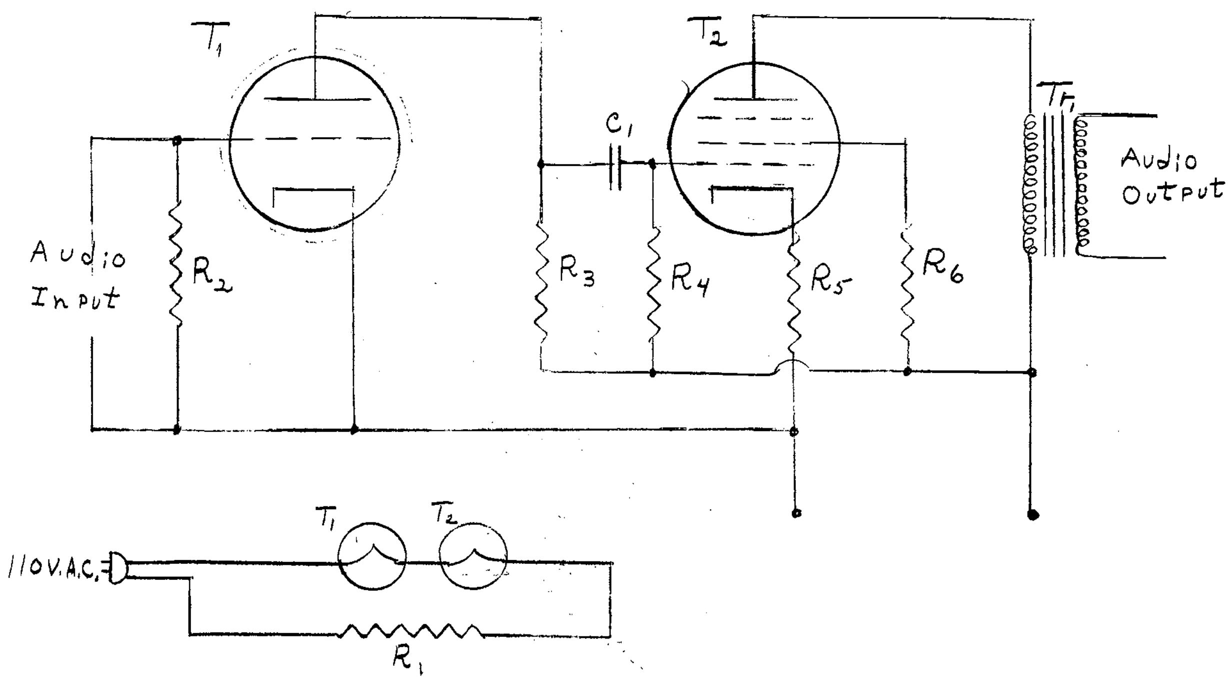
THE AMPLIFIER

The amplifier employs two tubes, and is almost identical to that found in millions of small table model radios. T_1 acts as a voltage amplifier to drive the power amplifier, T_2. (Refer to Figure 5, Page 10.)

In typical operation, a source of varying voltage is applied across the input terminals, j and v. This source can be a microphone, a phono pickup, a photo cell, or any of various other devices. As the potential between j and v varies, the grid of T_1 will experience a change in potential with respect to the cathode. If the grid becomes more negative, the electron stream from the cathode to the plate will be thinned out somewhat due to the repelling action of the negative grid. This depletion of the electrons in the stream increases the internal resistance of T_1, and thus the current in R_3 is lowered. If the grid becomes less negative, the electron stream becomes more intense, the internal resistance of T_1 decreases, and more current flows in R_3. T_1, in effect, acts as a variable resistor in the series circuit of T_1 and R_3.

R_2 is a bleeder resistor which allows electrons to leak off the grid. This prevents an accumulation of negative charge on the grid. This would shut the tube off completely or, at least, radically lower its efficiency.

A very small voltage variation on the grid causes an appreciable current variation in the R_3 circuit. The result is a variation in the



R_1	400 ohm 25 watt wirewound resistor
R_2	1 megehm 1/4 watt carbon resistor
R_3	220,000 ohm 1/2 watt resistor
R_4	470,000 ohm 1/2 watt resistor
R_5	220 ohm 1/2 watt resistor
R_6	1200 ohm 1/2 watt resistor
C_1	.05 mfd. 200 volt tubular capacitor
T_1	12AV7 vacuum tube
T_2	50C5 vacuum tube
Tr_1	output transformer

FIGURE 5

Schematic Diagram of the Amplifier

voltage drop across R_3, which is exactly in unison with the source of varying voltage, but has a much greater amplitude. Ideally, greatest amplification will occur when R_3 is equal to the rated internal resistance of T_1, but in practice R_3 is usually two thirds to three fourths of the T_1 resistance value. This lowers the amplification but gives better fidelity.

C_1 is connected from the plate of T_1 to the grid of T_2. When a capacitor is connected in this way it is referred to as a coupling capacitor. It enables the passage of a pulsating signal from plate to grid while preventing the positive plate potential from affecting the grid. As the voltage drop across R_3 varies, the charge on the positive plate of C_1 varies proportionately. This affects the charge on the other plate of C_1, but this plate is connected to the control grid of T_2. The charge variation on the plates of C_1 causes electrons to surge onto and off of the control grid of T_2. This varies the grid-cathode potential in exact accordance with the original signal.

R_4 is the bleeder resistor for T_2 and has the same function that R_2 has for T_1.

R_5 is connected in series with T_2 and the primary coil of Tr_1. It acts as a biasing agent in that it insures that the grid of T_2 will always be maintained well on the negative side with respect to the cathode. The grid is connected to the lower end of R_5, and the cathode to the upper end. Since the electrons are travelling upward in R_5, the lower end is negative with respect to the upper end. The grid, then, is connected to a point that must always be negative with respect to the cathode. This is necessary because T_2, as a power amplifier, has a low internal resistance, carries rather high current, and operates at high temperature. If the grid should swing positive, the tube would conduct too much current and would literally burn itself up. If a coupling capacitor shorts, even partially, the grid of the power amplifier gets a strong positive charge from the plate of the previous stage. The tube overconducts and becomes too hot. The plate may even become red hot. The amplifier might still operate with distortion, and reduced efficiency, but the tube will not last long. This happens occasionally in radios, phonographs, or other pieces of apparatus which employ power amplifiers. It is not a wise idea to replace a bad power amplifier tube without first making sure that the coupling capacitor is all right.

The current variations in the plate circuit of T_2 are transferred by induction into the secondary coil of Tr_1, and thence into the voice coil of the speaker.

R_6 is connected to the second grid of T_2, and is for the purpose of maintaining that grid at a strong positive potential. The third grid of T_2 is internally connected to the cathode, and can be ignored as far as wiring is concerned. RCA Receiving Tube Manual (1956), Pages 3 to 10, gives an excellent discussion of the function of the elements of vacuum tubes. In fact, a current issue of the RCA tube manual is, in the opinion of the writer, the most valuable book an experimenter or beginning student in electronics can buy.

R_1 is connected in series with the heaters of T_1, and T_2 to complete the voltage drop between line current and the lower voltage requirements of the two tubes (12.5 and 50 volts respectively.) It is important that R_1 be mounted above the wooden panel (1/4 inch clearance is sufficient) since a good deal of heat is dissipated. R_1 dissipates seventeen watts of power, but it was felt wise to use a twenty five watt resistor for a sufficient safety factor.

In the instructions that follow, refer to Figures 6 and 7.

Construction Procedure for the Amplifier

1. ( ) Drill the twenty two one sixteenth inch holes, a through v as shown in Figure 4.
2. ( ) Drill hole x three sixteenth inch in diameter.
3. ( ) Mount the two tube sockets each two inches below the top of the panel, and one and one half inches, and six inches respectively from the left end. Position pins one and two toward the bottom of the panel. Pins number counterclockwise when looking at the top of the socket.
4. ( ) Drill a three sixteenth inch hole as near as possible to pins three and four of each tube.
5. ( ) Fasten line cord at a with a cable holder. Allow six inches for connecting.
6. ( ) Pass one wire of the line cord through hole x, beneath the panel to the hole under pin 3 of T_1. Bring up to pin 3 (S).
7. ( ) Run a length of heavy wire from pin 4 (S) of T_1 beneath the panel to pin 4 (S) of T_2.
8. ( ) Run a length of heavy wire beneath the panel from pin 3 (S) of T_2 to soldering lug beneath panel on bolt at c.
9. ( ) Mount the 400 ohm wirewound resistor R_1 on screws at b and c. Use three nuts on the bolts and mount the resistor about one fourth inch above the panel. This is necessary because of the large amount of heat liberated by the resistor.
10. ( ) Connect the short wire of the AC cord to b (S).
11. ( ) Mount the output transformer Tr_1 with bolts at t and m. Mount with short, bare leads facing u and n.

12. ( ) Connect the short bare leads of Tr_1 to bolts at u and n.

13. ( ) Connect one of the long wires of the output transformer to a bolt at s, and the other at i. Since this is stranded wire it is a good idea to twist it into an eye large enough to pass over a bolt, and then tin it thoroughly. This makes a very neat connection.

14. ( ) Run a heavy piece of wire from e to h via i.

15. ( ) Run a piece of heavy wire from d to v via g and f.

16. ( ) Run a piece of heavy wire from pin 1 (S) of T_1 to j.

17. ( ) Connect a one megohm resistor from f to the wire from j to pin 1. Solder to the wire so that the resistor is perpendicular to the longitudinal axis of the panel.

18. ( ) Run a piece of heavy wire from pin 2 (S) of T_1 to wire fg (S).

19. ( ) Connect a 220 ohm resistor from pin 1 (S) of T_2 to wire fg. The wire from the resistor to fg should be heavy and should be bent into a small semicircular hump where it crosses wire hi. This hump should be large enough that it is readily apparent at a distance that the two wires do not connect. They must not connect since this would constitute a dead short of the power supply.

20. ( ) Run a short piece of wire from pin 2 (S) of T_2 to q via k.

21. ( ) Connect a 470,000 ohm resistor from k to a point on the wire below the 220 ohm resistor.

22. ( ) Run a piece of heavy wire from pin 7 (S) of T_1 to p via o.

23. ( ) Connect a 220,000 ohm resistor from p to h.

24. ( ) Connect a .05 tubular capacitor from p to q.

25. ( ) Run a piece of heavy wire from pin 7 (S) of T_2 to s via r.

26. ( ) Connect a short piece of wire from pin 6 (S) of T_2 to l.

27. ( ) Connect a 1200 ohm resistor from l to wire hi (S).

28. ( ) Solder a three foot length of two conductor cord to the two voice coil soldering points on the speaker.

29. ( ) Fasten the cord to the speaker frame with a cable holder.

30. ( ) Connect alligator clips to the ends of the speaker cord.

31. ( ) Fasten the square piece of hardware cloth over the face of the speaker by bending the corners over the speaker frame.

32. ( ) Connect two alligator clips to the two wires of the microphone cord.

This completes the construction of the amplifier. Insert T_1 and T_2 into the proper sockets and plug into a 110 volt AC source. The tubes should light normally. Unplug and measure the resistance between points d and e. With the tubes cold this should be on the order of several hundred thousand ohms. Connect the red lead of the rectifier to e, and the black lead to d. Plug in both amplifier and rectifier. Connect the speaker leads to posts u and n. When the tubes are warmed up, touching post j with the finger will cause a squeal in the speaker. The microphone can now be connected between j and v.

TABLE II

PARTS LIST FOR AMPLIFIER

T_1	12AV7 voltage amplifier tube
T_2	50C5 power amplifier tube
R_1	400 ohm, 25 watt wirewound resistor
R_2	1 megohm, 1/4 watt carbon resistor
R_3	220,000 ohm, 1/2 watt carbon resistor
R_4	470,000 ohm, 1/2 watt carbon resistor
R_5	220 ohm, 1/2 watt carbon resistor
R_6	1200 ohm, 1/2 watt carbon resistor
C_1	.05 microfarad, 200 volt tubular capacitor
Tr_1	Thordarson 24S48 output transformer

6 foot AC cord

8" x 10" x 1/4" plywood panel

2 feet of heavy uninsulated copper wire

2 seven pin miniature sockets (Burstein-Applebee, type XS7, Catalog number 17B262)

23 nuts and bolts 1/16 inch by 3/4 inch

6" x 6" piece of hardware cloth

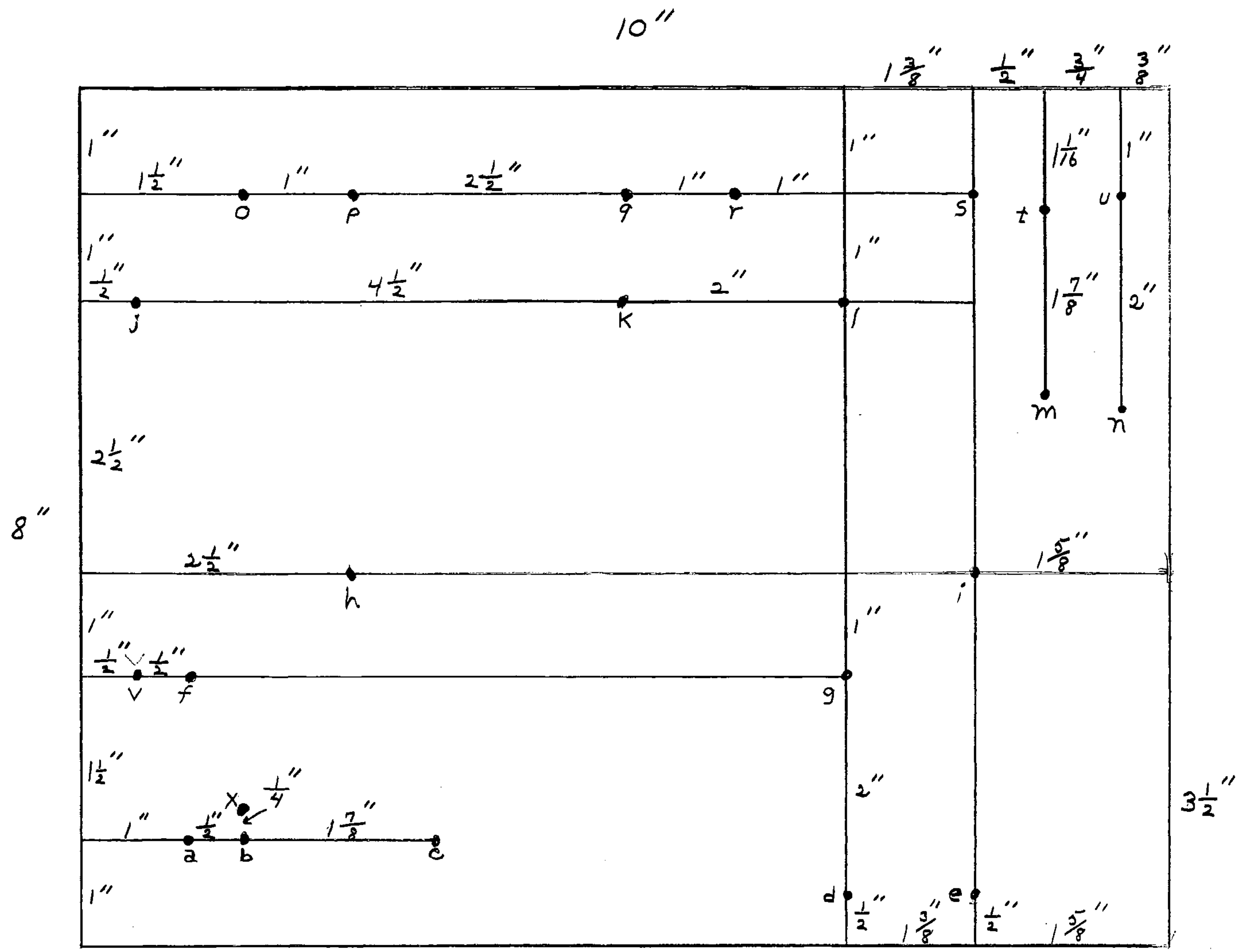


FIGURE 6

Hole Drilling Layout for the Amplifier Panel

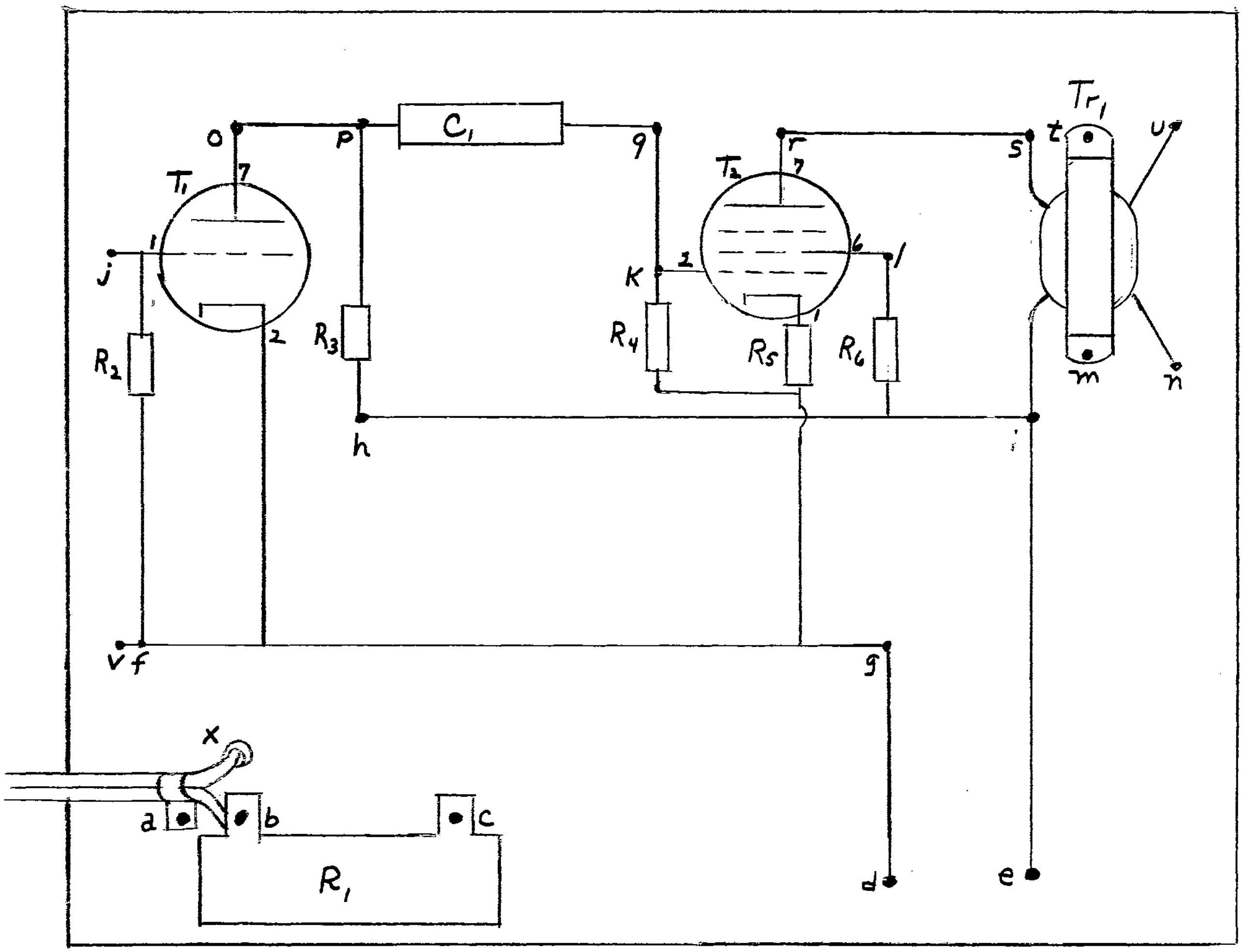


FIGURE 7

Pictorial Diagram of the Amplifier

CHAPTER III

EXPERIMENTS

With an oscilloscope, several interesting things can be done to demonstrate the function of the vacuum tube and the capacitor, as well as those of selenium and silicon rectifiers. Three oscilloscope traces are available in the rectifier circuit as indicated in Figure 2. (A) can be obtained by connecting the vertical input of the scope across the AC line using a suitable capacitor and dropping resistor. (B) shows up between d and g with S_1 and S_2 both open. Closing the switches gives (C). These traces can be used to show both rectification, and filtering. The 117Z3 tube can be replaced with a silicon diode or a selenium disc rectifier connected across pins 5 and 6. Care must be used to ensure that the positive side of the rectifier or diode is connected to pin 6. This is necessary to prevent damage to C_1 and C_2.

The amplifier uses the rectifier for its source of plate voltage. A .05 microfarad tubular capacitor should be connected to the grid terminal of the 12AV7. Signals should be fed into the loose lead of this capacitor.

A plastic comb can be charged by rubbing briskly with a piece of wool. If this charged comb is brought near the input lead, a series of sharp pops will be heard in the speaker, caused by the transfer of the charge from the comb onto the plates of the condenser.

When a crystal microphone is connected across the input, the amplifier becomes a small public address system. If the microphone is brought near the speaker a very loud squeal is heard. This is the result of feedback which is the principle of operation of oscillator circuits. Feedback is the transfer of some of the output signal energy into the input. This will cause sustained oscillations of any desired frequency. The frequency, of course, is governed by the inductance and capacitance in the circuits involved. Feedback is usually accomplished by passing the output signal through a coil which is placed near the input circuit. The amount of feedback can be controlled by the spacing of this coil. A simple oscillator circuit is shown in Figure 8.

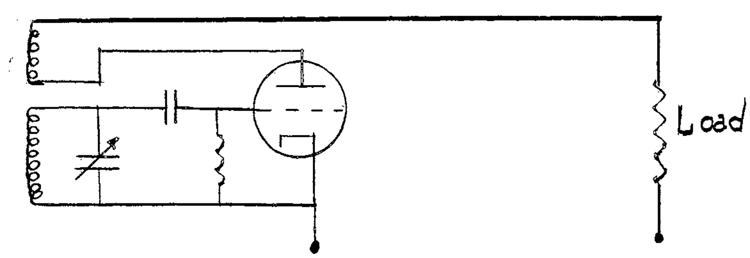


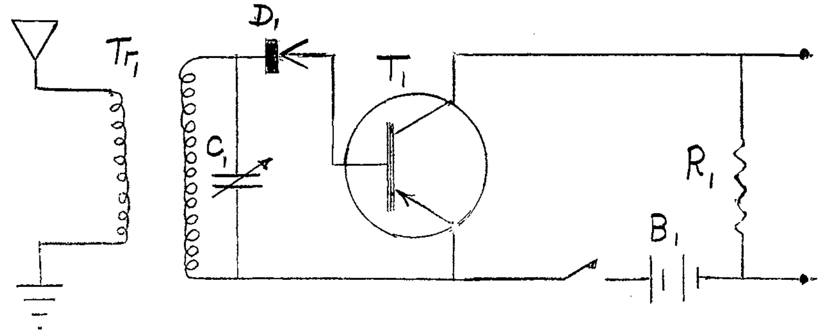
FIGURE 8

Typical Oscillator Circuit

A small transistor radio can be played through the speaker by hooking the headphone terminals of the radio to the input of the amplifier. If a radio with a loopstick is used, the radio should not be grounded. The negative side of the power supply is connected directly to the power line. Since a loopstick has a single winding, grounding might cause a short. It is safer to merely allow the radio to ground through the power supply.

The author had good results with the circuit of Figure 9. Note that the antenna coil has a primary and a secondary winding. This isolates the ground terminal from the power supply.

R_1 should be omitted if headphones are connected across the output. It is included as a load resistor to provide a voltage drop across the input terminals of the amplifier.



Tr_1	Miller 44-A antenna coil
C_1	365 mmfd variable capacitor
D_1	1N34 germanium diode
T_1	2N107 transistor
R_1	12000 ohm 1/4 watt carbon resistor
B_1	15 volt hearing aid battery (Burgess Y-10)

FIGURE 9

Schematic Diagram of a Transistor Receiver

There are other experiments which might be devised, but time and facilities have not permitted their investigation.

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