A DEMONSTRATION TRIODE FOR VISUALIZING ELECTRONIC PHENOMENA*

F. E. ELDREDGE AND H. F. DART**

Several discoveries that were later to prove fundamentally important in the design of electronic tubes were made shortly before the turn of the twentieth century. Edison, in 1889, had just invented a practical and commercial electric lamp. In 1895, Roentgen, the German, showed his first x-ray pictures. In 1896, Becquerel, the Frenchman, discovered radioactivity. Two years later, radium was discovered by the Curies in France. From these discoveries arose many new concepts of physics and many developments that later evolved into extremely useful tools.

Starting in 1900, many theories of physics required an electron. Milliken measured the electric charge of the electron and found the value so minute that it is difficult to picture its size. In their book, *Photocells and Their Applications*, Zworkin and Wilson say:

"To realize how small the mass of an electron is, imagine an electron speeding through space at the rate of 100 miles an hour or about 150 feet per second. Let us calculate the force of a blow it would give to an obstacle placed in its path, assuming the electron was brought to a dead stop in one-tenth second. We will find the average force experienced by the obstacle would have the amazingly small value of one hundred-thousand-million-billion-trillionth of a pound, or 1/100,000,000,000,000,000,000,000,000,0001b."

It is interesting to note how quickly the fields of industry and amusement have put the new ideas into practical, every-day use. In fact, one of the amazing characteristics of this age is not only the willingness to accept changes, but the will to utilize the achievements of science and scientific minds.

To be more specific, let us consider the filament of a lamp. It receives heat energy, which causes luminescence. An incidental by-product is the liberation of electrons near this filament. In a lamp, however, they do not serve any direct useful purpose. Placing to one side of a heated filament a piece of metal or a plate, on which a positive voltage is applied, will produce an appreciable flow of current between the heated filament and the plate. A modification of this simple device has considerable importance, for in a proper circuit it will convert alternating into direct current suitable for operating arcs of motion picture equipment, for

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charging storage batteries, for driving trolley cars, and for a host of other similar applications.

Some thirty years ago, Dr. Lee de Forest discovered that a grid, placed between the heated filament and the plate of the tube, exerted a definite control over the passage of electrons from the filament to the plate. The result was the three-electrode tube, which depends for its operation upon the unidirectional flow of electrons from a thermionic cathode to a positive plate, with a grid between the two. A small voltage applied to this grid can oppose or add to the effect of voltage on the plate. In other words, the grid permits controlling the space current flowing between the plate and the cathode.

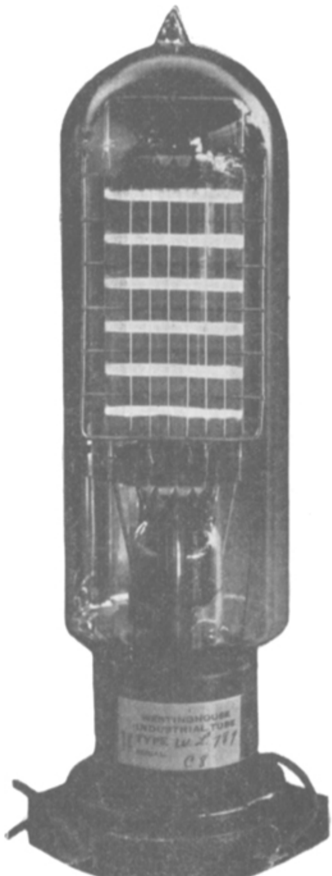
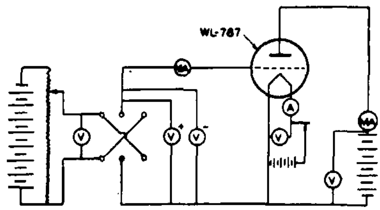


FIG. 1. The effect of the electrons striking the plate, which is coated with willemite, is seen in luminous bands. The width of these light bands may be varied by changing the voltage of the grid or the plate.



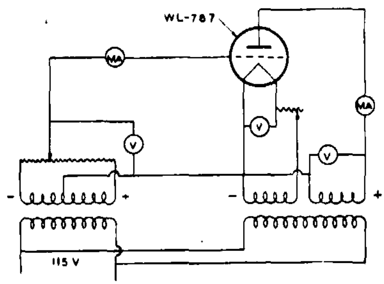


FIG. 2. (*Above*) Circuit for operating the *WL-787* triode on direct current.

FIG. 3. (*Below*) Circuit for operating the *WL-787* triode on alternating current.

The action of the grid may be likened to that of a valve in a water-pipe. A small amount of energy, applied to opening and closing the valve, controls a much larger amount, represented by the water under pressure. The grid is usually operated at a potential negative with respect to the cathode, since then no current is drawn by it, and, consequently, no power.

Thus, within a few years a new tool—the electronic tube—has been developed, which has since become indispensable in the fields of communication, manufacturing, amusement, medicine, and many others. Typical examples are the universal use of electronic tubes in radio transmitting and receiving equipment; long-distance telephone lines; the quick response a decade ago of the motion picture industry to add sound to their films, thereby utilizing phototubes, rectifiers, and amplifier tubes; oscillator tubes in short-wave therapy equipment; and now industries of all kinds are using phototubes, amplifiers, high- and low-voltage rectifiers, and grid-glow tubes in the initiation and control of many manu-

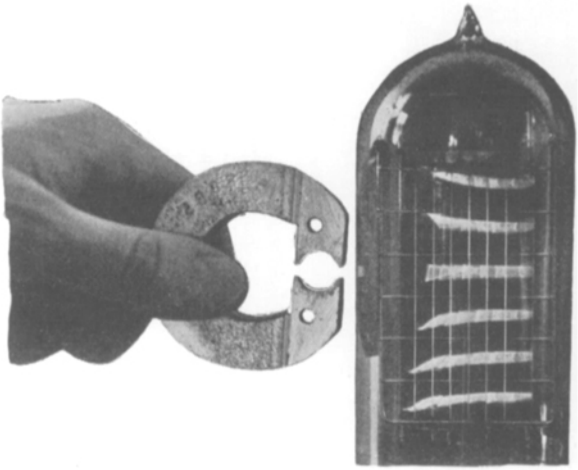


FIG. 4. Showing the magnetic effect upon the fluorescent pattern.

facturing processes. There is now a degree of reliability and constancy of characteristics not approached by the tubes of a decade ago.

"SEEING" ELECTRONS BY FLUORESCENCE

The widespread use of electronic tubes in all fields of endeavor has led to the introduction of courses of instruction in electronics in the curricula of many universities, colleges, and technical schools. The Westinghouse Demonstration Triode *WL-787* was developed for use in studying the fundamental principles and operation of the three-electrode tube. It shows visually, in a manner impossible to accomplish in any other way, exactly what takes place when changes are made in the grid and plate voltages of a vacuum tube.

By varying the grid voltage in steps, the effect of changing excitation upon the electron flow from the filament to the plate, and the correlation of this action with fluorescence on the anode, can readily be shown. The controlling effect of the grid upon the electrons radiated by the filament is demonstrated by the fluorescent pattern upon the plate. When greater and greater negative voltage is applied to the grid, the fluorescent strips opposite the openings of the grid become narrower and narrower, until finally they disappear. This condition corresponds to the grid-bias value at which plate current cut-off occurs, and under which condition no electrons will reach the plate.

The grid may be made still more negative, without further apparent change. Such condition corresponds to that existing in an actual triode when the net voltage of the grid is greater than that required to produce plate-current cut-off.

Lessening the negative voltage of the grid will cause the fluorescence to reappear, and the width of the strips will increase as the net voltage is decreased. The fluorescence will be proportional to the rate at which the electrons reach the plate, which is also a measure of the plate current. As the grid becomes positive with respect to the filament, the fluorescent lines become still wider and wider; until, when the grid becomes positive, the fluorescence covers the entire plate with quite uniform intensity.

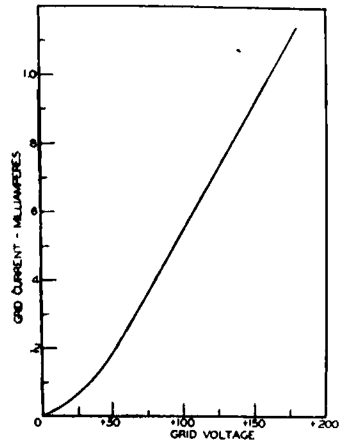


FIG. 5. Average grid characteristic of the *WL-787* triode; characteristics of individual tubes may vary widely from those shown.

EFFECT OF DISTORTION

Distortion in an amplifier may be demonstrated by using a large excitation signal or a wide range of grid voltage. It may thus be shown that the width of the fluorescent bands does not vary in proportion to changes of grid voltage, particularly when the excitation is so great as to cause plate-current cut-off. In the latter case the width of the fluorescent bands will not accurately follow the excitation voltage values, corresponding to the conditions existing in a triode when there is distortion in the ouput.

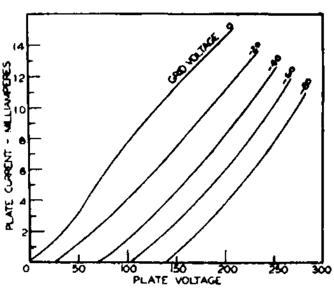


FIG. 6. Average plate characteristic of the *WL-787* triode.

The amplifying effect of the tube may be demonstrated by noting the grid and plate voltages for a certain amount of fluorescence on the plate, and then changing the grid voltage by a few volts, say, 10. It will be found that the plate voltage must be changed by a much greater amount to restore the fluorescent bands to their original width. The ratio of the change of voltage of the plate required to compensate for the change of grid voltage is the amplification factor of the tube.

Another interesting demonstration is to hold a strong magnet near the side of the plate. In addition to showing visually the effect of the magnetic field upon the electrons and their distribution, it is possible under favorable conditions to obtain a representation of the lines of magnetic force.

The filament consists of several parallel oxide-coated wires, all of which are located in one plane, so as to distribute the plate current uniformly. The anode is the usual flat plate mounted parallel to the plane of the filament. The grid is a fairly open and conventional structure mounted between the filament and the plate. A coating of willemite on the side of the plate toward the grid and filament shows a bright greenish fluorescence when bombarded by the electrons emitted by the filament. The glow is pronounced and clearly visible wherever the electrons strike, producing a definite pattern of the grid upon the plate.

TABLE I

Design Data and Ratings of Type WL-787 Triode

	Voltage		Current	
	Normal	Max.	Normal	Max.
Filament	6.0	6.3	1.6 a.	
Plate		300		100 ma.
Grid		±200		50 ma.

Amplification factor	2 (approx.)
Filament	Oxide-coated
Plate size	3 × $1^1/_2$ inches (approx.)
Overall height	10 inches
Maximum diameter	$2^5/_8$ inches
Base	4-pin industrial
Socket	Ser. No. 793202

The size and arrangement of the parts have been made such as to render the tube useful in demonstrating the action of the grid in a three-electrode tube. The plate is large enough to permit the action to be visible to everyone in a lecture or classroom of reasonable size. A slight amount of experimentation will show how to handle the tube to demonstrate the desired effects. The tube is practically fool-proof, and will withstand a wide variety of operating conditions. Either alternating current or direct current may be used to heat the filament and to supply voltages for the grid and plate. A tube socket and adjustable sources of voltage are all that are needed to operate the tube, although a few meters will be convenient for making adjustments and readings.

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