MULTIPLE AMPLIFIER*

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Summary—The development, by the author, of amplifying tubes utilizing secondary emission is discussed. Various designs are shown, including the latest type which is described as possessing the quality of small dimensions, high sensitivity (10–100 amperes per lumen), high over-all amplification \(10^6\), high voltage output, minimization of noise, absence of microphonics.

The characteristics of these tubes are mentioned and their application for such use as television and talking pictures are included.

The amplification of electronic currents by means of secondary emission presents one of the most important problems of today and introduces into electron technique an entirely new principle promising developments in many fields.

Some information bearing on the question can be found in technical literature dealing with the recent experimental work of Farnsworth and Zworykin.\(^1\)

In the present paper a brief description is given of similar research carried out at the All-Union Institute for Television, Department of Electronic Devices.

The investigations are based on the definition principle of multiple amplification of the secondary emission, given by the author in 1930,\(^2\) which consists of the repeated conversion of the energy of a stream of secondary electrons into another more powerful secondary electron emission. It had previously been suggested\(^3\) that use might be made of the emission of secondary electrons from a set of electrodes, each of which, when struck by the electrons from the preceding one, becomes the source of a new, more powerful emission. An arrangement of the kind is shown\(^4\) in Fig. 1.

It consists of several electrodes with highly efficient emitting surfaces arranged in such a way that the secondary electrons produced at the first electrode under the influence of the primary beam are drawn towards the next electrode causing a considerably increased emission.

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1 Jour. Frank. Inst., October, (1934); Electronics, November, (1935); Wireless World, November, (1935).

2 Certificates No. 24040 and No. 45765. Application for Patent 74242, 1930.


4 Given in the description to certificate No. 24040 (1930).
of secondary electrons at its surface; these again are drawn towards the next electrode, and so on, producing an avalanche-like increase of the electronic current in the evacuated space.

Thus, if the coefficient of secondary emission be denoted by \( \sigma \), i.e., the ratio of the secondary to the primary current \( \sigma = \frac{i_2}{i_1} \) for a given potential difference between two adjacent electrodes, then the growth of the electronic current can be expressed as follows

\[
I_n = i_1 \sigma^m
\]

where \( i_1 \) is the primary current striking the first electrode, \( I_n \) the current collected at the last electrode and \( m \), the number of stages.

The above formula clearly expresses a geometrical progression.

The same expression is obtained for the amplification in a multistage electron tube amplifier with equal stages. With regard to amplification, the above system is seen to be equivalent to a multistage amplifier, but possesses the further advantage that the amplification is purely electronic in character and takes place in a single evacuated space.

It is this latter circumstance which determines the superiority of cumulative secondary emission over the usual multistage electronic tube amplifier, the process being entirely free from the disturbing influence of extraneous factors, such as the variation of resistance owing to frequency and phase distortions, or the Schrott-effect due to the direct-current component of the electronic current in the tube.

These advantages are very important and the cumulative principle might be expected to produce a complete change in electronic technique, especially since the present state of development allows the use of electronic tubes of much simpler design and smaller size than the tubes hitherto used. At the same time, with the new device, a million-fold amplification can be obtained.
The first practical devices, constructed and tested in 1934, were of the type shown in Fig. 2. As the design is still of interest from the constructional point of view, a brief description follows. The general principle of the design is illustrated in Fig. 3. The electrodes of thin silver are in the shape of cylindrical rings and a special electrode is placed along the axis. Holes provided in the rings facilitate the mounting and handling of the device. The inner surface of the cylindrical electrodes are treated with oxygen and cesium in a way similar to that used in the construction of photocells to obtain photosensitiveness and high emissivity simultaneously. By means of a high resistance potenti-

Fig. 2—Secondary emission amplifier with ring electrodes.

Fig. 3—Schematic section of Fig. 2.

Fig. 4—Secondary emission amplifier with ring electrodes.

ometer a potential step-up of some 200 or 300 volts is applied to each successive electrode.

The source of primary electronic emission consisted either of a thermionic cathode of small intensity the weak electronic emission of which was passed on through a slit to the first electrode, or of an illuminated photoactive surface. A tube of this kind using a thermionic cathode and a grid is shown in Fig. 4.

On the basis of certain theoretical considerations regarding the movement of electron streams in complex electric and magnetic fields, it is to be expected that when the arrangement is placed in a magnetic field of the required intensity and direction, the tracks of the moving electrons emitted from the inner surfaces of the ring electrodes will be as shown in the diagram. Since experimental tests completed in June, 1934, confirmed this view, devices containing six ring electrodes were constructed, the amplification being of the order of 1000.

Somewhat later, in September, 1934, the operation of the device was demonstrated to a number of highly qualified visitors, including both Soviet and foreign scientists. About the same time satisfactory results were obtained with the design shown in Fig. 5, a modification of the one previously described. A photograph of the tube is shown in Fig. 6. Tubes with twelve ring electrodes, i.e., twelve cascades, were also used and are shown in Fig. 7.

The above device, however, was lacking in simplicity, and other methods were developed to afford better facilities for mass production. With this end in view the inner surface of the glass was coated with a metallic film obtained by precipitation, and the film was afterwards subdivided into a number of separate parts by a special chemical method, Fig. 8.

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6 Academicians Joffe, Chernysheff, Zworykin, etc.
7 Application for Patent No. 146218, April, 1934.
8 Application for Patent No. 166537, April, 1935.
Mounted electrodes are entirely absent, the process of splitting the film into separate electrodes occupies on the whole only a few minutes, no matter how primitive the method used.

Fig. 6—Secondary emission amplifier with cylindrical array of electrodes.

The results obtained with these devices were summarized and presented on February 2, 1935, at a special meeting held in Leningrad\(^9\) at which a number of eminent Soviet specialists were present. Tubes with ten electrodes were demonstrated giving an amplification of the order of a 1,000,000, with a photosensitivity of one ampere per lumen.

**Modern Types of Cascade Tubes**

A comparison of tubes containing mounted electrodes (Figs. 2, 6, and 7) with those with chemically separated metallic films on the glass walls (Figs. 8 and 9) showed that the latter presented many constructional and operative advantages, and all subsequent work was therefore confined in this direction. Designs of this kind are shown in Figs.

\(^9\) A stenographic report has been published in the *Jour. for Automatics and Telemechanics*, no. 1, (1936).
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10 and 11. Fig. 12 represents a vertical section of the tube; on the inner surface of the glass a number of circular films are seen at an angle to the axis. Usually the films consist of colloidal silver precipitated from a special solution used for silvering and submitted to a special treatment in vacuum with active oxygen first and then with cesium. No other metallic electrodes are employed. The use of inclined electrodes is a characteristic feature of this system. Part of a still more positive electrode is situated near any part of the preceding active electrode, so that a positive gradient is set up at the surfaces which emit secondary electrons, and the influence of space charge, as well as that of the negative electric field from those electrodes having lower potentials, is compensated.

The proposed construction presents many advantages and possibilities; in addition to extreme compactness and simplicity, it has the further merit of being free from microphonic disturbances.

Cooling conditions are also very favorable; the evolved heat is easily carried away across the thin glass walls by conductivity and
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diffused over large surfaces by direct contact with thermal conductors. A simple calculation, supported by experimental evidence, shows that when the temperature of the inner electrode attains 100 to 150 degrees (which may be considered the maximum temperature in the case of an activated silver film) from five to ten watts will be carried off from every square centimeter of surface, whereas an electrode mounted in vacuum would give off only 0.2 watt per cm².

In the system described a millionfold amplification can be obtained, while its photoelectrical sensitivity attains some 100 amperes per lumen.

Since no complicated mounted electrodes are used, the dimensions of the tube can be considerably diminished; thus, tubes only 100 millimeters long and 12 millimeters in diameter have been constructed in the laboratory; a photograph is given in Fig. 13. The general features of these tubes will be described below.

In some cases, it may be desirable to avoid the use of magnetic fields; for this reason, a tube is now being designed where magnetic fields are eliminated. The design is based on the use of a central elec-

Fig. 11—Secondary emission amplifier in housing.

Fig. 12—Schematic section illustrating construction of amplifier with inclined electrodes deposited on interior wall of glass envelope.
trode a description of which was given by the author in 1934. At that time it was intended to use several truncated cones or other electrodes together with a central electrode (Fig. 14). Later on, a metallic wire was substituted and the truncated cones were replaced by rings (Fig. 15).

This type can be easily constructed by using the previous method of depositing the electrodes on the inner glass surface. The operation of the tube requires a special distribution of the potential applied at the separate rings.

The characteristics of the tube and the amplification afforded do

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not differ much from those obtained in the devices previously described.

We also might mention some other systems suggested by the author in 1934 incorporating a series of activated grids or ribbed electrodes resembling a Venetian blind. The idea has been made use of in some later systems.

**THE CHARACTERISTICS AND APPLICATIONS OF TUBES WITH SECONDARY ELECTRONIC EMISSION**

The tubes, after manufacture, were submitted to a detailed study. Some of the experimental data obtained are given below.

The relation between the output current and the intensity of the incident light beam striking the photocathode was examined; the results are plotted in Fig. 16, and show a linear relationship over a wide range of intensity in accordance with theoretical expectations.

In order to elucidate the nature of the process going on in the tube, the amplification was measured at each cascade. On the diagram of Fig. 17 the logarithms of the current in a given cascade are plotted against the number of the latter. It is easy to see that the amplification is almost uniform from one cascade to another, the emission ratio being nearly the same for all the rings. Equation (1) may therefore be used without considerable error.

Current potential characteristics were also obtained for the last cascade, and the maximum potential variations at the output which do not lead to notable distortion determined. These were found to depend to a large extent on the size and the shape of the anode. A curve of this kind (Fig. 18) refers to a tube with a large anode occupying considerable space and shows that large potential variations on the anode
(within the limits of some 200 to 300 volts) do not result in notable distortion.

The above fact shows that variations of the anode potential due to the output do not depend on those factors which determine the value of the initial current. In this respect, the tubes differ essentially from the conventional vacuum tubes, especially when grids are applied for the control of the primary electronic currents.

Fig. 17—Logarithm of the current value per stage plotted against the number of stages which illustrates the uniform amplification obtained in each stage.

The use of grids for the control of electronic currents in tubes with single secondary electron amplification had been suggested before by more than one author. However, these tubes have not been found to be of practical use, for direct amplification, owing to the impossibility of obtaining sufficiently high amplification. The latter fact is due to

Fig. 18—Variation of output current with stage voltage.

the lack of materials with a high ratio of secondary emission. The maximum value which has been hitherto obtained does not exceed ten.

Given the development of multistage secondary emission electron tubes, we are in a position to reconsider the problem of amplifiers, generators, etc., which would differ essentially from the existing vacuum tubes.
Even in its present state of development, it is possible to visualize "filamentless" vacuum tubes with parameters similar to those of ordinary vacuum tubes.

Some attempts in this direction have already been made in our laboratory showing the possibility of controlling the electronic current in secondary emission electron tubes by means of special grids.

In this case, the characteristics are much like the grid characteristics of ordinary vacuum tubes. A tube of this type has been used as a detector and amplifier in several of the simplest radio receiving sets. The radio transmission, for which a good loud-speaker was used, ceased when the tube was shielded by the hand. The tube acted as an amplifier and detector simultaneously.

In this case, back coupling and complicated systems with several grids can be applied, just as in schemes with vacuum tubes, and even more successfully.

It must be acknowledged however that the design of secondary emission electron tubes used for potential amplification is not yet sufficiently developed and values as high as those in current amplification cannot be obtained. Secondary emission electron tubes have been operated directly on alternating current (fifty cycles) without any rectifier. The present designs have been successfully applied in the construction of sensitive photorelays, the latter being directly connected to the transformer without rectifiers. A relay of this kind can be operated from the alternating-current line and can be widely applied in various automatic devices.

The sensitivity of a tube, operating on alternating current, has been found to be ten amperes per lumen and even higher. We also tried to determine the maximum sensitivity of the tubes.

Experimental data, as well as theoretical considerations, show that the principle of electronic amplification outlined above secures a new method for amplifying the smallest electronic currents, far below those which can be amplified by means of the existing methods using vacuum tubes.

The usual factors by which the application of vacuum tubes is limited, such as fluctuations of the resistance, the Schrott-effect due to the direct-current component of the electronic current, phase and frequency distortion in the external circuit, are here absent, since the whole process of amplification is a purely electronic one and practically free from inertia.

All this is a point of the utmost importance in television problems, which were formerly handicapped in their development by the impossibility of amplifying very low currents.

The use of electronic tubes with secondary emission together with
some mechanical device, as for instance the Nipkow disk, will consider­
ably increase the value of such systems.

M. Lurie of our Institute, by using a mechanical device intended for a sixty-line picture, succeeded in reducing the illumination of the object to one tenth of the usual while simultaneously diminishing the number of cascades.

Transmission could be obtained at an illumination of only 200 to 400 lux, which already approaches the usual lighting conditions. A

![Fig. 19—Nipkow disk scanner with secondary emission amplifier.](image)

photograph of the disk transmitter employed, with its tube and amplifier, is shown in Fig. 19.

The principle of electronic conversion, whether applied to transmitters using an electronic image or to a system collecting the charge, means an important advance in the development of this extremely complicated problem.

On the theory of cathode transmitters with collected charge proposed by Zworykin, we have devised a system\(^\text{11}\) with the simultaneous use of collected charges and secondary electronic conversion. Second-

\(^{11}\) "Television," Russian. Published by the Radio State Commission, (1935).
ary electronic conversion can be applied in such systems, due to a new method of converting the collected charge into component impulses which are not transmitted by capacitance coupling, as in Zworykin's system, but in the form of electronic emission accompanying the commutation process.

Further details on this subject may be found in the above-mentioned article.

Work now being conducted shows the possibility of a practical solution of the problem.

The use of secondary electronic emission for the detection and measurement of extremely low currents (those arising in high velocity processes, for instance) which it would be impossible to determine by the existing methods, opens new fields in various domains of physics, biology, medicine, etc., and will enable many scientists to attack problems hitherto considered hopeless because of the lack of technical means for the measurement of low emission currents.

In conclusion, we may mention the applicability of the above tubes for sound motion pictures and other acoustical problems. The tube presents a supersensitive photocell, with a sensitivity many hundred thousand times exceeding that of the most perfect vacuum cell, and its use promises to simplify considerably the whole of the sound equipment and to result in a reduction of noise and distortion. Tests have already shown that with a sensitive loud-speaker, the sound may be reproduced with sufficient loudness without even the use of a multi-stage vacuum tube amplifier. In this case, the loud-speaker must be connected directly to the tube. By using a one-stage amplifier, an output of five to ten watts can be obtained, which is quite sufficient for large lecture rooms.

Space does not allow us to consider even a small fraction of the many applications involved in the further development of the given principle. There is however no doubt that we are dealing with an entirely new principle of electronic technics which opens up new paths of development.