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A NEW TYPE OF RADIO VACUUM TUBE

THESIS FOR DEGREE OF B. S.

IN ELECTRICAL ENGINEERING

CHAUNCEY M. PARK ORIN D. DAUSMAN

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A NEW TYPE OF RADIO VACUUM TUBE

A Thesis Submitted to
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By

Chauncey M. Park

Orin D. Dausman

Candidates for the Degree of
Bachelor of Science
in
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The use of vacuum tubes in radio transmitting and receiving sets has increased rapidly in the past few years. This extended use has uncovered certain limitations and disadvantages of the old type of vacuum tube. For this reason, it seemed advisable, not only from an educational standpoint, but from an economic standpoint, to investigate the possibilities of the construction and the operation of a new type of vacuum tube.

The old style of vacuum tube consists of three elements, a filament, a plate, and a grid. The filament is an emitter of negative electrons. The plate, due to the high positive potential at which it is charged, attracts the electrons. The grid is a net-like structure located between the filament and the plate. In passing from the filament to the plate, the electrons must pass through the grid. Due to the negative charge carried by the electron, its motion is affected by any electro-static potential in the vicinity. This property makes it possible, by changing the potential impressed on the grid, to control the quantity of electrons passing from filament to plate.

Although this tube is sensitive and amplifies without distortion, it has several disadvantages. Some of these disadvantages are the necessity for using high plate voltages, its sensitivity to

comparatively weak electrostatic fields, its tendency to build up undesirable oscillatory currents in resonant circuits, and the necessity for an extremely high degree of vacuum. The new tube has been designed with the intent of overcoming these disadvantages and making other improvements.

It is a well known fact that an electric current is affected by the presence of an electromagnetic field. This fact is made use of in the design of the new type of tube. The new tube, as first proposed, was to consist of a filament, two like plates, a parabolic reflector, and a control solenoid. These elements were to be arranged as shown in Plate #1, Fig. #1. The filament F was to be located at the focus of the parabolic reflector R. The axis of the parabola was to pass between the two plates, P_1 and P_2 . The control solenoid was to be placed around the enclosing tube. In operation, a negative potential would be impressed on R, and equal positive potentials on P_1 and P_2 . In the absence of a magnetic field, the electron flow would be equally divided between P_1 and P_2 . In the presence of a magnetic field, the electron flow would be deflected from one plate to the other depending upon the direction of the field. If leads are brought from these plates to opposite ends of a solenoid, and if the plate potential is supplied



Fig. 1.



Fig. 2.



Fig. 3.



Fig. 5.

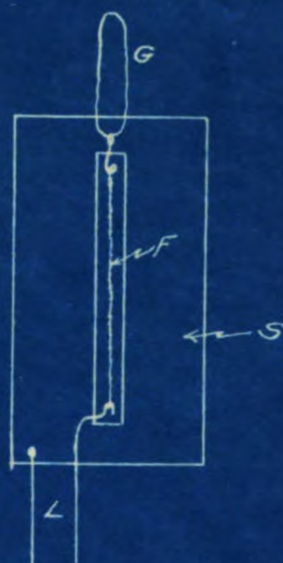


Fig. 4.

through a center tap on the solenoid, the flux in the solenoid due to the equally divided plate currents will be zero. Now if the plate currents are unbalanced, due to a changing magnetic flux in the tube, flux will be set up in the solenoid. It is easily seen that this is the condition obtained in a push-pull amplifier with the old style of tubes.

The greater part of the material used in the construction of the new tube was obtained from burned out tubes of the old style. It was necessary to obtain non-magnetic material for the elements. If magnetic material were used for the elements, the magnetic field set up by the control coil would be concentrated in the elements and would have little effect in controlling the electron flow. It was found that the plates of General Electric Co. tubes were of non-magnetic material and so this material was used for the reflector and plates of the first set of elements constructed. Plate #1, Fig.1 shows the arrangement of the elements. These elements were made about two inches in length and of lateral dimensions to fit in a one inch test tube. The filament was of oxide-coated platinum obtained from the Western Electric type of tube. The base used was the base of an old

Western Electric tube. It was considered undesirable to actually construct the base because of the difficulty of making an air tight joint when fusing leads through glass.

After some experimenting, it was found that the best way of fastening the elements to the leads was by brazing with brass. The leads were depended upon to support the elements. This was the first real difficulty encountered. It was found to be impossible to hold the elements rigidly by this method.

At this time, a new type of construction was decided upon. The plan of the elements is shown on Plate #1, Fig.2. The opposite plates P_1 & P_1' and P_2 & P_2' were connected as shown by Fig. 3. The reflector was replaced by the the shield shown in Fig. 4. The filament was suspended in the slot in the shield.

The plates and shield were constructed of sheet copper because it was found that the material obtained from the old General Electric Co. tubes oxidized very easily and it was very difficult to remove the oxide. Also this metal was very brittle. It would probably not be desirable to use copper in a commercial tube because of its tendency to hold occluded gases.

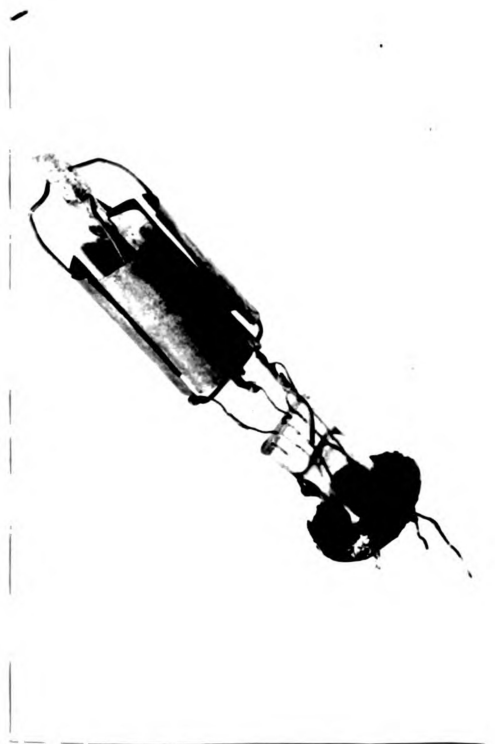
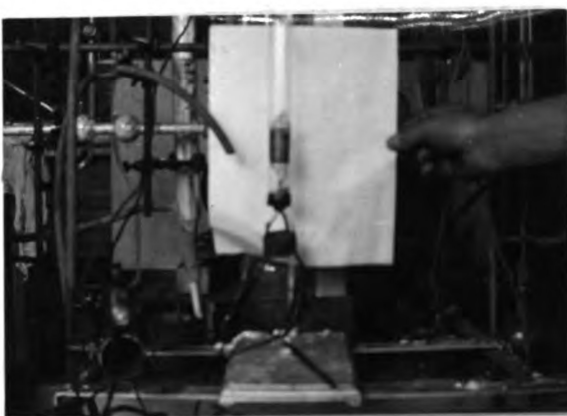
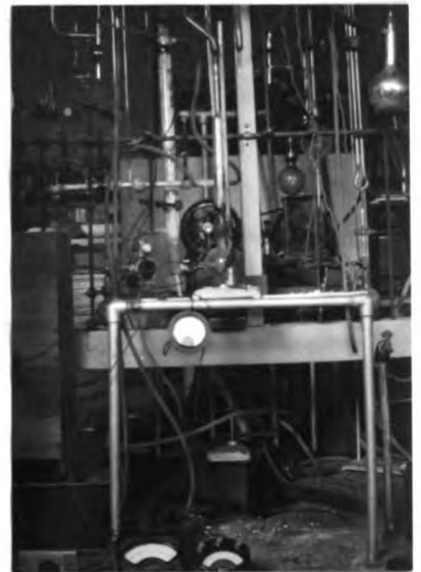
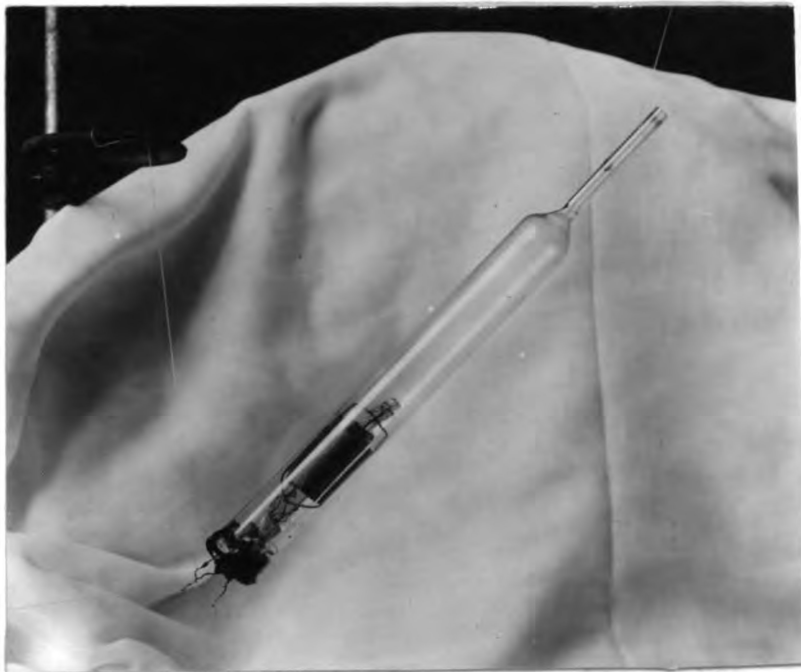
The elements were made of a size such that they

would just slip inside a one inch test tube. This gave a rigid support for the plates. The top of the shield and the crossleads between the plates were fused into a piece of glass which supported them as well as insulating them from each other. The top end of the filament was connected directly to the shield. The shield thus served as one filament lead while the other filament lead was kept apart from the other elements. The leads from the two sets of plates and the filament leads were brazed to the leads through the glass base. The entire group of elements then appeared as in the accompanying print on Plate #2.

The next problem was to inclose the elements in a glass tube of the form shown in Fig. 5, Plate #1. After a great amount of difficulty, working with soft glass, it was found to be necessary to construct the tube of Pyrex glass and fasten this to the soft glass base with De Khotinsky cement. De Khotinsky cement is the only compound known which will form an air tight joint with glass. This completed form of tube is shown by the print on Plate #2.

Dr. Ewing of the chemistry department made possible the use of the vacuum pump owned by that department. The evacuation of the tube proved to be a long process. During this process two filaments

Plate #2.



were burned out, making it necessary to remove the tube from the pump for replacements. At another time, the mercury pump on the evacuating system became over heated, which made it necessary to remove the tube from the pump.

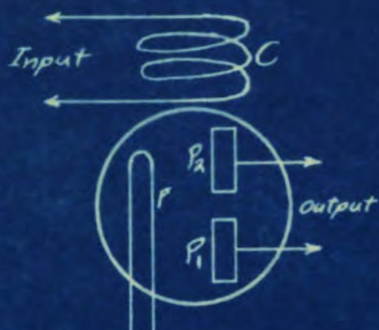
After considerable time had been spent trying to reduce the pressure in the tube to such a degree that ionization would not occur at ordinary plate voltages with the filament lighted, it was decided to test the tube while it remained on the pump. The definite reason for being unable to prevent ionization is not known. It is thought that some air may have filtered through the De Khotinsky cement, or that the cement actually evaporated, thus reducing the pressure. The gage on the pump indicated a pressure of only .0002 millimeters of mercury at that time.

The only quantitative tests possible to take of the tube were static tests. The connection diagram for taking these tests is shown on Plate #4, Test Connection #1. On Plate #2 will be seen the prints of the tube on the pump with the testing apparatus in place. The data from the static tests is given on the following pages.

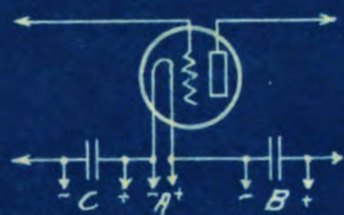
Plate #3.



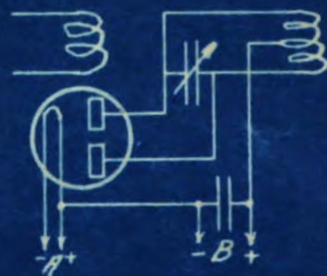
Old Style Tube



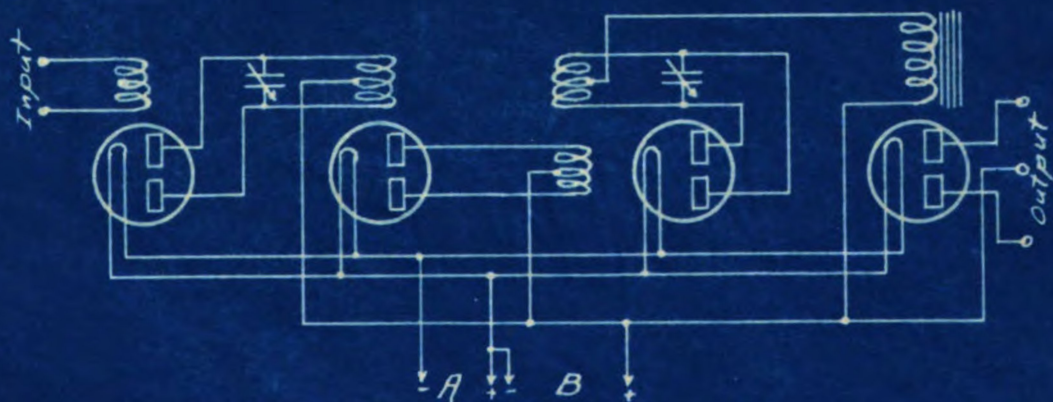
New Style Tube



Old Style Circuit

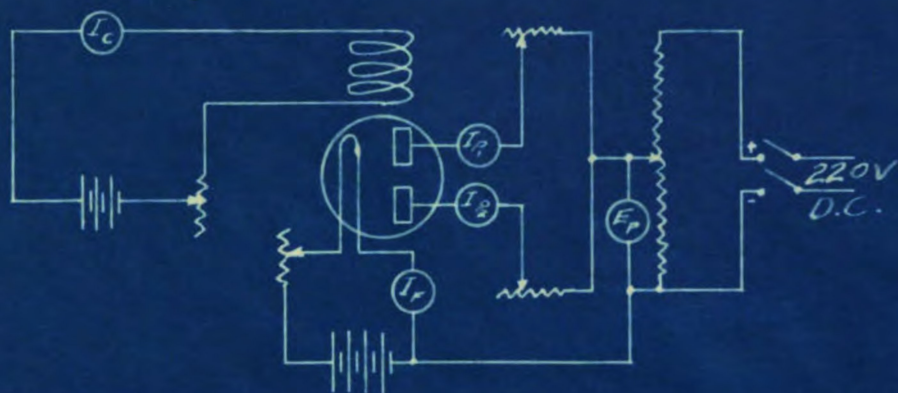


New Style Circuit

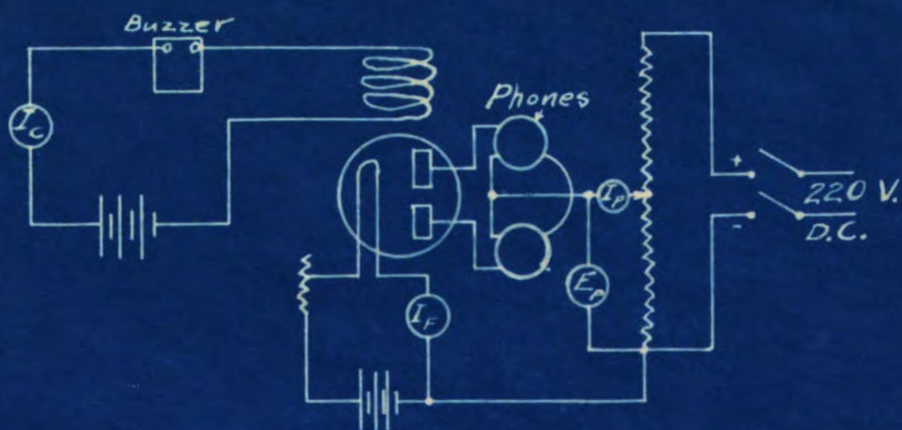


Complete Receiving Circuit

Plate #4.



Test Connection #1.



Test Connection #2.

In the following data, I_f = filament current,
 E_p = plate voltage, I_{p1} = milliamperes in P_1 ,
 I_{p2} = milliamperes in P_2 , R_p = resistance in the
plate leads, and I_c = current in the control coil.

$I_f = 1.25$ $R_p = 2000$ $E_p = 90$

When $I_c = 0$, $I_{p1} = 3.3$, and $I_{p2} = 3.9$.

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} + .6$
.3	3.4	3.7	.3
.6	3.4	3.8	.2
.9	3.3	3.6	.3
1.2	3.3	3.5	.4
1.5	3.35	3.6	.35
1.8	3.2	3.5	.15
2.1	3.35	3.5	.45
2.4	3.35	3.5	.45
2.7	3.30	3.4	.50
3.0	3.35	3.3	.65

$I_f = 1.25$ $R_p = 2000$ $E_p = 60$

When $I_c = 0$, $I_{p1} = 1.95$, and $I_{p2} = 2.3$

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} + .35$
.3	1.98	2.23	.10
.6	1.98	2.13	.20
.9	2.00	2.13	.22
1.2	2.01	2.10	.26
1.5	2.05	2.10	.30
1.8	2.05	2.06	.34
2.1	2.05	2.00	.40
2.4	2.12	1.87	.60
2.7	2.10	1.83	.62
3.0	2.15	1.80	.70

$I_f = 1.25$ $R_p = 2000$ $E_p = 30$

When $I_c = 0$, $I_{p1} = .7$, and $I_{p2} = .92$.

I_c	I_{p1}	I_{p2}	$I_{p1}-I_{p2}+.22$
.3	.79	.87	.14
.6	.82	.82	.22
.9	.87	.80	.29
1.2	.91	.77	.36
1.5	.95	.72	.45
1.8	1.00	.67	.55
2.1	1.01	.63	.60
2.4	1.06	.58	.70
2.7	1.11	.50	.83
3.0	1.16	.45	.93

$I_f = 1.25$ $R_p = 2000$ $E_p = 20$

When $I_c = 0$, $I_{p1} = .35$, and $I_{p2} = .37$.

I_c	I_{p1}	I_{p2}	$I_{p1}-I_{p2}+.02$
.3	.39	.33	.08
.6	.40	.28	.14
.9	.45	.22	.25
1.2	.49	.18	.33
1.5	.51	.17	.36
1.8	.52	.15	.39
2.1	.56	.13	.45
2.4	.59	.12	.49
2.7	.60	.08	.54
3.0	.61	.07	.56

$I_f = 1.09$ $R_p = 2000$ $E_p = 88$

When $I_c = 0$, $I_{p1} = .40$, and $I_{p2} = .60$.

I_c	I_{p1}	I_{p2}	$I_{p1}-I_{p2}+.20$
7	.90	.10	1.00
6.1	.83	.13	.90
5	.81	.17	.84
4	.76	.23	.73
3	.65	.33	.52
2	.57	.43	.34
1	.50	.53	.17
0	.40	.60	.0
-1	.30	.70	-.20
-2	.25	.76	-.31
-3	.21	.80	-.39
-4	.19	.80	-.41

$I_f = 1.09$ $R_p = 2000$ $E_p = 50$

When $I_c = 0$, $I_{p1} = .27$, and $I_{p2} = .37$.

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} + .10$
6.5	.61	.00	.71
5.2	.56	.03	.63
4.	.51	.09	.53
3.	.50	.13	.47
2.	.42	.20	.32
1.	.35	.30	.15
0.	.27	.37	.00
-1.	.21	.43	-.12
-2.	.18	.47	-.19
-4.	.09	.50	-.31
-5.2	.03	.50	-.37
-6.5	.00	.50	-.40

$I_f = 1.09$ $R_p = 2000$ $E_p = 20$

When $I_c = 0$, $I_{p1} = .13$, and $I_{p2} = .13$

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} - 0$
4	.21	.00	.21
3	.23	.01	.22
2	.21	.02	.19
1	.20	.05	.15
0	.13	.13	.00
-1	.10	.17	-.07
-2	.08	.20	-.12
-3	.03	.20	-.17
-4	.00	.20	-.20

$I_f = 1.29$ $R_p = 2000$ $E_p = 40$

When $I_c = 0$, $I_{p1} = 2.85$, and $I_{p2} = 3.30$.

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} + .45$
5.2	4.35	1.80	3.00
4.0	3.9	2.13	2.22
2.9	3.45	2.73	1.17
2.	3.2	2.87	.88
1.	3.08	3.13	.35
0.	2.85	3.30	.00
-1.	2.7	3.27	-.12
-2.	2.5	3.23	-.28
-3.	2.29	3.20	-.46
-4.	1.98	3.43	-.99
-5.1	1.35	3.67	-1.87
-6.3	1.00	3.97	-2.52

$I_f = 1.29$ $R_p = 10,000$ $E_p = 40$

When $I_c = 0$, $I_{p1} = 1.28$, and $I_{p2} = 1.33$.

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} + .05$
6.5	1.45	.00	1.50
5.	2.65	1.03	.67
4.	1.8	.83	1.02
3.	1.7	.90	.85
2.	1.5	1.07	.48
0.	1.28	1.33	.00
-2.	1.13	1.67	-.49
-4.	.75	1.63	-.83
-5.5	.40	1.63	-1.18

$I_f = 1.29$ $R_p = 2000$ $E_p = 20$

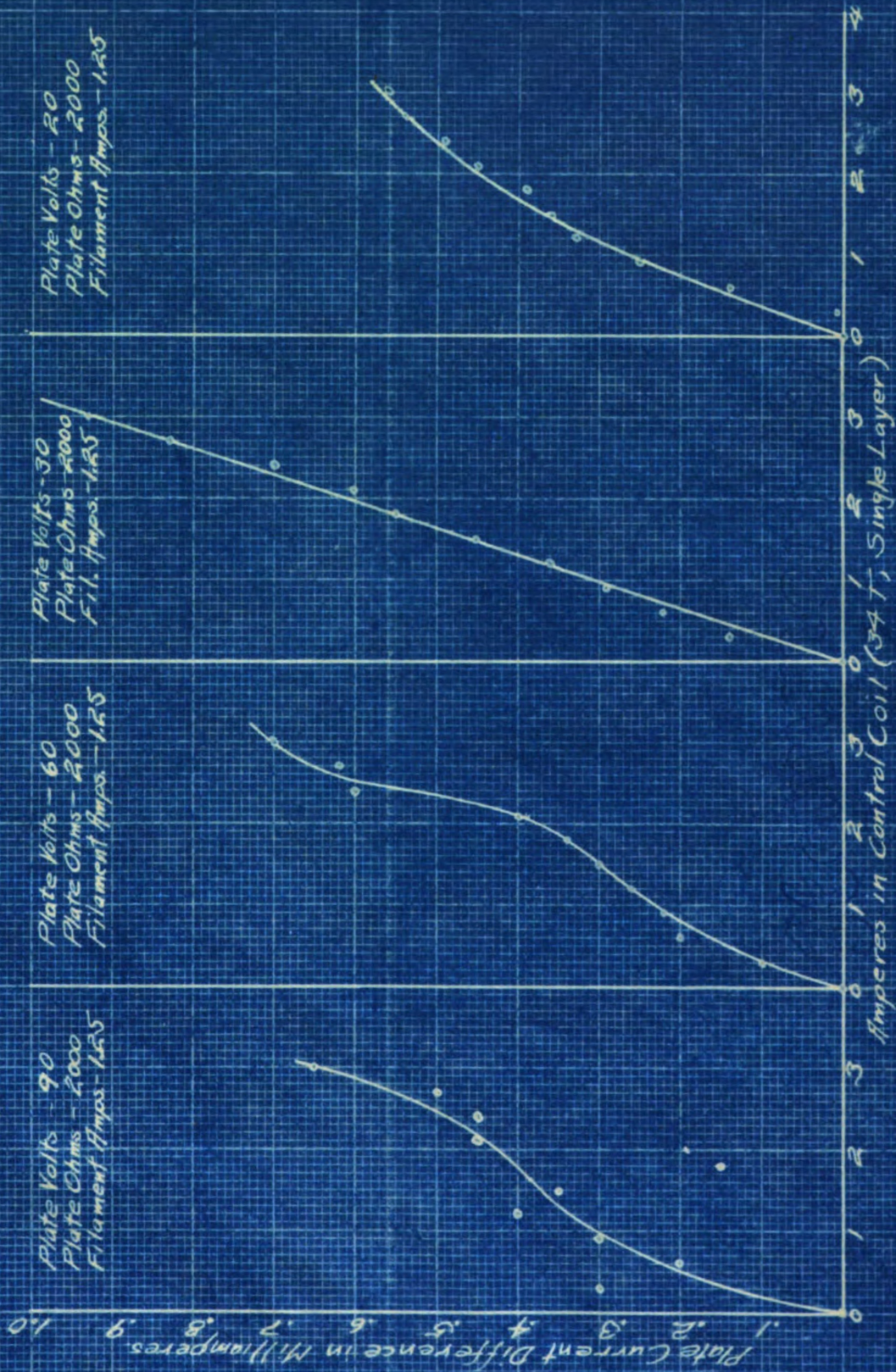
When $I_c = 0$, $I_{p1} = .38$, and $I_{p2} = 1.10$.

I_c	I_{p1}	I_{p2}	$I_{p1} - I_{p2} \cdot 01$
3.1	.55	.00	.54
2.9	.59	.07	.51
2.	.57	.10	.46
1.	.50	.22	.27
0.	.33	.37	.00
-1.	.23	.43	-.16
-2.	.19	.50	-.32
-3.	.09	.53	-.41
-4.1	.04	.53	-.50
-5.1	.00	.40	-.54

Since the output of this tube is controlled by the current in the control coil, it is desirable to know the relation which exists between the coil current and the currents in the two plates. Curves showing this relation for various conditions of plate voltage, filament current, etc. may be found on the Curve Plates #1, #2, #3. The amount of unbalance between the plate currents is plotted against the current in the control coil.

Consider Curve Plate #1. The first curve shows the result of a high degree of ionization of the residual gas in the tube. This ionization produced such an unstable condition in the tube that the points determining the curve are widely scattered. It is interesting to note the point of

Curve Plate #1



Curve Plate #2.

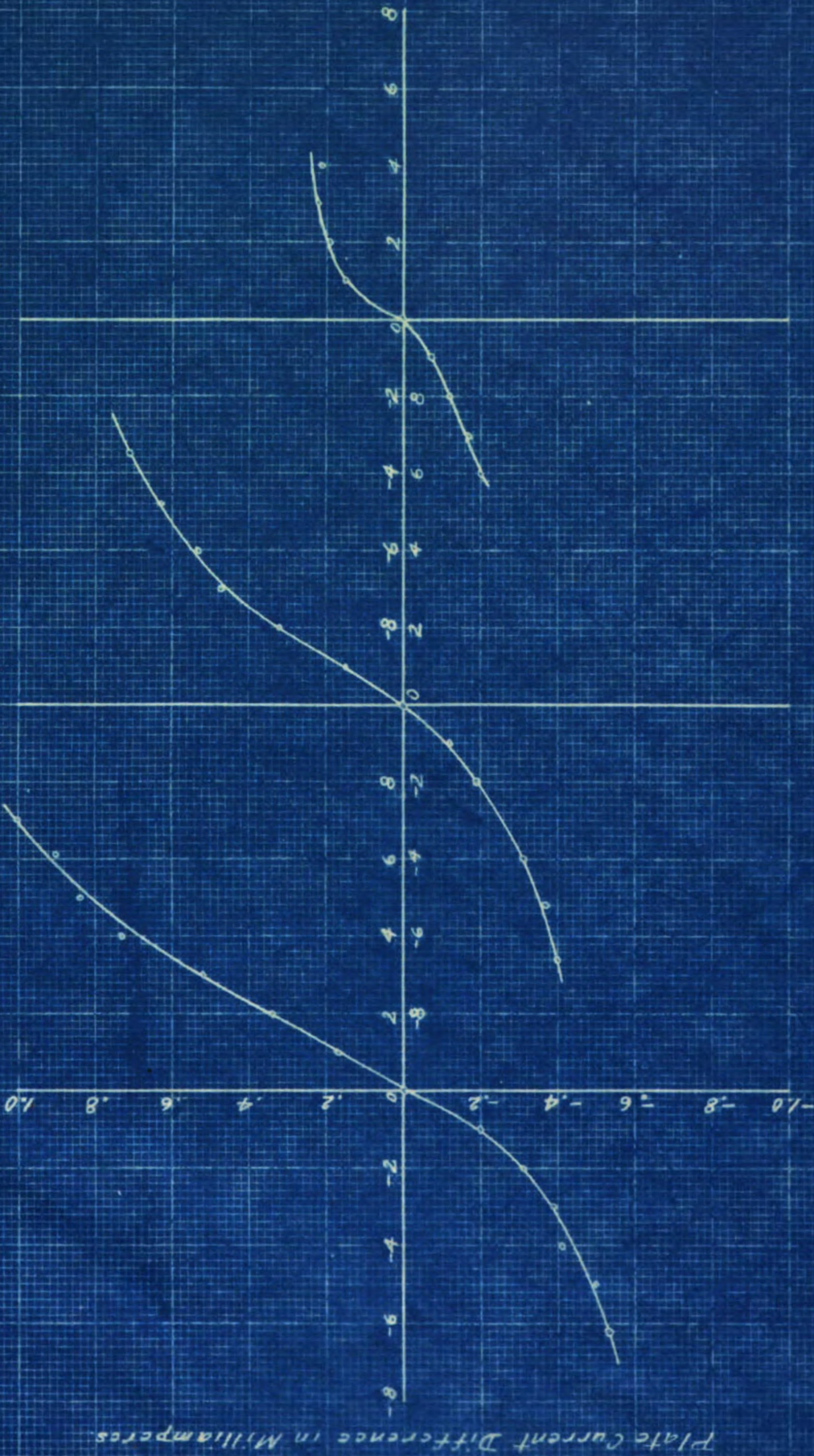
Filament amperes - 1.09

Resistance in leads - 2000

Plate Volts - 88

Plate Volts - 50

Plate Volts - 20



Amperes in Control Coil (34T, Single Layer)

Curve Plate #3 (Filament current 1.24 Amps.)

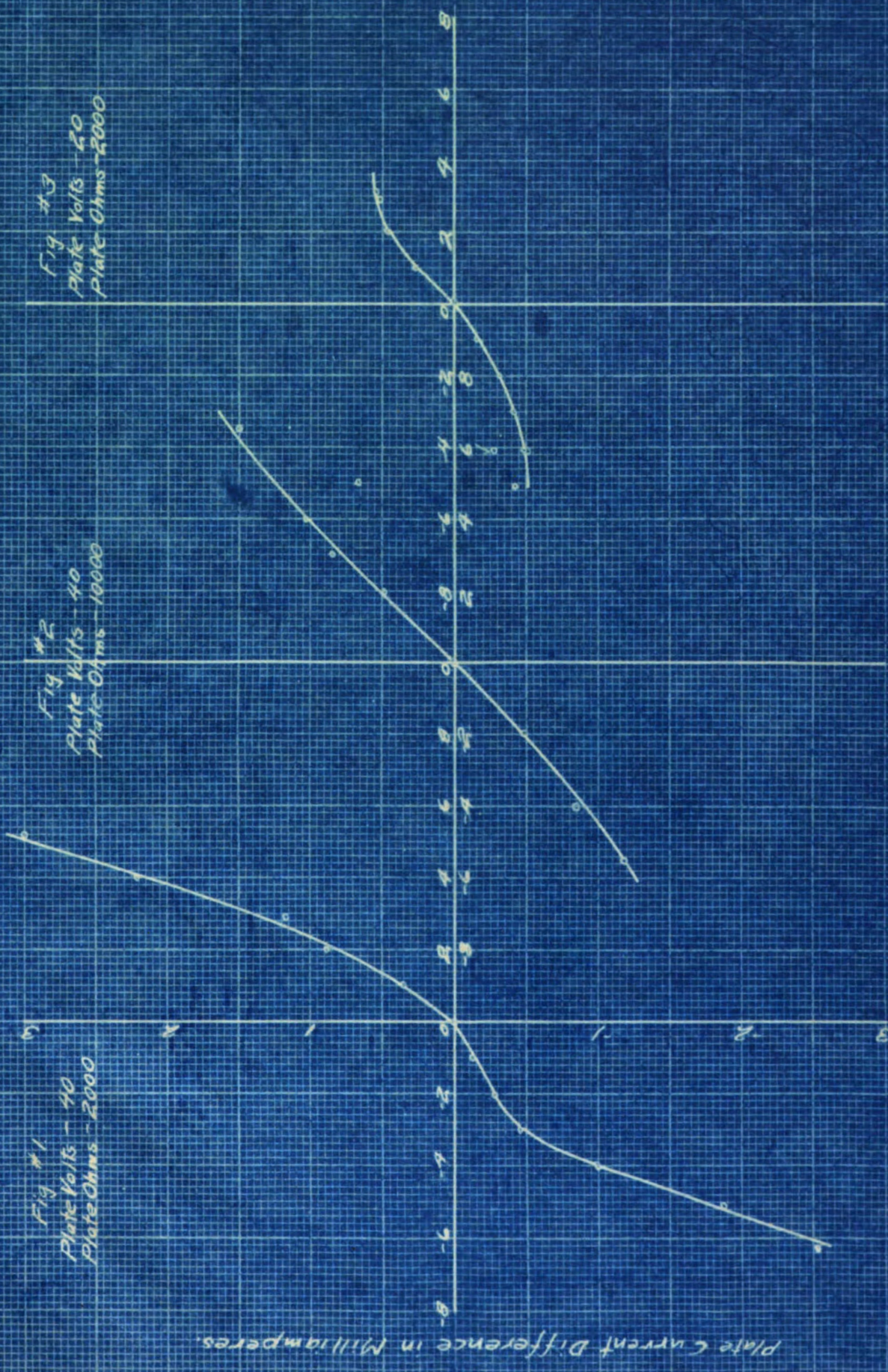


Fig #1
Plate Volts - 40
Plate Ohms - 2000

Fig #2
Plate Volts - 40
Plate Ohms - 40

Fig #3
Plate Volts - 20
Plate Ohms - 20

Amperees in Control Coil (34 T, Single Layer)

inflection on this curve, and on the next one also. This may be explained as follows. Below the point of inflection the curvature is due to the approach of saturation - the entire filament emission is being concentrated on one plate. At this point, the concentration of electrons seems to cause the gas to become much more highly ionized - or it may be that there are two gases in the tube, and that one does not ionize until a critical concentration is reached. This change was accompanied by a sudden increase in the currents from both plates, and by a marked change in the illumination of the ionized vapor. Saturation is again being approached at the upper end of the second curve.

The third curve indicates a very stable operating voltage. The characteristic curve is nearly a straight line. It appears from this that thirty volts is the best operating potential for the tube.

The last curve also shows a very stable condition, but the shape of the curve indicates that saturation would be reached at a much lower value of plate current than on the preceding curve.

The first two curves show the effect of a highly ionized condition of the gas in the tube. Curve three was taken just on the verge of ionization. Curve

four might be a reproduction of curve three to a smaller scale, since operation below the ionization point is stable.

Curve Plate #2 differs from the one just considered in that the leads to the control coil were reversed to get the maximum deflection in both directions. These curves were taken at a lower filament temperature, and consequently do not show the effects of complete ionization. Filament temperature seems to have had much more effect on the degree of ionization than the plate voltages. The fact that the curves are unbalanced is probably due to lack of symmetry in the mechanical construction of the tube. The most noticeable thing about the curves is their resemblance to the characteristic curves of the ordinary three electrode tube.

The first two curves on Curve Plate #3 were taken with the same plate voltages but with different resistances in the plate leads. The resistance served two purposes. It was protection for the instruments in the circuit and to obtain conditions that would approach the conditions of dynamic operation. The last curve shows the effect of lowering the voltage on the plates. It has been impossible to find a suitable explanation for the irregularities of the first curve.

A consideration of the curves indicates that, for certain voltages at least, straight line amplification can be expected over a rather large range.

Another thing to determine that is very important is the ratio of power input to the power output, or the amplification ratio of the tube. This was found to be a difficult thing to determine, especially when there was but little resistance in the plate circuits. One way was to find the ratio between the output copper loss and the input copper loss, since no power is involved except the losses. Take Fig. 2 on Curve Plate #3. It appears that a maximum current output of about one and one-half milliamperes is available without a serious introduction of harmonics. This output calls for a maximum of six amperes in the control coil of thirty-four turns, or two hundred four ampere turns in a coil of three inches in diameter. These values would correspond to effective alternating currents of 1.05 milliamperes, 4.2 amperes, and 142.8 ampere turns. With 10,000 ohms in each plate circuit, the effective A. C. power output would be

$$.00105^2 \times 20,000 = .022 \text{ watts.}$$

For a coil of 34 turns, the current would be 4.2 amperes and the resistance would have to be

$$\frac{.022}{17.6} = .00125 \text{ ohms.}$$

This would call for a coil of larger than #1 wire, to have an amplification ratio of one to one. With a coil of 100 turns the current would be 1.43 amperes. The resistance for this coil being $\frac{.022}{2.05}$ or .0107 ohms. This would call for about #6 wire. For a coil of 500 turns, the current would be .236 amperes and the allowable resistance, $\frac{.022}{.0318}$ or .269 ohms. The length of wire would be about 150 feet, and the size about #12. For 5,000 turns, the current would be .0236 amperes and the allowable resistance, $\frac{.022}{.000318}$ or 26.9 ohms. This would call for #22 wire. The tube, from this standpoint would be impractical, since to obtain a power ratio of five to one would require a coil of about 25,000 turns of #22 wire.

In an effort to find if the tube, in an ionized condition, would respond to audible frequencies, apparatus was connected as shown in connection #2, Plate #4. Using a control coil of 100 turns and with the buzzer taking an effective direct current of from .2 ampere to .5 ampere, a clearly audible note could be heard in the receivers. This indicates that currents through ionized gas can be ^{controlled} magnetically at audible frequencies.

In general it may be said that both electronic and ionic currents may be controlled by electro-

magnetic fields. Also in a tube of this type, at a certain plate voltage, and within a rather wide range, the controlled currents are a linear function of the controlling currents.

On the other hand, it appears that more power would be required to control the output than the output itself would amount to. In other words its amplification would be negative.

It is quite possible that, with a more carefully constructed tube, a circuit could be designed which would give the tube an amplification ratio which would make it commercially practical.

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