A STUDY OF THE VOLTAGE SENSITIVITY OF A DIRECT CURRENT AMPLIFIER

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FOREWORD

The rapidly increasing importance of the photo-electric cell, in many branches of scientific research as well as commercially, during the last few years has necessitated the development of a more sensitive method of measuring the very minute photo-electric currents. In the past, the only method of measurement was by the use of the quadrant electrometer. However the sensitivity of this instrument is not sufficient for most photo-electric problems, and in addition its manipulation requires great skill. Hence the necessity of constructing a more sensitive instrument for the measurement of photo-electric currents lead experimenters to concentrate their efforts on methods of amplifyimg these small direct currents. The results of their investigations were an instrument called "a direct current amplifier", employing in its construction the thermionic vacuum tube, and also the construction of a special thermionic tube, suitable for use in amplifiers, known as the FP 54.(1) Since then rapid strides have been made in the construction of other types of amplifiers, one of the best-known being the bridge amplifier type. Using commercial thermionic tubes designed for radio reception in this balanced circuit a voltage sensitivity of 10^{-5} volt/mm. has been obtained.(2) DuBridge (3) using two FP54's in the bridge circuit obtained a sensitivity of $4x10^{-6}$ v/mm.

(1) Physics Review, November 1930
(2) Razek and Mulder, J.O.S.A. and R.S.I. Dec. 1929.
(3) L.A.DuBridge, Phys. Rev. Feb. 1931.

The sensitivity of an amplifier is greatly reduced due to the fact that the plate current of the tube masks the comparatively small "amplification current" by necessitating a relatively insensitive meter in the plate circuit. However it has been found that considerable increase in sensitivity may be obtained by introducing into the simple circuit an auxiliary battery [4] in such a manner that it forces a current through the plate current meter equal to the plate current but in the opposite direction. Thus the sensitivity of the meter employed can be increased until irregularities in the plate current make the zero unsteady. A second method is by substituting the plate current of a second vacuum tube [5] for the current due to the auxiliary battery, then the fluctuations in the two tubes can be made to offset each other to a considerable extent allowing further increase in sensitivity to be obtained.

MacDonald and MacPherson [6] devised an amplifier employing ordinary commercial vacuum tubes, which they found to be extremely stable, rugged and to have a voltage sensitivity of 3×10^{-4} volt/mm. The fact that this type of amplifier showed such a high degree of stability suggested the possibility of greater sensitivity being obtained by applying the two methods of increasing the sensitivity mentioned above. The purpose of this paper, therefore, is to describe the steps taken in the

(4) Razek and Mulder J.O.S.A. and R.S.I. June 1929.
(5) J.M.Eglin, J.O.S.A. and R.S.I. 1929.
(6) Philosophical Magazine, Jan. 1933.

investigation of this problem and to indicate the degree of sensitivity which can be obtained with this type of amplifier.

CHAPTER 1.

History of Direct Current Amplification.

Since the foundation of all direct current amplifiers is the thermionic vacuum tube, a knowledge of the development, construction and characteristics of the vacuum tube is essential before making a study of the amplifier.

1. Development of the Vacuum Tube.

About 1884 Edison discovered that if inside an exhausted incandescent electric lamp of the ordinary type, containing a filament whose two ends were connected to two wires insulated from each other, there was introduced a third wire insulated from the filament connections and maintained at a potential positive with respect to the filament, then a current would flow across the vacuum inside the tube from the third wire to the filament as long as the filament was incandescent, but that the current ceased as soon as the filament became cold. In 1896 J.A.Fleming [7] also studied this phenomenon but it was left to J.J.Thomson [8] and O.W.Richardson to give a true understanding of what took place inside the tube. They showed that negative electricity was given off from the hot filament in the form of electrons. In 1901 Richardson [9] showed that the electrons were emitted solely by virtue of their kinetic energy and need no chemical reaction at the surface of the filament. When Richardson gave his explanation of the mechanism of the emission of

(7) Phil.Mag. Volume 42, 1896.
(8) Phil.Mag. " 48, 1899.
(9) Proc. Camb.Phil. Soc. Vol. 2, 1901.

the emission of electrons from hot bodies, it was not thought of a contribution of practical value.

In 1905, his principle was applied by Fleming, when he conceived the idea of using the thermionic tube as a rectifier for the detection of electromagnetic waves. It was DeForest, in 1907, who first introduced the control grid, resulting in a device of tremendous potentialities. This at once introduced the possibility of amplification and it was immediately used as an amplifier and oscillator generator. By 1914, the three electrode tube was used as a repeater in the commercial system of telephone communication. Since then thermionic tubes have been constructed containing four, five, and even six electrodes. However only those tubes containing three and four electrodes have been applied to the direct current amplifier investigated in this paper.

2. Construction of Thermionic Tubes.

The simplest form of thermionic tube consists of an evacuated vessel usually of glass, containing a filament which is heated by passing a current through it and an anode usually in the form of a plate or two plates, or a cylinder surrounding the filament.

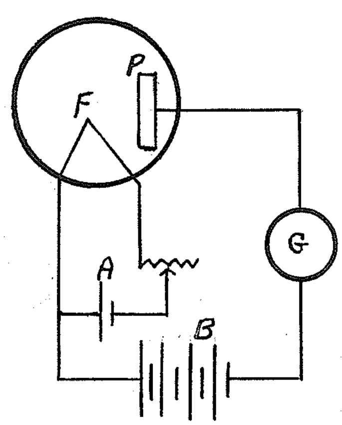

Figure 1.

Figure 1 indicates how such a tube is connected. The filament is heated by means of the current from the battery A and emits electrons which are drawn to the anode or plate P under the influence of a potential difference, maintained by the battery B, between the filament and the plate, positive with respect to the filament.

The next step in the development of the thermionic tube is the three electrode tube. This type contains, in addition to the filament and plate, a third electrode known as the control grid. The control grid is placed between the filament and plate and is in the form of a wire mesh or grid. The function of the control grid is to control the flow of electrons from the filament to the plate. This control is accomplished by applying potential variations to the grid and as a result of these variations the flow of electrons can be increased or decreased according as the grid is made positive or negative with respect to the filament. Figure 2 shows the position of the electrodes and how they are connected in a circuit.

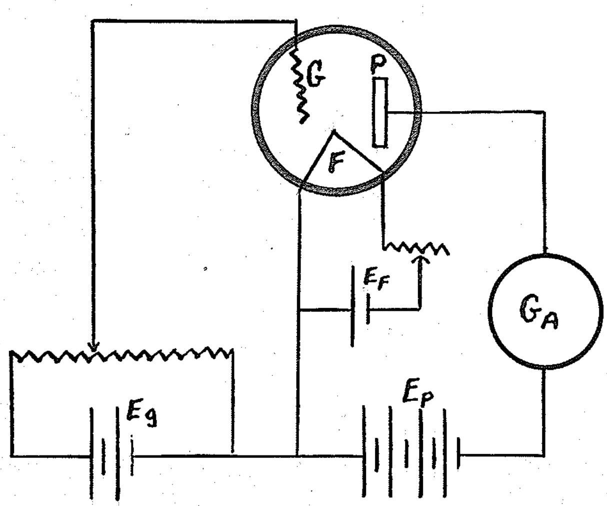

Figure 2.

A further step in the development was the introduction of a second grid, termed the screen grid, and its function ~~is~~ is also to control the plate-filament current by acting upon the space charge or free electrons. Figure 3 indicates the position of the screen grid and how it is connected in a circuit.

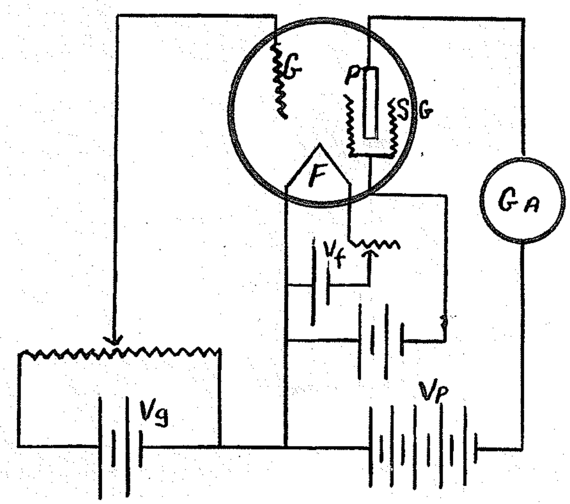

Figure 3.

3. <u>Characteristics of Thermionic Tubes</u>.

Two-electrode or diode tubes.

When the filament is heated to a definite temperature T_1 the current to the plate or anode for various potentials applied between cathode and anode,mresults in a curve as shown in Fig.4. Any increase in voltage over that at A_1 causes practically no further increase in the current and the upper section A_1B_1 is termed the saturation current. If the temperature of the cathode is increased to T_2 curve OA_2B_2 is obtained.

Next let a definite potential E_1 be applied between anode and cathode, and the anode current observed as a function of