

# The History of Electric Measuring Instruments and Active Components

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## Abstract:

Precision electric meters are indispensable to the development of technology in this age. The first electric measuring instruments, however, were physically impossible to transport, and were functionally inadequate for use in a laboratory. The measuring instruments of today have evolved into sturdy, easy-to-use instruments with higher performance, adopting new active components which have appeared one after another.

Expanding in functionality, measuring instruments that have adopted such new technology have enabled even more precise measurement. The users have also expanded from research organizations and educational facilities, to the manufacturers of electrical equipment and electronic parts. The measuring instrument manufacturers were able to supply more convenient measuring instruments to the user, and conversely, the user, the manufacturers of electrical equipment and electronic parts, needed more easy-to-use and highly precise measuring instruments in order to respond to a rapidly increasing demand. Consequently, cheap and high quality electronic parts were supplied to the market, and the measuring instrument manufacturers were also able to develop new measuring instruments using those parts. In fact, it can be said that they have been mutually complementary. It should not be forgotten that the demand for electronic components for consumer use has also driven the whole in the meantime.

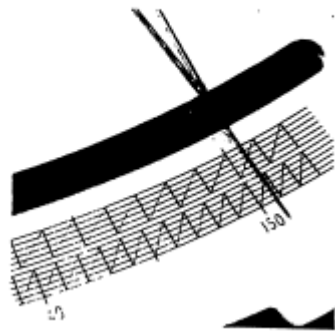
## (1) Practical electric measuring instrument: Weston moving-coil DC ammeter: electromagnetic mechanism <sup>1) 2)</sup>

After Volta's battery was invented in 1600, the first utilization of electricity was in telegraphic communication. What kind of measuring instrument was required for telegraphic communication? Probably, neither voltage nor current needed to be measured regularly. Measurement was necessary only at times of failure or in preparation. Even when trans-Atlantic telegraphic communication was successfully completed in 1866, the Kelvin Mirror Galvanometer was used as a telegraphic receiving instrument. In other words, a measuring instrument as an electric component was not independently used.

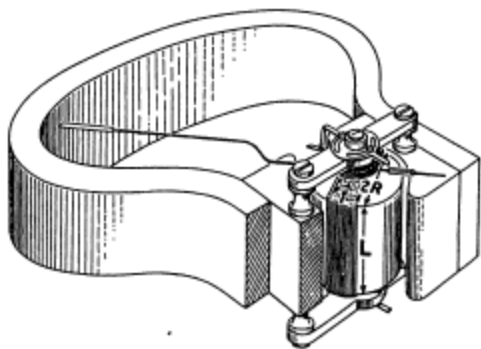
When the electric power industry began to develop in the second half of the 19th century, current and voltage needed to be measured regularly. One of the engineers who put the precision DC ammeter into practical use was Edward Weston (1850-1936). He named the meter the Portable Instrument, as the electric meters until then could be used only in the laboratory, and could not be transported anywhere to make measurements.

Weston aimed at making a highly reliable infallible meter, rather than a sensitive meter, which could be used by anybody, anywhere, with a voltage value read immediately from a scale. He used a permanent magnet for the DC meter, and realized the equal magnetic field in the coil moving portion. A square frame type coil, pivot supports, and two hair springs were then used, making a current pass through the coil. An indicator was attached to the tip of the coil.

In 1886 Weston completed a portable DC ammeter with an accuracy of 0.5%, and subsequently aimed at creating an ammeter for large currents and an AC meter. For that purpose, he invented stable resistance Manganin. In fact, the key component of the meter was a stable permanent magnet and the supporting mechanism of the pivot.



(Fig. 1) Weston portable meter: moving coil, a permanent magnet and an indicator



(Fig. 2) Precise reading of scale

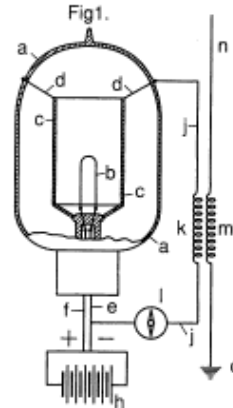
**(2) The advent of the Fleming Valve and the prototype of AC measurement: Measurement of high-voltage-high frequency <sup>3) 4)</sup>**

In 1892, J. A. Fleming (1849-1945), Edison's British adviser, became interested in the "Edison effect." Later, he became an adviser for the Marconi Telegraphy Co., searching for an application of chemical action for a wave detector to replace a coherer. It is said that he started his research because he remembered the "Edison effect," and attempted to carry out supplementary examinations. In contrast to Edison's method, he put a metal plate, then a cylinder into the electric bulb, naming the equipment an "Oscillation Valve." It was known as the "Valve," a device that lets the flow move in one direction only, because current flows in the cylinder only when a positive voltage is applied. Later, since the shape resembled the electric bulb, it was also known simply as a "Bulb."

E. Doyle and L. Chubb applied this valve to the measurement of high voltages. They are both reported in AIEE. There had been no alternative but to use a spark to measure high voltages until then. This was the first step in adopting the use of an active element in the voltmeter. The valve was filled with mercury or rare gas, and for both the anode plate and the cathode plate, tungsten was

used. The meter operated stably as a voltmeter in both cases.

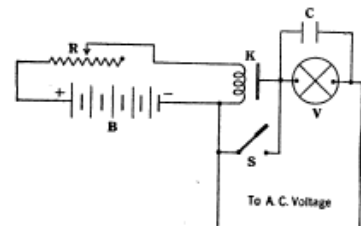
No. 803,684. J. A. FLEMING. PATENTED NOV. 7, 1905. INSTRUMENT FOR CONVERTING ALTERNATING ELECTRIC CURRENTS INTO CONTINUOUS CURRENTS. APPLICATION FILED APR. 19, 1905.



(Fig. 3) Fleming Valve (1905/11/7), U.S. patent 803684 "Instrument for AC/continuous current"



CREST VOLTMETER (CHUBB)



(Fig. 4) Crest voltmeter

**(3) De Forest Audion (Audion Vacuum Tube) and BARUBORU (Vacuum Tube Voltmeter): High sensitivity measurement**

Hoping first to improve the characteristics of the valve used in the wave detector, L. De Forest (1873-1961) also put a third electrode in the electric bulb. The electrode was made of a zigzag platinum line, and was put in between the filament and the plate. The effect was more than expected, and it turned out that plate current

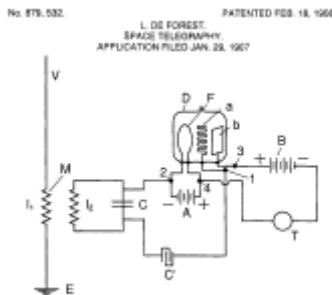
could be controlled by the voltage applied to the grid.

The triode vacuum tube, called Audion, is categorized from present eyes, as a tube containing gas. It was filled with a small amount of gas. Argon and Cesium steam were injected with a low degree of vacuum first. The injection of gas was thought to improve detection sensitivity. However, when high voltage was applied to the tube, a flaw, causing an internal electric discharge, was found. Later, I. Langmuir of GE realized a tube with a long life and high power, using a high vacuum.

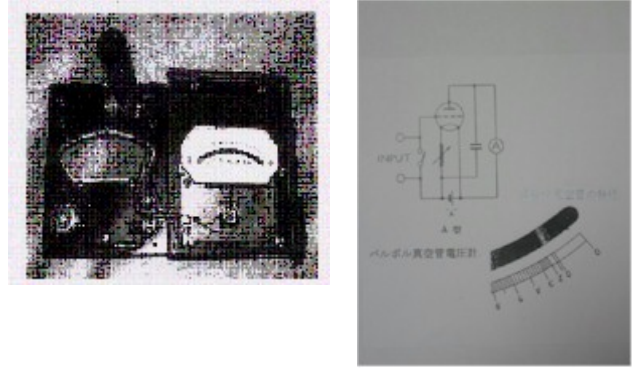
The vacuum-tube voltmeter incorporated this tube as an amplifier or a wave detector, being called a Valve-Voltmeter or Vacuum-Tube Voltmeter. In Japan it was uniquely called BARUBORU. The first vacuum-tube voltmeter was invented by E.B. Moullin of the University of Cambridge in 1922, and was put on the market as the product of the Cambridge Scientific Instrument Company. Several kinds of voltmeters were then manufactured, varying from an A-type voltmeter for AC and DC use, the technology of which was most fundamentally on the plate detector, to a B, D-type (AC), a C-type (double range), and a P-type (with a probe).

Fig. 6 is a Japanese-made A-type. The catalog of those days had the following explanation: "This voltmeter uses a rectification of the triode vacuum tube and is scaled so that an alternating voltage applied to the grid may be read by the change of the DC of the Plate current. It is a DC meter, and is also called the Moullin Thermionic Voltmeter. It is characterized by the ability to measure low voltage AC almost without disturbing circuits. If it is used appropriately, the meter can be used in a wide range of applications." The catalog emphasizes that this voltmeter has high impedance and does not take energy from measured objects.

The scale of the BARUBORU of those days was not linear because the nonlinear nature of the tube appeared as it was.



(Fig. 5) L. De Forest triode tube, U.S. patent 879,532 "Space telegraphy" 1908/2/18.



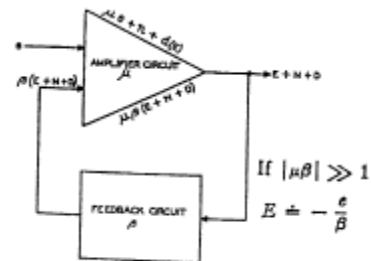
(Fig. 6) The inside of an A-type vacuum-tube voltmeter (Yokogawa Electric Corp. manufactured around 1930)

Rating: 0-1.5 V, DC--up to several 100 kHz, uses 6-V battery, consists of only one tube (UX-110, a large glass tube made by Matsuda (Toshiba)) and a large indicator. The zero point was adjusted at every measurement. The scale was not linear, either.

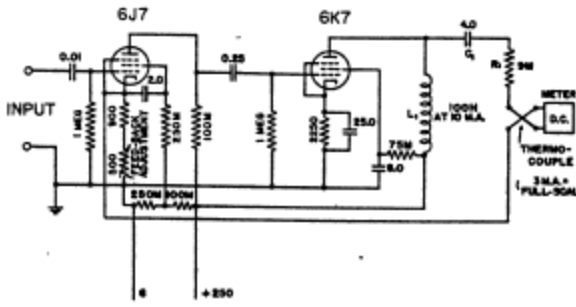
**(4) Stable BARUBORU: Linear scale 5) 6)**

H. S. Black (1898-1983) devised a negative feedback circuit in 1927 through the study of the carrier telephone amplifier of Bell Laboratories. This circuit improved the stability of the amplifier and its nonlinear nature, and the way to quantitative measuring instruments was established. Moreover, A. D. Blumlein (1903-1942) invented the differential circuit in 1936, and a more stable DC amplifier was realized.

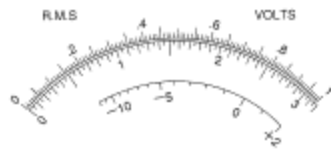
BARUBORU using such circuits were put on the market by Ballantyne, HP, GR, and RCA at the end of the 1930s. Meters featuring the ability to measure from a direct current to a high frequency on a linear scale, and with no requirement for zero point adjustment, were also manufactured. A negative feedback and a differential circuit needed many tubes. However, in the 1950s, the practical small vacuum-tube voltmeter using a miniature tube was finally completed. Moreover, the meter became easier to use because a linear scale was created using negative feedback.



(Fig. 7) Principle of a negative feedback circuit



NOTE 1: FEED BACK ADJUSTMENT MADE BY SCREW DRIVER TO GIVE REQUIRED SENSITIVITY.  
 NOTE 2:  $I_1$  AND  $R_1$  REQUIRED TO PREVENT RUSH OF CHARGING CURRENT TO  $C_1$  THAT WOULD BURN OUT THERMO-COUPLE.  
 Circuit diagram of a feedback voltmeter design for audio-frequency service.



(hp-400 シリーズ)

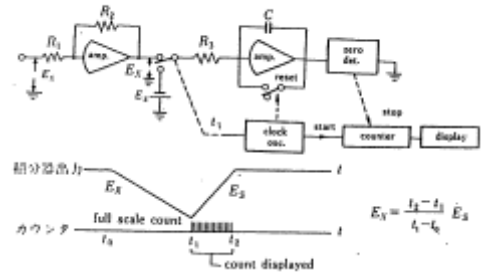
(Fig. 8) Hewlett's circuit with negative feedback and its scale

### (5) Challenge to Digital: High precision measurement 7)

The dual slope analog-to-digital conversion circuit, developed in 1957, was an excellent circuit for measuring instruments. This circuit was characterized by dramatically reducing the noise of the commercial frequency existing in the vicinity, and being capable of performing stable digital measurement. Rosewell Gilbert of Weston invented the circuit, but could not put it into practical use in those days, because the A/D converter assembled with tubes was as big as the drawer of a desk. Weston Corp, a prestigious company specializing in measurement, was absorbed by a company not specializing in measurement.

In the 1970s, when the price of semiconductors went down, the circuit was put into practical use for the first time. The size of the complicated electrical circuit was shrunk by the use of transistors and ICs. Gilbert was blessed with a gift for inventing, but not timing.

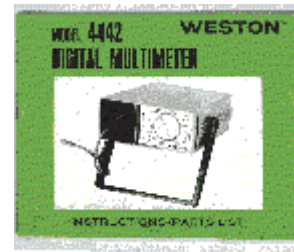
In the 1980s especially, complicated electrical circuits became small and cheap and very reliable. The digital voltmeter uses many small electronic parts as supporting components, including resistors, capacitors, transistors, ICs, and connectors. Occasionally, a voltmeter is not an independent measuring instrument, but is a part of an integrated electronic device. As both parts and as a sophisticated instrument, many digitized voltage measurement circuits were used in both production lines and at the measuring spot.



(Fig. 9) Dual slope integrating circuit (Gilbert)



(Fig. 10) Weston vacuum-tube voltmeter

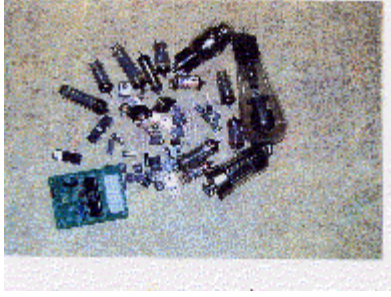


(Fig. 11) Weston digital multimeter

### (6) Conclusion

We have been looking back on the technology and the key components which formed the foundation of voltage measuring instruments. When mechanism parts, the tube, transistor, and A/D converter were developed, they were soon adopted to create the necessary measuring instruments. New technology requires not only invention, but also supporting technology to be incorporated in the measuring instruments, thus allowing the hardware to be realized. A measuring instrument will choose technology, and the technology that can satisfy the instrument will survive. Technology is useless if it is too early or too late. History chooses inventions and people, and so does the world of electric measuring instruments.

Tracing the history of the change in the quantity of production of electronic parts, one is occasionally able to see changes in industry and technology. For example, from around 1960, the tubes began to decrease in number, and on the other hand, semiconductor passive components, transistors, ICs, increased rapidly; making clear the change in technology.<sup>8)</sup>



(Fig. 12) Changes in electronic parts: From a large tube to a small tube, a transistor, and IC. Presently, electronic parts such as liquid crystal displays, microcomputers, memory, and printed boards have come to support measuring instruments.

## References

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