(002W)

On some Home-made Triodes

By Dr. Hidetsugu Yagi

Abstract

This is the report of tests of some home-made triode vacuum tubes, carried out in the Tohoku Imperial University about eighteen months ago.

The static characteristics are first given, from which the operational constants such as "Mutual Conductance", "Amplification Constant" etc. are derived.

After reviewing the behavior of the different types of tubes, some essential points are brought out about their design.

How the mutual conductance varies with the filament heating is then experimentally studied. The "Lumped Characteristics" of two entirely different kinds of triodes are plotted, as suggested by Prof. Eccles.

The photograph of the triodes under test is reproduced.

When author conducted research on the wireless communication by receiving science research subsidy from the government, a chance had given by collecting domestic triode tubes and test their characteristics as foreign specimens were hard to obtain. The results have suggested that some promising points exist although there seems some limitation in their manufacturing skills. As we realize that there must be big progress carried on the recent foreign technology and problem solving skill, reporting results of this test series may not be useful, but have decided to report it as there may have value to some people. Since these tests were conducted mainly from the year 1919 through spring of 1920, and therefore ask readers allowing us to somewhat outdated and insufficient results.

There were only five factories from which the specimens we have tested this time were supplied, and only two factories in them were manufacturing **Pliotron***[1] and **Oscillion***[2] type tubes for oscillation, and all others were manufacturing only small tubs which are in the same category of **Audion***[3]. Moreover, one of the **Pliotron**s supplied this time was failed to give an acceptable result, and had to be excluded from this report. Therefore there was only one product reported here as **Pliotron**.

*[1]: **Pliotron** is a trade name of Transmitting Tube by G.E., U.S.A.

*[2]: **Oscillion** is a trade name of Transmitting Tube by deforest, U.S.A.

*[3]: **Audion** is a trade name of Receiving Tube by DeForest, U.S.A. ------ Ed.

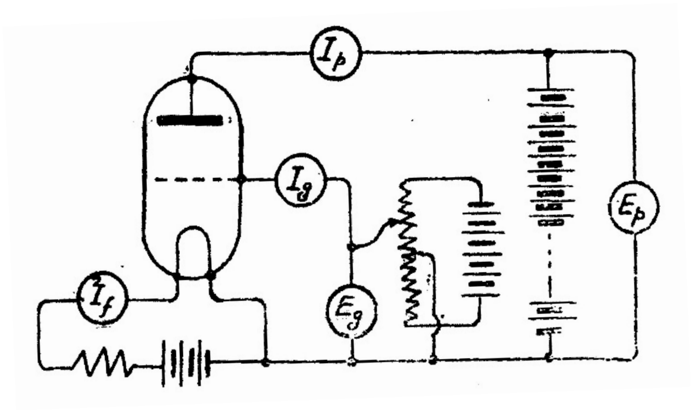


Fig.1: Test Circuit

At first, tested static characteristics by keeping plate voltage constant (in various value) with the connection diagram as shown in **Fig.1**. From these tests, curves were obtained as in **Fig. 2**, and from them mutual conductance[*4] can be determined. Mutual conductance equals slope against horizontal line.

Next is amplification constant (or voltage amplification)[*5]. This is defined graphically as Eccles described in Radio Review.

*4: Now known as μ
*5: Now known as Gm ------ Ed.

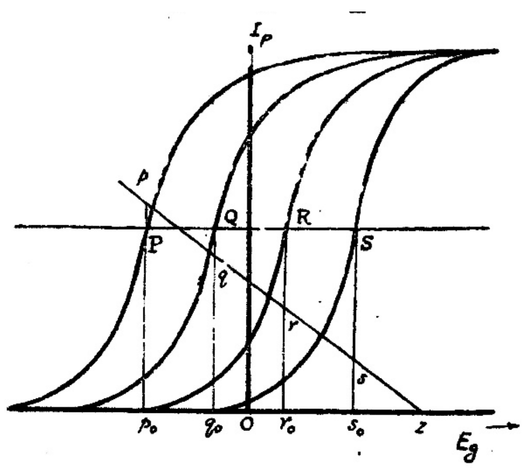


Fig.2: Typical Curves obtained

In **Fig.2**, draw arbitrary horizontal line PQRS, then draw vertical line p_0, p, q_0, q, etc., and make their length proportional to plate voltages. And draw a straight line nearest to p,q, etc. and let it reach the horizontal line. As PQRS is a straight line with constant plate current, $(E_p + kE_g)$ is constant. Therefore when E_p has changed, kE_g compensate the variation.

Therefore slope of the line pq--- should show k (Refer to p.74, Vol.1, No.2: Radio Review, Nov., 1919).

The value of k (amplification constant) determined by static characteristics is expressed as a function of plate current. When mutual conductance μ and amplification constant k are determined, internal impedance R can be calculated as: $R = k / \mu$. But here, μ is expressed as a function of grid voltage E_g with plate voltage E_p as parameter, and k is simply a function of plate current I_p. Therefore not easy to determine R. As to these three constants, refer to Tohoku University Report.

In order to determine right values in filament current, plate voltage E_p and grid voltage E_g for the tubes gathered here are somewhat difficult. As described below, in case of **Audion** in general, static characteristic curve indicates convex against horizontal line, and when E_g has changed from negative to zero, form of saturation rarely appear. However, some **Pliotron** already show saturation in I_p when E_g is still negative. From this observation, it seems that filament heating may be too much for **Audion**, and insufficient for **Pliotron**. But this may not be avoidable. In case of **Audion**, it is impossible to raise E_p much as it has low vacuum. Namely, high level of thermion is obtained as filament heating is sufficient, but as E_p is so low, and therefore never saturates. But in case of **Pliotron**, E_p can be much higher as its vacuum level is very high, but having relatively narrow distance between electrodes, and therefore describe a result for tendency of saturate even filament generates high thermion. Therefore **Pliotron** shows maximum value in mutual conductance (refer to point of inflection in static characteristics). Many **Audions** show no point of inflection and therefore no maximum point in mutual conductance. Even in case of **Audion**, similar curves will be obtained as in **Pliotron** if filament heating is insufficient.

Total number of tubes we tested this time reached 50-60, but few pieces in each categories are picked up here, and characteristic curves are shown and explanation added for 16 selected specimens. And lastly, we intend to describe a result for influence of filament heating, and so-called Lumped Characteristics.

Pliotron: "T" Company: Tubular- #2, Spherical- #a

Audion: "T" Company: Type A- #b / #e, Type F- #b / #d
"N.M." Company: Tubular- #La / #Lb
"A" Company: Type- #p / #s / #c / #r
"O" Company: Spherical- #b / #d
"J.N." Company: Spherical- #a / #b

Note: a.: The company names assumed are: "T" as TEC, "N.M." as Nihon Musen (JRC), "A" as Annaka??, "O" as Oki??, and "J.N." not sure.

b: We guess that there was a trend in Japan at that time not to disclose a specific product and/or name of the company who made it, but it is quite regretful matter to us. Frankly, this report does not have much value without tube types and supplier's names, but editor decided to report here because it was one of the earliest reports in this category, specially referred in the first document (001W), and the author was Dr. H. Yagi, famous as inventor of Yagi Antenna. ----- Ed.

Pliotron ("T" Co., Tubular- #2)

This tube shows quite satisfactory results as oscillator. As its filament is surrounded by grid, amplification constant shows large value as 14. Vacuum level is good, and no grid current flows at $E_g < 0$. It suggests good design and manufacture. It is unknown if it is still good when higher voltage than 700V and much higher power output is required as we could not test this time.

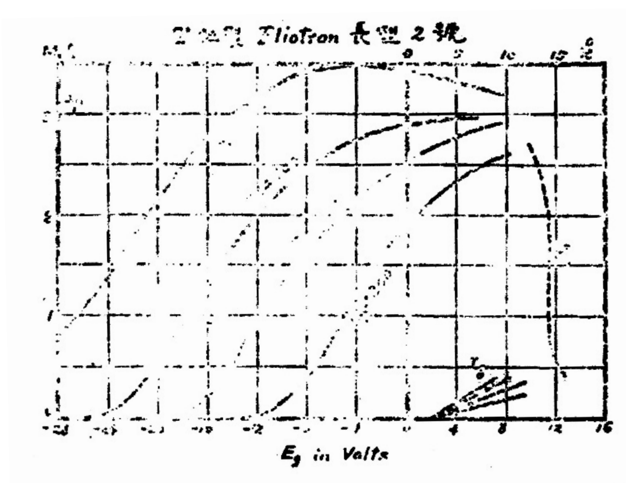


Fig. 3a: "T" Co.- Pliotron, Tubular- #2

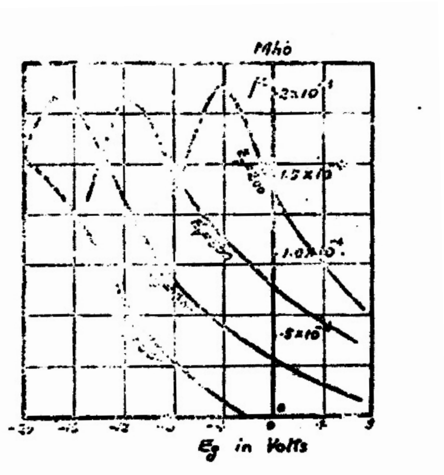


Fig.3b: "T" Co.- Pliotron, Tubular- #2

Pliotron ("T" Co., Spherical- #a)

This specimen looked also good, but sufficient result could not be obtained as there was a limitation in plate battery.

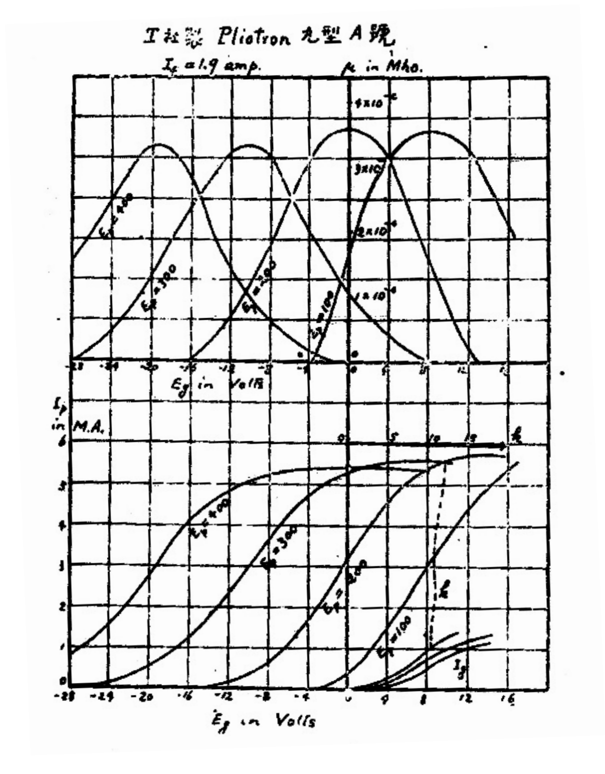


Fig. 4: "T" Co- Pliotron, Spherical- #a

Audion ("T" Co., Type A- #b & e) Note: High vacuum version of Spherical **Audion** by TEC? --- Ed.

So-called **U.S.** type and have only 5 in k value. The sample #b has maximum point in μ, and this may be caused by current diverted to grid rather than shortage of filament heating. Tubes of type A are generally uniform in quality, having small k value and I_p is hardly reaching zero when E_g gets negative. It is preferable to be in high reliability, but in case of receiving tube, there are product of less reliable, but having higher sensitivity.

We are always obtaining satisfactory results by generating oscillation with stable specimens.

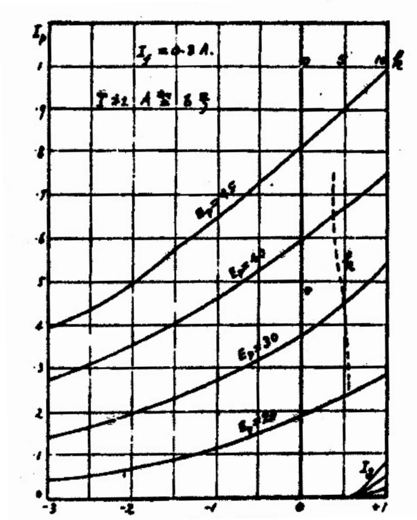


Fig. 5a: "T" Co.- Audion, Type A- #b

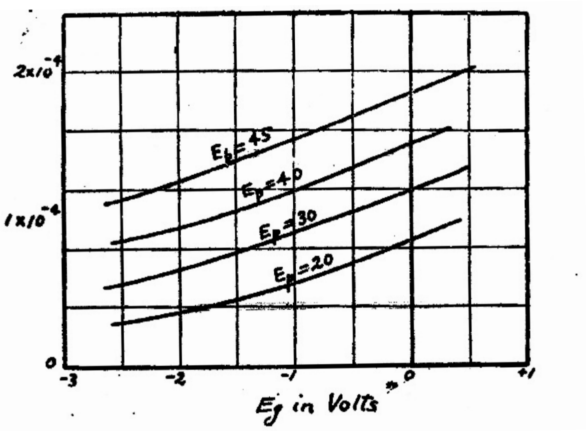


Fig. 5b: "T" Co.- Audion, Type A- #b

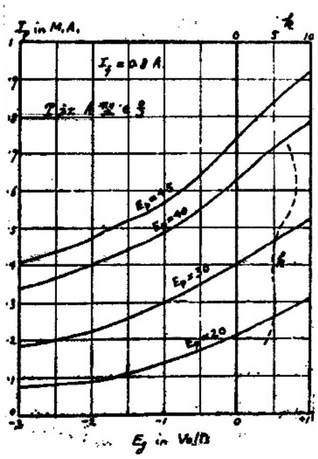


Fig. 6a: "T" Co.- Audion, Type A- #e

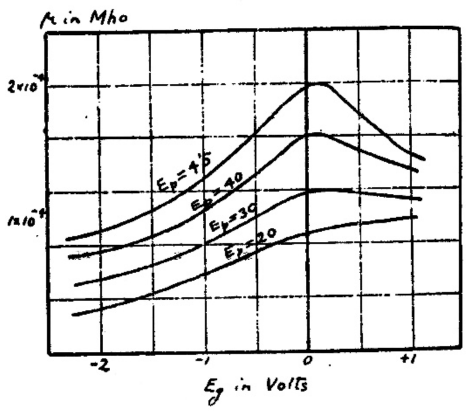


Fig. 6b: "T" Co.- Audion, Type A- #e

Audion ("T" Co., Type F, #b & d)   Note: May be **UF-101** by TEC ----- Ed.

Called **French** type. Filament is surrounded by cylindrical grid, and therefore large amplification of k value (13-15) is obtained. As 0.6 Ampere of filament current has passed, curve of μ is bent as in the graph. If filament current gets higher, the μ curve should bend reversed (refer to "O" Co.'s product described later), but as their filament looks fragile, we assumed that this may be a limit. Looking from characteristic curves, it is obvious that the **French** type is more superior.

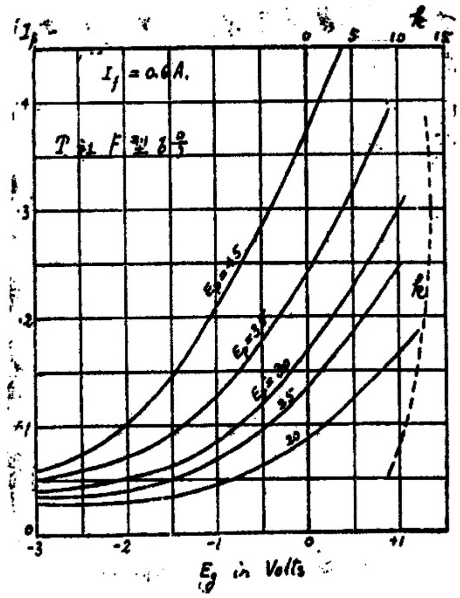


Fig. 7a: "T" Co.- French Type- #b

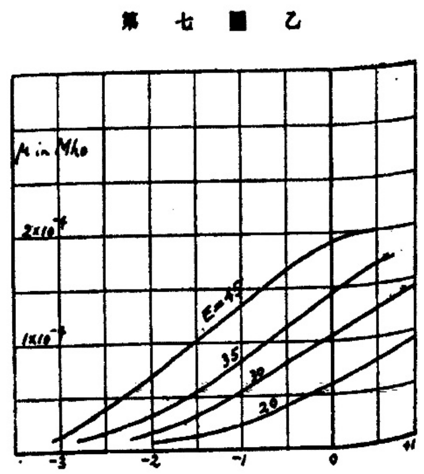


Fig. 7b: "T" Co.- French Type- #b

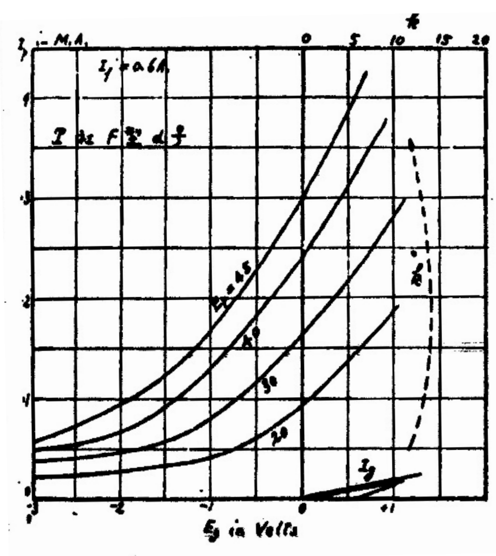


Fig. 8a: "T" Co.- French Type- #d

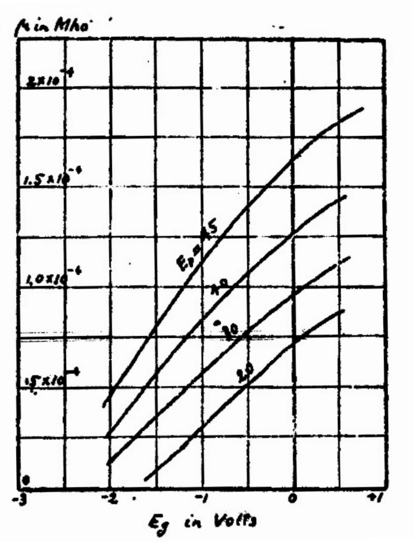


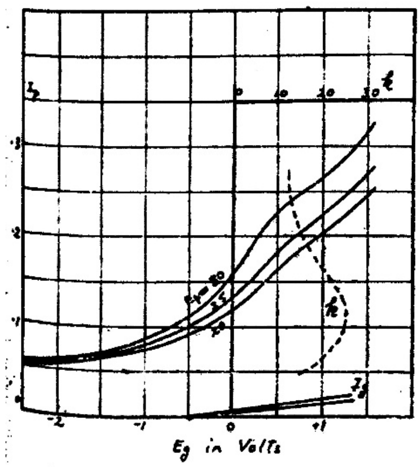
Fig. 8b: "T" Co.- French Type- #d

Audion ("N.M." Co.- Tubular- #a & b) Note: Maybe **C1** or **C2** by JRC ---- Ed.

Many of this type have large amplification constant k (like over 20) because of tubular shape, but vacuum level is found very low and poor uniformity between each product. But some of them show unusually high receiving sensitivity in certain conditions.

This type is hardly usable for oscillation as it is too easy to generate glow, and therefore be limited to receiver use. But it tends to generate self-oscillation even in the receiving equipment as it is operated near glowing condition. As obvious from the test results, its characteristic curves are not smooth, and grid current appears early which confirms that it is not pure electron discharge. When E_g is positive, it easily generates ion bombardment which cause glow, and mutual conductance curve deforms vigorously. At near E_g = 0, detecting sensitivity tends to gets extremely high, and show much superior sensitivity over other high-vacuum products like "T" Co.'s type **A**. Therefore it seems good sensitivity does not always satisfy reliable products too.

This company's new product looks similar to **French** type, but level of vacuum and other parameters are similar to the above product. We assume that this is because of incomplete vacuum system they use which is shame, but similar situation may be seen in other companies. For example, **Moorhead Audions** which is marketed by DeForest for amateur use show fairly good sensitivity, but seems having inferior vacuum which may be appealing to amateur users.



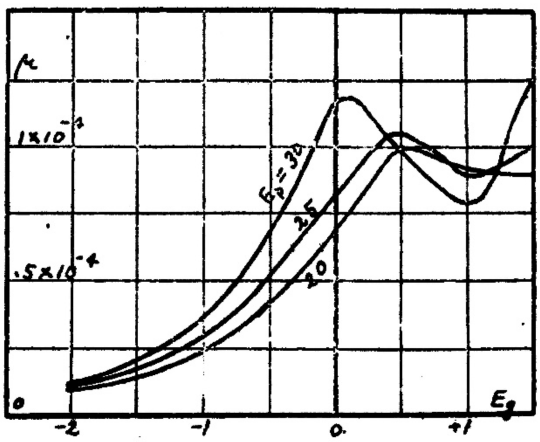
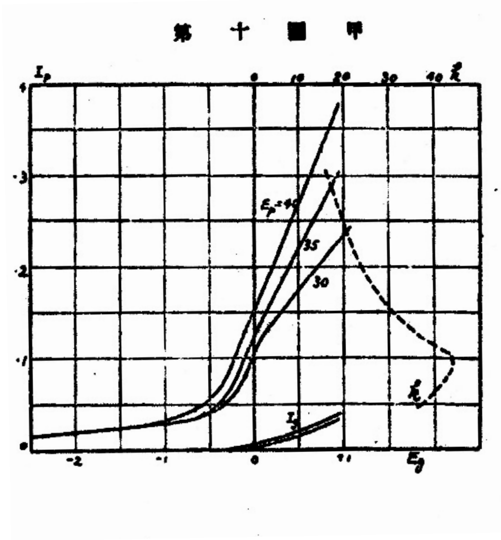


Fig. 9a: "N.M." Co.- Audion, Tubular- #a **Fig. 9b: "N.M. Co.- Audion, Tubular- #a**



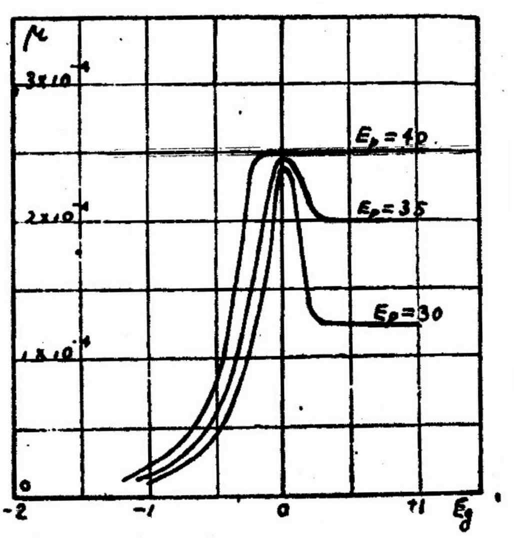


Fig. 10a: “N.M.” Co.- Audion, Tubular- #b Fig. 10b: “N.M.” Co.-Audion, Tubular- #b

Audion (“A” Co.- #p)

This product has a unique construction. Both grid and plate consist of Tungsten wire wrapped around square jig. We are unable to evaluate merit and/or demerit of wired plate, but test results suggested that this tube is far superior to ordinary **Audions** for oscillation as they claim. As its vacuum level is extremely high, it could be used up to 400V of plate voltage although outer diameter is only 6cm. We rate this tube as good for oscillation as **Pliotron**.

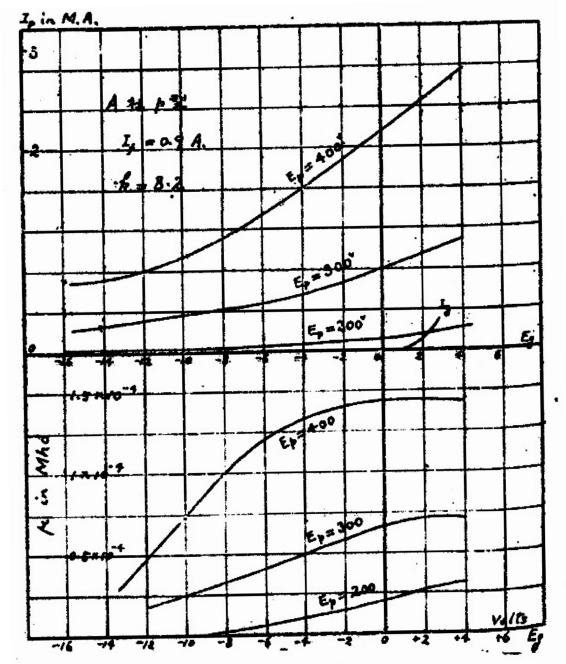


Fig. 11: “A” Co.- Audion- #p

Audion ("A" Co.- #s)

This is a small version of **#p**, and found as **Audion** with low vacuum. The reason for having high amplification factor (20 toward 40 for higher E_g) may be because of wired plate rather than that of ordinary sheet metal. It seems that higher amplification constant may be obtained when both grid and plate are wired. This subject must be calculated as a problem of static field, but German word "Durchgriff" has deep meaning, and in this case, k value appears larger as durchgriff of plate against filament is small. Therefore large k value does not always mean good tube

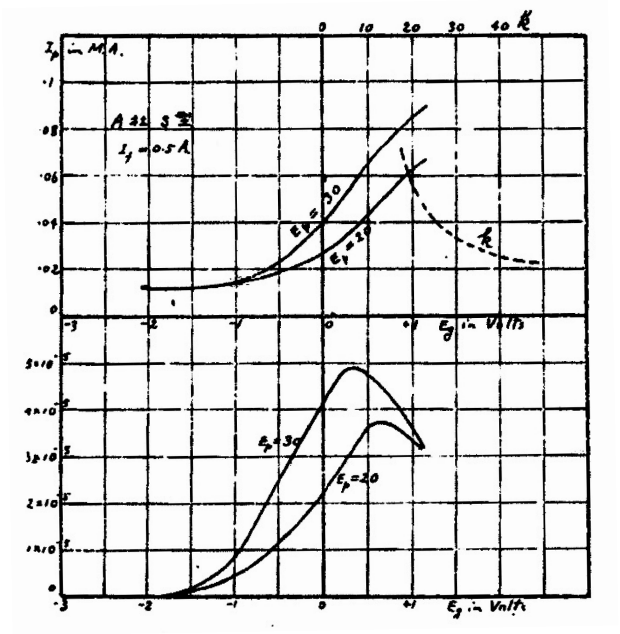


Fig. 12: "A" Co.- Audion- #s

Audion ("A" Co.- #c)

Plate is cylindrical shape as in **French type**, and k value exceeds 20. As grid pitch is fine, durchgriff is small as in #s.

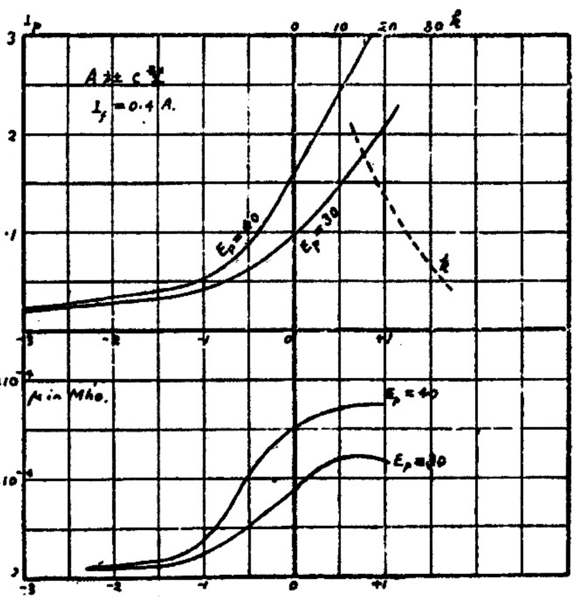


Fig. 13: "A" Co.- Audion- #c

Audion ("A" Co.- #r)

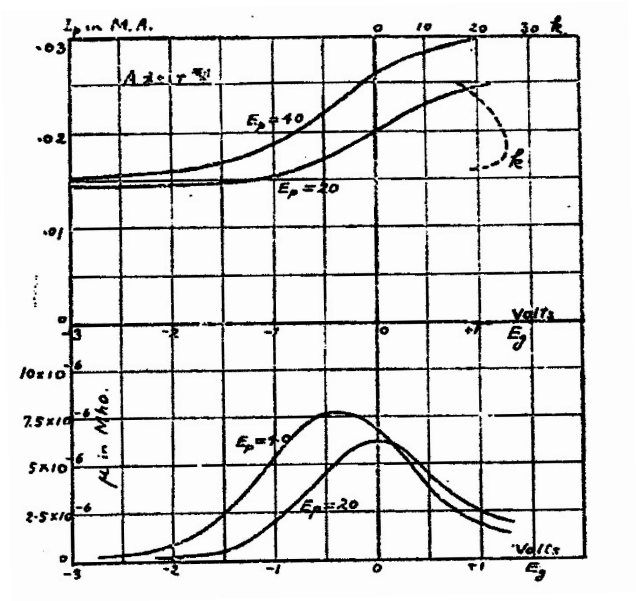


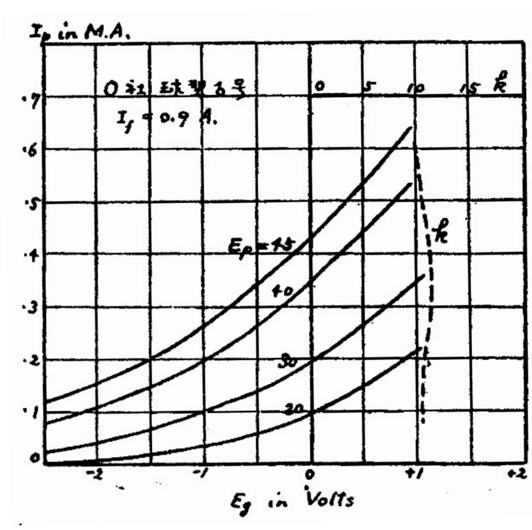
Fig. 14: "A" Co.- Audion- #r

Plate is a circular disc at the top, grid in the middle and filament at the bottom, and space between each electrode is not narrow. Therefore plate current could not be minimum even with negative E_g. Although k value reaches 20, we are unable to say that this tube is a successful sample.

As a conclusion for evaluating tubes by "A" Co., first **#p** type is rated as good, but all of them seem having too small durchgriff, and suggests that area of plate and pitch of grid wire must be important factor for design.

Audion ("O" Co.- Spherical- #b and d)

From external appearance and characteristics, uniformity of products may look better than type **A** of "T" Co. (early DeForest **Audion** type), amplification constant ranges 11-13 whereas the ones by "T" Co. is around 5. Therefore these specimens should be evaluated as quite good for ordinary **Audion.** Recently, **French** type with large amplification are popular, but this company only offered so-called **U.S.** type.



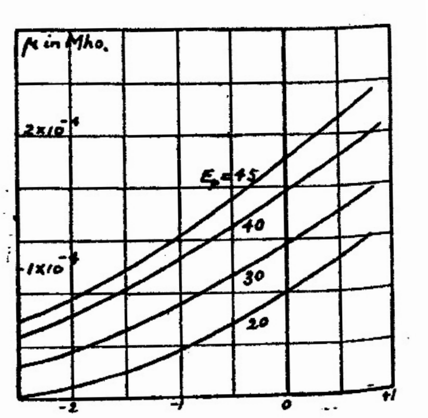


Fig. 15a: "O" Co.- Audion, Spherical- #b **Fig. 15b: "O" Co.- Audion, Spherical-** #b

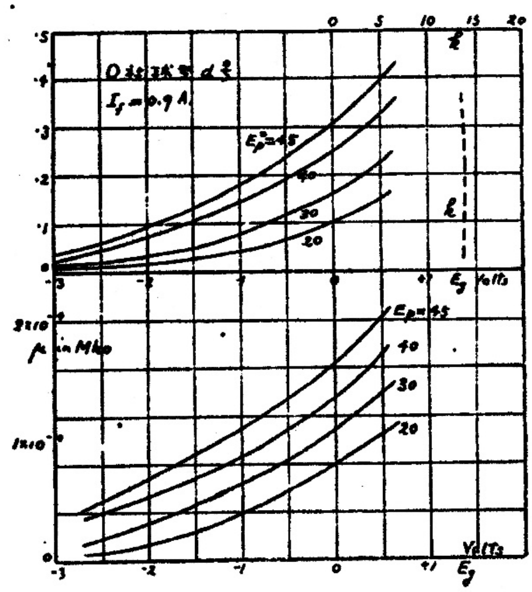


Fig.16: "O" Co.- Audion, Spherical- #d

Audion ("J.N." Co.- Spherical, #a and b)

This company offered fairly precise **Pliotron**, but regret that we could not list here because of inferior record. For old U.S. type **Audion**, the results as indicated here were obtained. These specimens seem taking very long time after their production, and therefore having slightly lower vacuum level. Their filament required more than 2A, and shown small amplification which must be points to improve. In these points, the ones by "O" Co. are better. But note that the ones making record in receiving sensitivity are with lower vacuum, easy to generate glow like **tubular** type, **French** type, etc. rather than **U.S.**type with high vacuum as described in **tubular** "N.M." type.

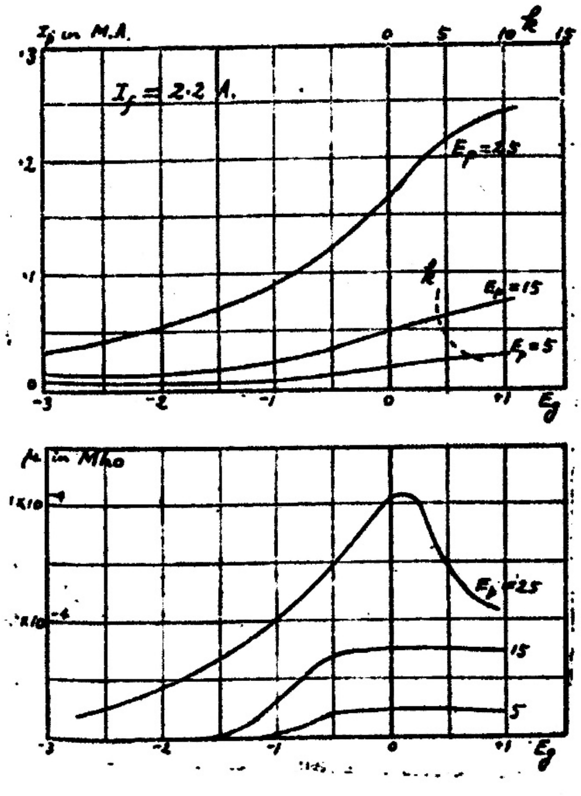
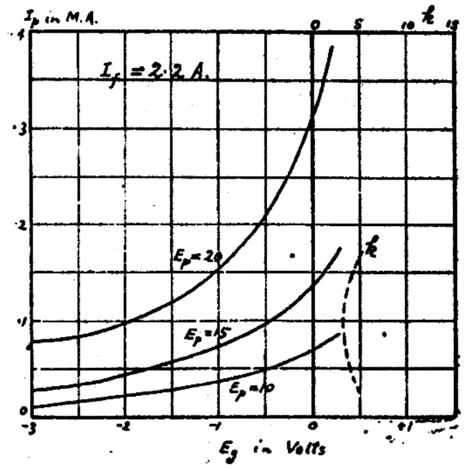


Fig. 17 ("J.N." Co.- Audion, Spherical- #a)



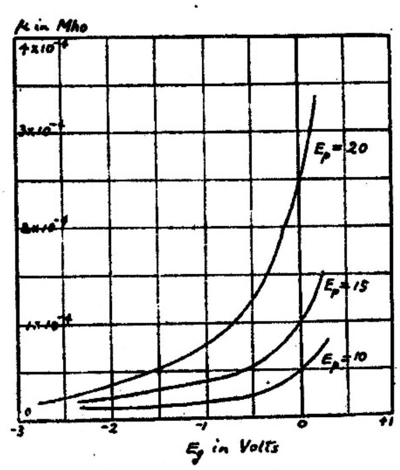
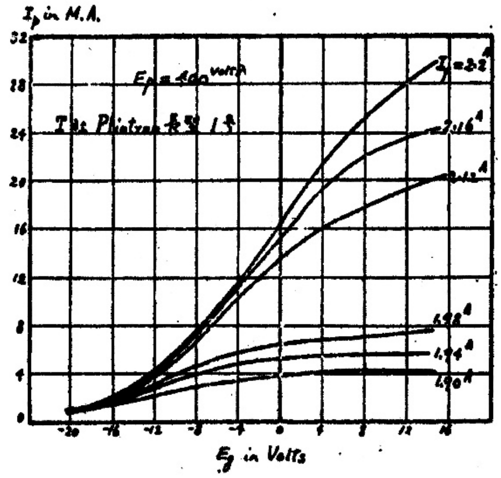


Fig. 18a: "J.N." Co.- Audion, Spherical- #b Fig. 18b: "J.N." Co.- Audion, Spherical- #b

Characteristics varies against filament temperature

We have conducted special tests finding out variation in tube characteristics against filament temperature. The result were shown in **Fig.19**. From this, calculated mutual conductance as **Fig.20**. The point for maximum μ shifts toward right hand side when filament temperature gets higher, and when it gets to low and unable to produce sufficient thermion, then the curve quickly saturates and mutual conductance become lower, and therefore maximum value of μ occurs at a much lower value.



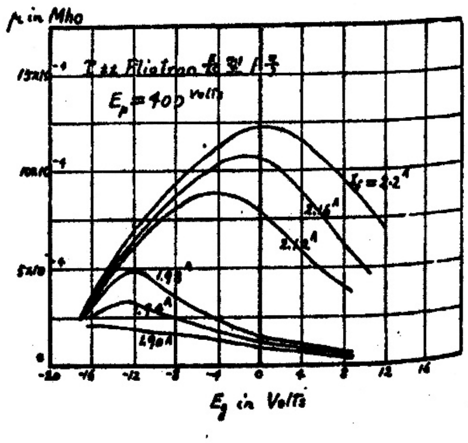


Fig. 19: Filament Temperature vs. Filament Current

Fig. 20: Mutual Conductance vs. Filament Current

Lumped Characteristic

According to Prof. Eccles, plate current I_p is a function of plate voltage E_p and grid voltage E_g, and can be expressed as a function of (E_p + kE_g), and therefore when express this (E_p + kE_g) as E_l, and name this as Lumped Voltage, I_p can be expressed as:

$I_p = f\ (E_l)$

As already shown in **Fig.1**, when a group of characteristic curves are given, then amplification factor k can be determined. And next, calculate E_l namely (E_p + kE_g) on each point of characteristic curve, and make a graph of the relation between I_p and E_l. The resultant characteristic curves concentrate into an almost single line. Prof. Eccles named this single curve as Lumped Characteristic against certain filament current. It is said that straight portion of the curves match well, and only areas near saturation do not match.

In order to express characteristics of a given tube it is adequate to do it with a group of curves, and trial for attempt to show it with single curve like lumped characteristic may not be useless because it makes rather hard to realize as Prof. Howe pointed out earlier at the discussion held in Physical Society of London, it is essential to actually try if lumped characteristic made by many characteristic curves can be matched.

The author plotted many characteristic curves with vacuum tubes as described above, tried to draw few lumped characteristic curves.

Fig.21 shows relation between lumped voltage E_l and plate current I_p with

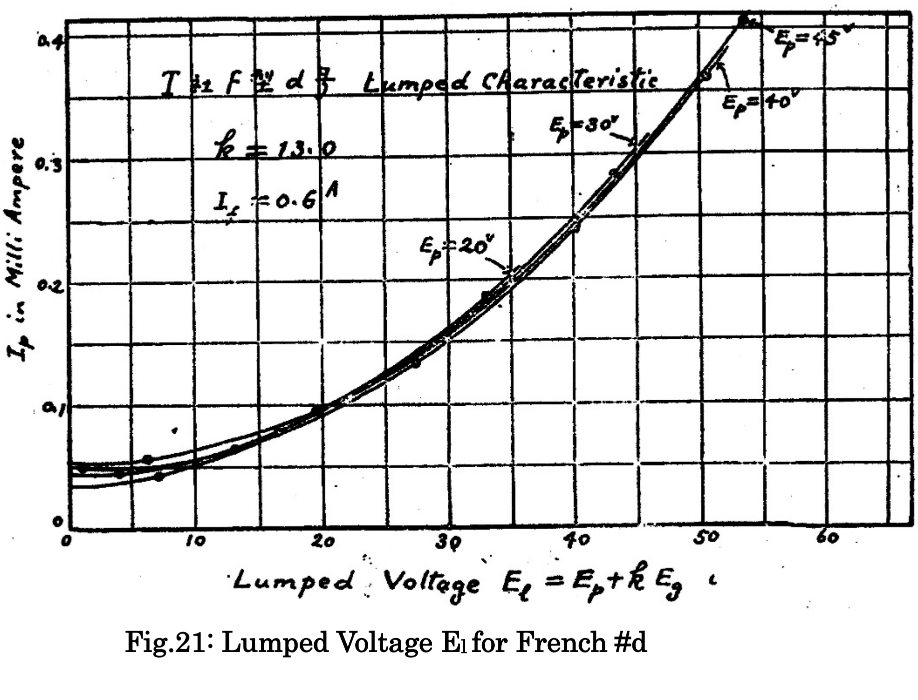


Fig.21: Lumped Voltage E_l for French #d

k = 13 on **French #d** tube, and confirm that the curve between 20 and 45V of E_p is quite well matched.

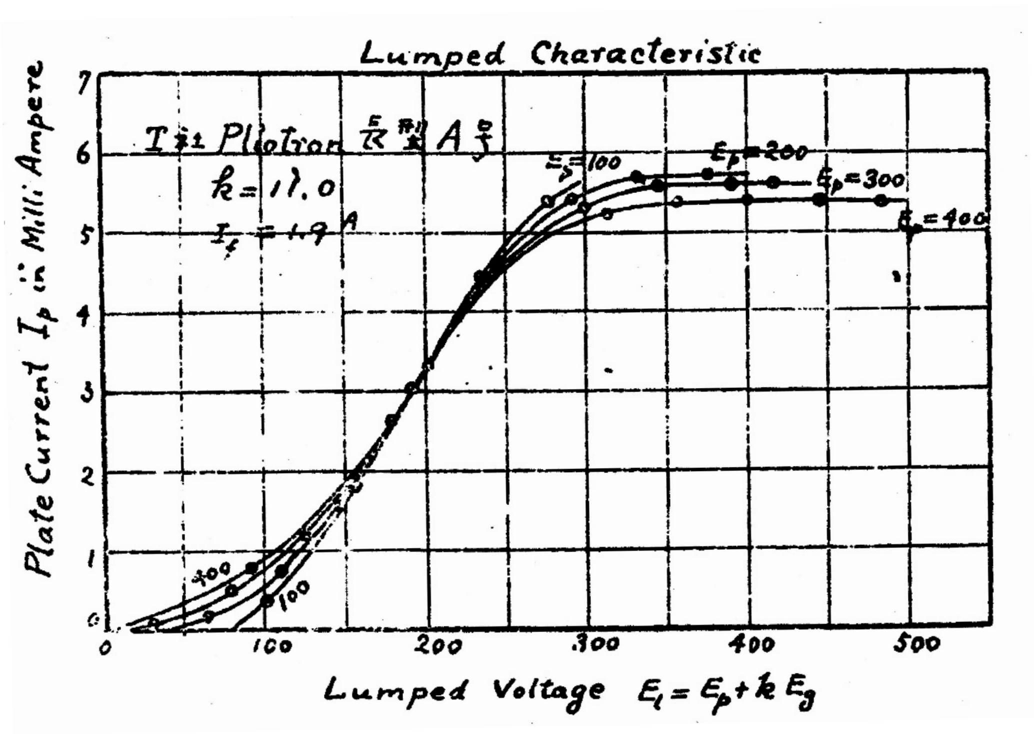


Fig. 22: Lumped Characteristics for "T" Co.- Pliotron, Tubular- #A

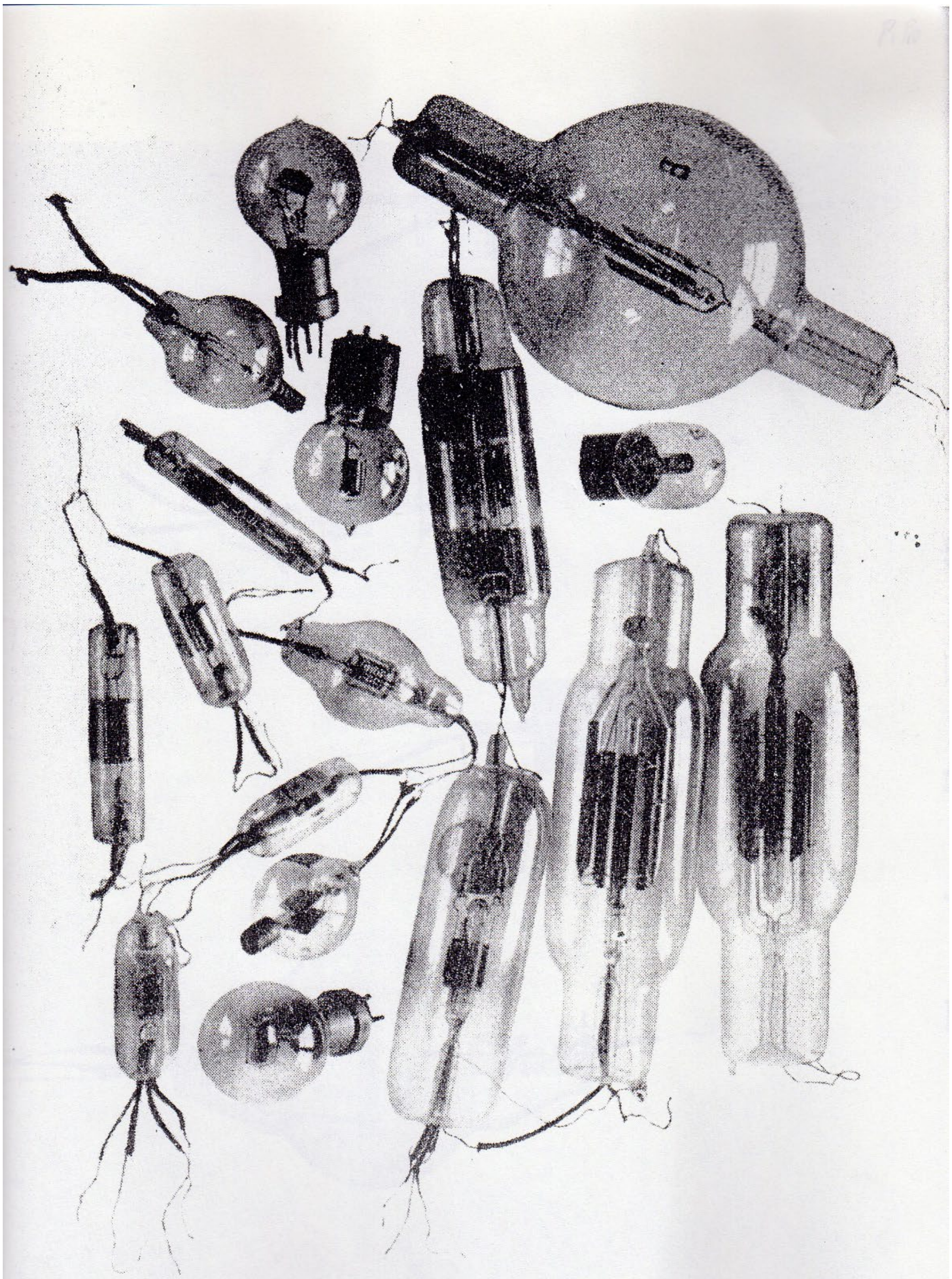
Fig.22 shows lumped characteristic between 100V and 400V of **Pliotron tubular #A**, and verifies that it matches well in the middle, and show separation at the both ends.

Looking from those results, lumped characteristic seems not much of practical value exist, but can be found that it is reasonably accurate to make I_p as a function of ($E_p + kE_g$), and at the both ends of curves, it should need adding another constant like e to match actual situation as:

$I_p = f\,(E_p + kE_g + e)$

(if keeping k value constant).

The author expresses his sincere appreciation to each tube manufacturer which supplied vacuum tubes for this series of tests, and gave convenience to the author's research work. And also express appreciation to my assistant, Zenroku Hanzawa.



Triode Vacuum Tubes used for this series of test

On some Home-made Triode: by Dr. Hidetsugu Yagi, p.p. 497-511, IEEJ Bulletin (DENKI GAKKAI ZASSHI) Vol.4, No. 396 (1921)