A FULL WAVE RECTIFIER

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INTRODUCTION

The transforming of alternating current to continuous current by means of valves is very young, for it has grown with the developments of the electron tubes. This transformation was made by means of motor-generator sets and synchronous converters until the electron tube was developed that could rectify alternating current. The motor-generator and the synchronous converter are preferred for rectifying large blocks of power.

The motor-generator and synchronous converter rectify alternating current to low voltage direct current. The electron tube has the advantage that it rectifies alternating current to high voltage direct current and does not have rotating parts. There are electron tubes that can rectify alternating current to 50 kilovolts.

A rectifier is any device which will offer a different resistance to the flow of current when the direction of flow of the current is reversed. A rectifier may be compared to a unidirectional valve in hydraulics. When the water is flowing in a given direction the weight of the flowing water will force open the valve and will allow the water to flow. Assume the water is suddenly halted and reversed in its direction of flow. Now, the weight of the water attempting to flow in the reversed direction will force the valve closed and prevent the water flowing in this reversed direction.

The rectifier is an electrical valve and is thus called, because of its similarity to the unidirectional valve. For a rectifier to be a good valve, it must offer very little resistance to flow in one direction and very high resistance to flow in the reversed direction.

The writer used a circuit diagram in the "Experimental Electronics Laboratory Experiments on Electron-Tube Theory" by the General Electric Company for the rectifier he built. This rectifier becomes a part of the equipment in the communication laboratory at the University of Tennessee.

THEORY

A. The charging of a conductor involves the addition or withdrawal of electrons from the conductor. A positively charged conductor has had some electrons removed, and a negatively charged conductor has had some electrons added.

It is impossible to remove all the electrons from a conductor. For example, assume a hollow copper shere of one centimeter radius which contains one cubic centimeter of copper, has 10^{25} atoms and that there is one free electron per atom. If it were possible to remove every free electron that has been assumed, 15,900 coulombs would be removed. An isolated sphere of one centimeter radius has a capacity of approximately one micro-microfarad. The voltage to which the sphere would be charged is:

$$V=\frac{Q}{C}=\frac{15,900}{1x10^{-12}}=1.59x10^{16} \text{ volts.}$$

This is an inconceivable voltage, for the air would break down before such a voltage is reached. The dielectric strength of air is approximately $3x10^{5}$ volts. It is physically impossible to remove one electron per atom.

B. If there are boundless numbers of free electrons in a conductor it is natural to suppose some of them leak off the conductor. This is not the case, for at the surface of every metal there is an electrical tension which prevents the escape of free electrons from the conductor into the surrounding air. In passing the surface of the conductor the electron loses a certain amount of energy in overcoming the surface tension and this loss of energy is known as surface work.

Imagine that at the surface of the conductor atoms and free electrons are in violent commotion. Suppose an electron is directed

toward the surface of the conductor obliquely. The velocity is too small and the free electron does not penetrate the surface tension. Another electron is heading toward the surface perpendicularly with sufficient velocity to penetrate the surface tension. The loss of the electron charges the spot positively at which the electron penetrated, hence there is immediately created a force tending to pull the electron back to the conductor.

The lowest perpendicular speed at which an electron may escape is known as the critical speed. An electron that has a resultant perpendicularly speed equal to or greater than the critical speed, even though it may approach the surface obliquely, will be able to overcome the surface work.

C. There are artificial methods which will give the electron sufficient velocity to penetrate the surface work. These methods are electric field, thermal agitation, electron bombardment, and photoelectric emission. Of these methods of getting electrons out of metals, this paper is only concerned with the thermal agitation method.

There are few metals that have a sufficiently high melting point that electrons will be evaporated before the metal melts. The heat supplied by artificial means gives the electrons greater velocities. This raises their kinetic energy and enables them to overcome the surface work.

An ordinary tungsten lamp when heated will emit many electrons, but they do not escape for the filament is immediately charged by their escape and they are attracted to the filament which they had previously left.

If an anode which is positively charged is placed close to the filament, an emitted electron will have two forces exerted upon it. If the plate is charged positively high enough, the electron will be attracted

to the plate, or if the plate is less than the filament the electron will reenter the filament. If the plate voltage is high enough it will attract all the emitted electrons and the current in this case is known as the saturation current.

Assume the filament is heated and the plate has a positive voltage upon it. The emitted electrons will flow to the plate. As the current flows the filament is becoming positively charged, for $V=Q \div C$. The filament has a definite capacity depending upon its radius and Q is the number of coulombs. Thus, the filament will soon become as positively charged as the plate and the current will flow no longer. In order to maintain the flow of electricity, the circuit must be completed. This allows the same number of electrons that are evaporated to be replaced and prevents the filament becoming as positively charged as the plate.

D. Consider a condenser that has air as its dielectric. If a positive electrostatic charge is impressed upon a plate a negative electrostatic charge will appear upon the other plate in response to the attraction set up by the positive charge. The two charges will exactly offset each other and as long as the positive charges are held constant, no other electrons will be attracted even though there was a free one.

An electron tube is a condenser to a certain extent. The filament, if heated, emits a steady stream of electrons which immediately speed toward the plate under proper conditions. Just outside of the filament it is possible that enough electrons will be present to offset the positively charged plate. Now, an electron between the filament and this layer of electrons will be repelled by this layer and attracted by the filament with the results that it will re-enter the filament. This layer of electrons is called the space charge. It is not necessary that this layer of electrons be equal to the positively charged plate for its

influence to be felt, for even though its charge is less than the plate charge it has a tendency to repell the electrons between it and the filament. The electrons may not reenter the filament, but it retards the speed of the electrons toward the plate.

The space charge limits the plate current for a given voltage in a hot filament vacuum tube, just as it was shown above. To increase the plate current, the plate voltage must be increased much more rapidly. The space charge tends to slow up emission which is a good thing for it prevents the tube being overheated and ruined.

E. Each electron that is pulled from the filament to the plate is accelerated. When it reaches the anode it possesses a kinetic energy equal to the product of its charge and the drop in potential through which it has passed. The movement of the electron is stopped by the plate and its kinetic energy is converted into heat. The heat represents the power equal to the product of the current and the voltage drop between the filament and plate, and must be dissipated by the plate.

The filament loss is the power used to heat the filament and give the electrons the necessary velocity to overcome the surface work. It is the product of the voltage across the filament and the current.

Application of Kenotron Rectifier

The kenotron rectifier is very rapid in action and its rectification is clean cut. Due to its simplicity of construction it is used where small amounts of power is needed in the laboratory and in radio work. It finds application in the power supply of radio receivers, smoke precipitation, high-voltage supply for X-ray, radio transmitters, and cable testing equipment.

The kenotron rectifier has a very bright future if the transmission of high-voltage direct current over long lines ever becomes practical, for its efficiency approaches ninety eight percent at high voltages in the order of fifty kilovolts. It is the only rectifier that will yield direct current at such voltages.

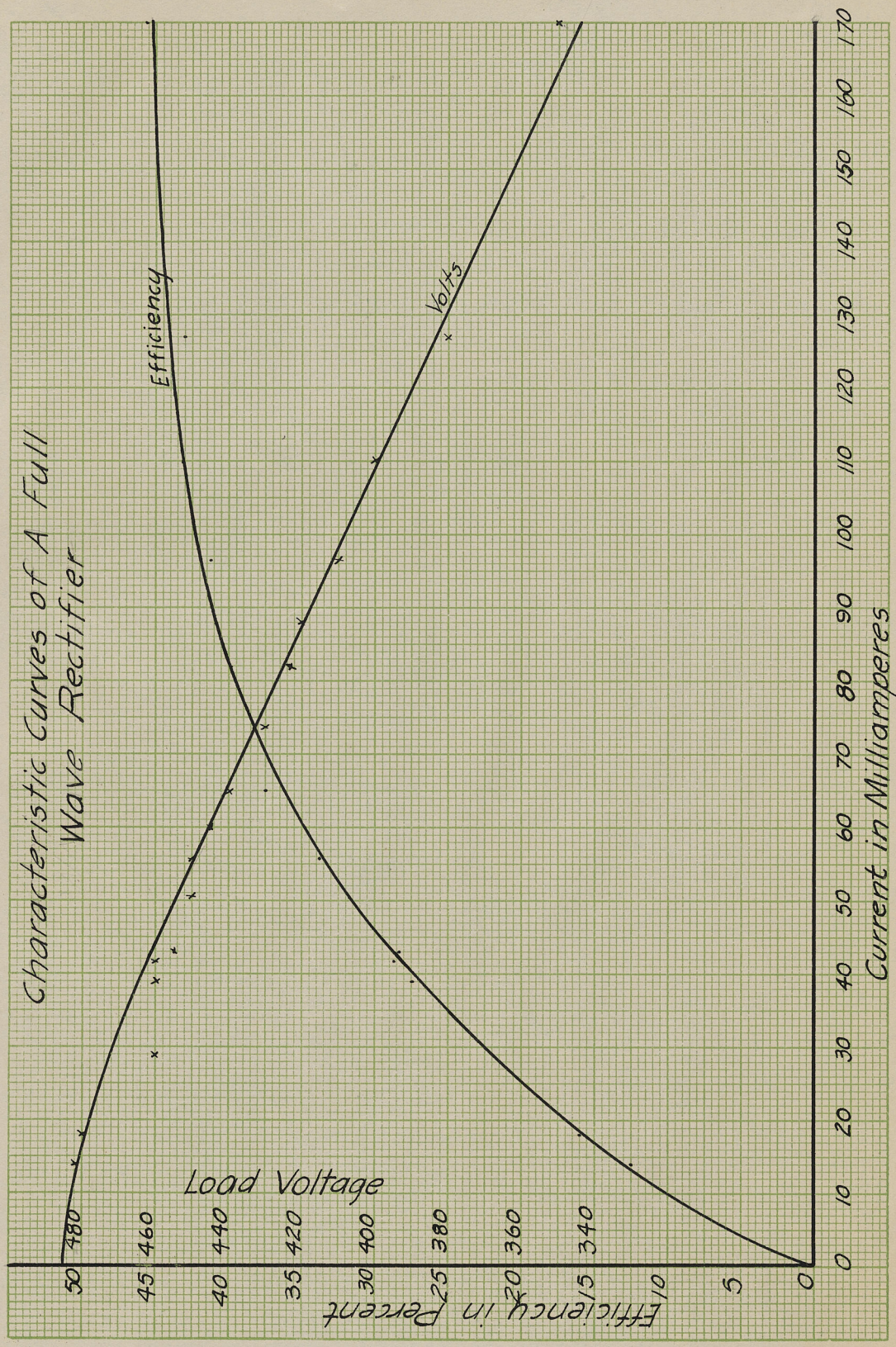
Testing The Rectifier

The rectifier had been permanently mounted with a bleeder resistance of approximately 35,000 ohms across the load line. The load applied to the rectifier had to be either equal to or less than this resistance. The maximum load was limited by the output of the tubes. The tubes were rated at 85 milliamperes each or a total current of 170 milliamperes.

The meters used were the standard General Electric meters. In each case the quantity to be measured was measured upon the smallest meter that could be used. These meters are accurate to within one or two percent.

The loading was accomplished by placing pure resistance in the circuit. Very large resistances were used which were gradually reduced until the maximum output of the rectifier was reached.

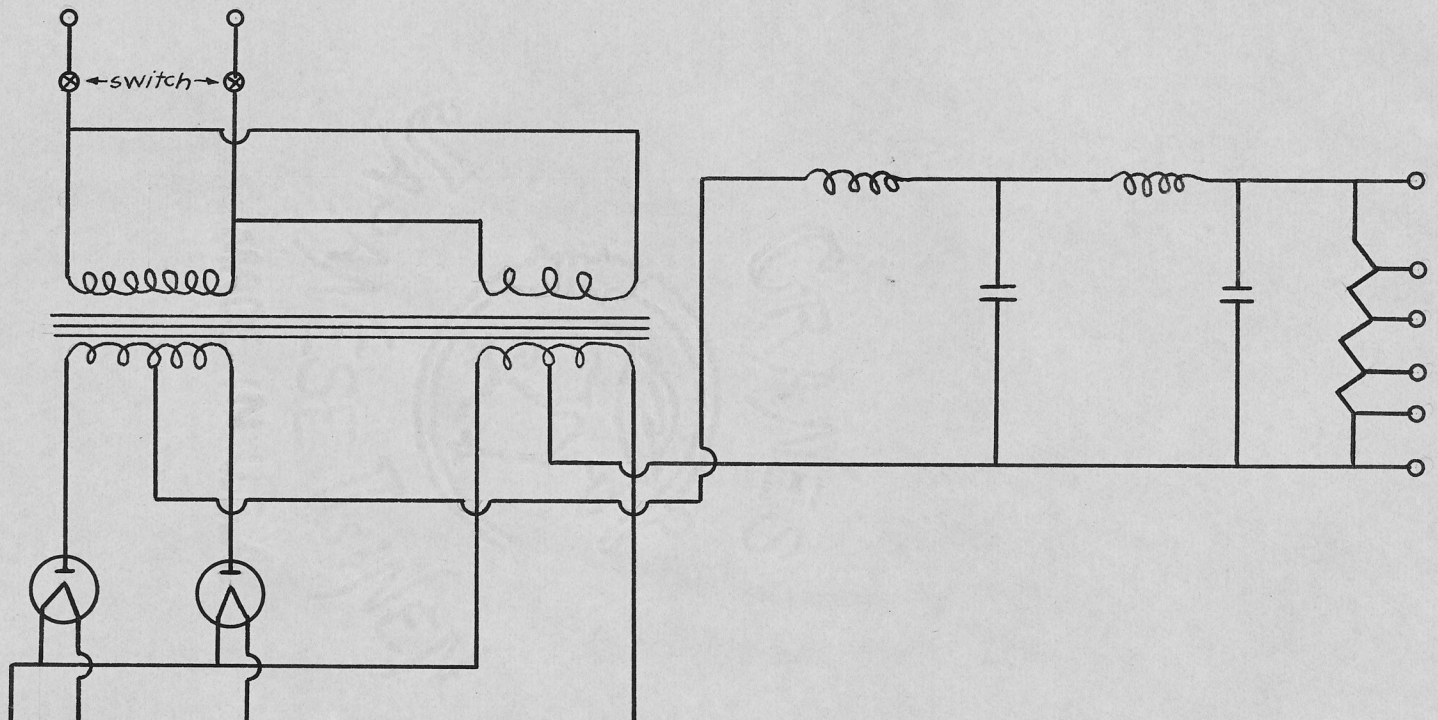
The supply voltage and watts, the load voltage and current were recorded for each run. The load watts were computed and the efficiency of the rectifier determined.



Published by The H. Cole Co., Columbus, Ohio. No. 290 G.

Conclusions

The efficiency of a power transformer reaches ninety eight percent and a kenotron rectifier will reach this efficiency at very high voltages. It will be seen from the graph that this rectifier does not approach this efficiency, but it must be remembered that the voltage of this rectifier will not exceed five hundred volts. For supplying small direct current in the laboratory for test equipment, this rectifier will be very useful, for it is small and various voltages may be tapped off the voltage divider.



Schematic Diagram

Data Sheet

Runs	E_S	W_S	E_L	I_L Milliam-peres	W_L	Eff. %
1	111.8	65.2	460	39.0	17.94	27.5
2	"	66.9	460	41.8	19.23	28.7
3	"	68.8	455	43.0	19.56	28.4
4	"	71.3	450	50.4	22.68	31.8
5	"	74.0	450	55.8	25.11	33.9
6	"	76.2	445	60.0	26.70	34.9
7	"	78.9	440	65.0	28.60	37.5
8	"	83.1	430	73.8	31.73	38.2
9	"	87.5	423	82.0	34.69	39.9
10	"	90.2	420	88.0	36.96	40.9
11	"	95.5	410	96.3	39.48	41.3
12	"	102.0	400	110.0	44.00	43.1
13	"	112.0	380	127.0	48.26	43.0
14	"	130.5	350	170.0	59.50	45.6
15	"	54.0	480	18.0	8.64	16.0
16	"	52.5	482	14.0	6.75	12.8

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Approval

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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