

預測強力振盪器工作情形的圖解方法

馮秉銓 徐秉錚

(嶺南大學物理系)

在分析強力振盪器的工作情形時，因為線路是非直線性的，所以用嚴格的數學方法來解決這個問題，所得結果往往非常繁複，而缺乏實用的價值。如果用數學方法，但加了許多近似的假定，則結果又和實際相去太遠。Chaffee 氏曾在設計強力放大器時，假定靜態工作點固定不變，利用諧波分析方法計算等值線圖，用以分析放大器的工作情形，結果較用其他方法更為準確。如果將 Chaffee 氏方法照樣用來設計強力振盪器時，則發生下列兩種困難：

- (一) 工作路並非一條直線。
- (二) 靜態工作點並非固定。

假如用適當的相角補償方法，使振盪器的工作路近於直線，則剩下的問題就是，如何得到一組等值線圖，可以用於靜態工作點變動的情形。本文敘述一種方法，假定直流板極電壓 E_{bb} ，激發比率 χ ，為兩個固定的自變數，而任靜態工作點變動，仍用諧波分析法計算功率輸出，板極效率，板極負載等等，由是所得的等值線圖，可用以預測強力振盪器的各種工作情形。詳細研究等值線的形狀，可以得到下列兩個有趣的結果：

(一) 如果振盪器的負載 $(R_b)_m$ 保持不變而調變柵漏電阻 R_c 時，則我們在沿着 $(R_b)_m$ 等值線移動，從等值線圖中，我們可以看出：當 $(R_b)_m$ 等值線和板極效率等值線相切時，板極效率最高。相當於最高效率點的柵漏電阻值，可以從等值線圖上直接讀得（圖 2）。

(二) 從等值線圖中，我們可以得到柵偏電壓 E_{cc} 和柵漏電阻 R_c 的關係曲線。在一定的負載情形下，調變 R_c 所能得到的最大柵偏電壓也有一定，超過了這個極大值，增加 R_c 反使 E_{cc} 減少。當負載變更時，柵偏電壓的極大值也隨之變更（圖 3）。一般的說來，相當於最大柵偏電壓的柵漏電阻並非就是最佳柵漏電阻。

本文所述的圖解方法，雖然在計算時相當冗長，但等值線圖一經完成，強力振盪器的各種工作情形，都可以由圖上直接讀得，設計時極為方便。和 Record 氏方法及實驗結果相比較，可以證明本文所述的方法相當準確（表 1）。

GRAPHICAL PRE-DETERMINATION OF THE PERFORMANCE OF POWER OSCILLATORS

By PING-CHUAN FENG and PING-CHENG HSU

Department of Physics, Lingnan University, Canton

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ABSTRACT

This paper presents a graphical method of pre-determining the performance characteristics of a power oscillator. Calculated results are compared with experimental data and the agreement was found to be better than other methods known at present.

1. INTRODUCTION

An oscillator is a non-linear device. Mathematical analysis of a circuit involving non-linear devices usually results in such a complicated form that correct and useful physical interpretation and conclusion cannot be easily drawn. At any rate, exact solution of such a problem is practically impossible. While many papers had been written on this subject, each method has its own limitation. Some started out with the differential equations of a generalized circuit, but had to limit the final solution to a limited specific form^{1, 2}. Some started out with certain assumptions regarding the shape of the current-voltage characteristics and proceeded to work out an exact solution^{3, 4}. However, it is generally very difficult to find a simple mathematical expression which fits the actual characteristics with sufficient accuracy. For this reason, the calculated results do not check too well with experimental

1. B. Van der Pol, "Non-linear Theory of Electric Oscillations" *I.R.E. Proc.* **22** (1934), 1051.
2. P. LeCorbeiler, "The Non-linear Theory of the Maintenance of Oscillations" *Journal I.E.E., Wireless Section*, **11** (1936), 292.
3. F. A. Record & J. L. Stiles, "An Analytical Demonstration of Hartley Oscillator Action", *I.R.E. Proc.* **31** (1943), 281-287.
4. E. A. Guillemin, "An Analytical Method of Predetermining Behavior of Vacuum Tube Oscillator", presented, Boston Section, *I.R.E. Cambridge, Mass.*, October 25, 1935.

data. This paper presents a graphical method by which the performance characteristics of a power oscillator can be represented in the form of a set of contour diagrams drawn in the plate voltage—grid voltage plane (e_b - e_c plane). Started out with the actual static characteristic curves of the power tube, contour curves are calculated by means of harmonic analysis in a very straight-forward manner. When represented properly in the e_b - e_c plane, many interesting conclusions can be drawn. The calculated results agree very well with experimental data.

2. GRAPHICAL REPRESENTATION

Chaffee⁵ demonstrated the usefulness and convenience of using power contour method in representing the performance characteristics of a power amplifier. This method proved to be very useful in the design of a class C amplifier and has been used by many authors^{6,7}. Briefly, this method consists of plotting constant contours for the power output, plate efficiency, driving power, load resistance, etc., in the e_b - e_c plane, assuming constant values for plate supply voltage E_{bb} and grid bias voltage E_{cc} . When values of E_{bb} and E_{cc} are fixed, the quiescent point is fixed. By assuming different positions in the e_b - e_c plane of the end points of the path of operation, which is a straight line for a tuned amplifier, the various quantities can be calculated and plotted. Since this method does not assume any particular wave form of the plate current and grid current pulses, it gives more accurate results than some of the other known methods^{8,9}.

An attempt of using Chaffee's method in the design of a power oscillator would face the following difficulties. First, the path of operation of a power oscillator is not necessarily a straight line¹⁰. Secondly, the quantity E_{cc} is not an independent variable. Since the grid bias in an oscillator is usually obtained by making use of the voltage drop across a grid resistor, it depends not only on the resistance but also on the average grid current which in turn depends upon the path of operation. It is obvious, therefore,

5. E. I. Chaffee, "The Operating Characteristics of Power Tubes", *Journal Applied Physics* **9** (1938), 471.
6. H. Stockman, "Power Efficiency of R. F. Power Amplifier Stages" *Electronics* **17** (1944), 134-137.
7. R. I. Sarbacher, "Analysis of Self-biased Modulated Amplifiers", *Electronics* **16** (1943).
8. W. G. Wagener, "Simplified Methods for Computing the Performance of Transmitting Tubes" *I.R.E. Proc.* **25** (1937), 45.
9. F. E. Terman and W. C. Roake, "Calculation and Design of Class C Amplifiers", *I.R.E. Proc.* **24** (1936), 620.
10. P. C. Feng, "Notes on the Plate Efficiency of Power Oscillators" *Chinese J. Phys.* **7** (1939), 249-257.

that Chaffee's method of representation which is good only for a fixed quiescent point, cannot be used in the case of an oscillator.

The question is how to obtain a set of contours with varying quiescent point. In the operation of ordinary oscillator circuits, the plate supply voltage E_{bb} and the excitation ratio χ (defined as the ratio of a.c. grid voltage to a.c. plate voltage) are usually kept constant. If we consider E_{bb} and χ as the two fixed independent variables, the path of operation can be drawn on the e_b - e_c plane as shown in fig. 1. It is seen here that all the paths must have the same slope, but the quiescent point would slide along the line $e_b = E_{bb}$. Any point on this plane, such as point A , can be considered as the end point of the path of operation which is represented by a straight line drawn from point A and making an angle $\arctan \chi$ with the vertical axis. The intersection point of this straight line and the horizontal line $e_b = E_{bb}$ is obviously the quiescent point Q . Several such lines are shown in fig. 1. These are to be superimposed on the constant plate and grid current contours

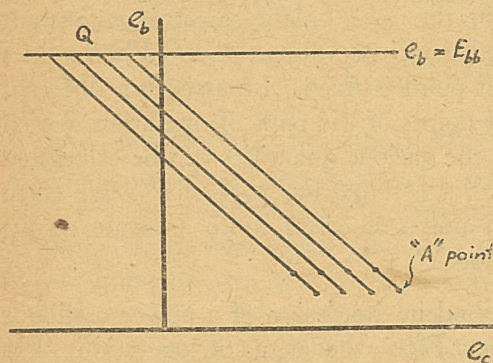


Fig. 1

drawn in the same plane. (not shown in fig. 1). By assuming as many such end points as possible, and by using an appropriate harmonic analysis,¹¹ the d.c. as well as the fundamental frequency components of the plate and grid currents can be calculated with good accuracy. Thus, for any given "A" point, the "Q" point is fixed, and the four currents can be calculated. The power output, input, plate efficiency, etc., are then calculated from the following simple relations.

$$\text{Driving power } P_d = E_g(I_g)_1$$

$$\text{Power input } P_{bb} = E_{bb}I_b$$

$$\text{Power output } P_o = E_p(I_p)_1 - E_g(I_g)$$

$$\text{Plate efficiency } \eta_p = P_o/P_{bb}$$

$$\text{Plate Load } (R_b)_\omega = E_p/(I_p)_1$$

$$\text{Grid Leak Resistance } R_c = E_{cc}/I_c$$

11. E. L. Chaffee, "A Simplified Harmonic Analysis", *Rev. Sci. Instru.* **7** (1936), 384.

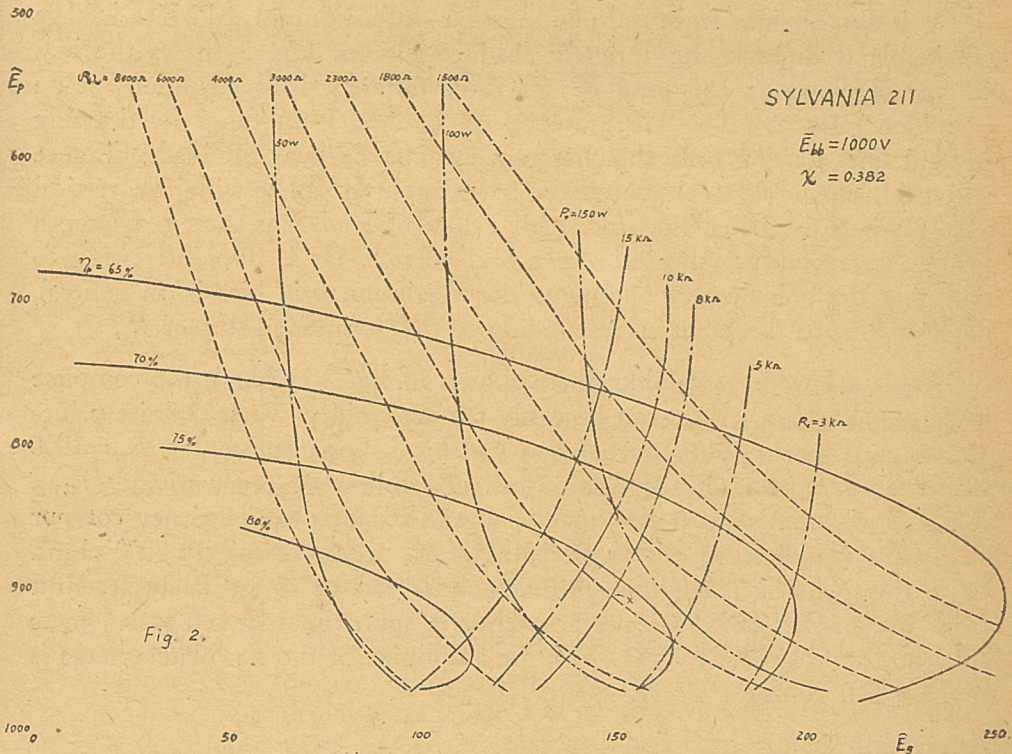
where I_b = average d.c. plate current

I_c = average d.c. grid current

$(I_b)_1$ = fundamental component of a.c. plate current.

$(I_g)_1$ = fundamental component of a.c. grid current.

The calculated results are then plotted in the form of contours as indicated in fig. 2, where several curves are shown for each of the following quantities, P_o , η_p , $(R_b)\omega$, and R_c . The forms of these curves are quite different from those of an amplifier drawn for a fixed Q point. Although it sounds



tedious to prepare a set of contour curves like this, but once obtained they would be a great help to the designer, because the diagram offers many possibilities in the choice of a good operating point. Having three or four

sets of contours like this, each set for a certain reasonable value of χ , the problem of design of a power oscillator becomes a very simple matter. Fig. 2 shows one of the typical examples calculated for tube T211 with $E_{bb}=1000$ volts and $\chi=0.38$.

Many interesting things can be seen from the shapes of these contours. For instance, when R_c is changed for a given fixed load, the locus of the end point would be along the constant $(R_b)_\omega$ contour. We notice that for each $(R_b)_\omega$ contour, there is a point tangent to the constant plate efficiency contour. This is obviously the point of maximum efficiency. It is also seen from the constant power output contours that at the point of maximum efficiency, the power output is also nearly maximum. For example, in fig. 2, if the load resistance is 1800 ohms, the optimum grid leak resistance should be approximately 4000 ohms.

It is also obvious from the plotting that the maximum grid bias voltage obtainable is different for different load conditions. Fig. 3 shows the bias voltage obtained by changing R_c for three different load conditions at an excitation ratio of 0.38. These are easily obtained from fig. 2 by drawing straight lines starting from the chosen end point (fixed by the load resistance and grid leak resistance) and making an angle $\arctan \chi$ with the vertical axis. It is to be noted that for small values of load resistance, too large a grid leak resistance results in lower bias voltage. It is also interesting to note that the point corresponding to the maximum grid bias is, in general, not the same as the point corresponding to the optimum value of R_c .

With a few diagrams like those shown in fig. 2 at hand, the complete performance characteristic can be easily pre-determined when definite values are assigned for any four independent variables. For instance, let $E_{bb}=1000$ volts, $\chi=0.38$, and $(R_b)_\omega=3000$ ohms. By following the constant $(R_b)_\omega$ contour, we found that it is tangential to a constant plate efficiency contour at a point (marked \times) where the value of R_c is approximately 8000 ohms. Once this point is fixed, the other quantities can be immediately read off from the chart. Thus, the power output is approximately 130 watts, plate efficiency approximately 75.5%, and the amplitude of the a.c. plate voltage is roughly 910 volts.

3. COMPARISON WITH EXPERIMENTAL RESULTS AND OTHER METHODS

The present method, like all other methods, is also limited to an assumed straight line path of operation. However, by using proper phase com-

pensation¹² and careful adjustment, a fairly good straight line path can usually be obtained. The graphs shown in fig. 2 and fig. 3 can be used for any feedback oscillator circuit. This method, although look tedious, is not any more complicated than other known methods. Since it makes no assumptions as to the particular shape of the static characteristic curves of the tube, the results so calculated are much more reliable than some of the other known methods. Table 1 shows a comparison between the results calculated from

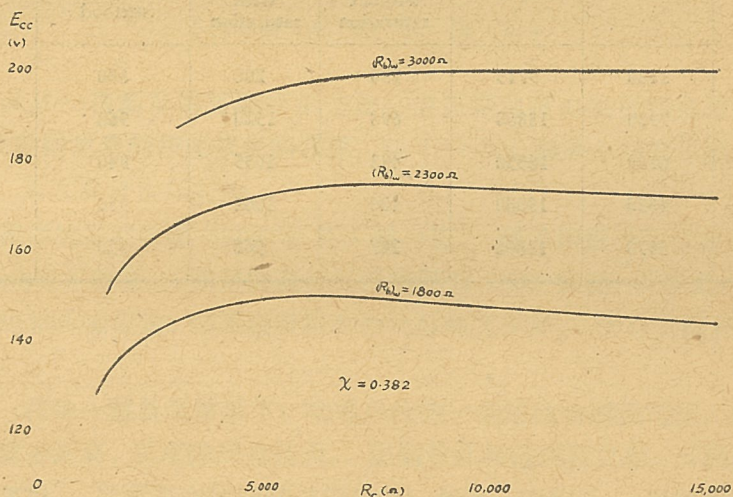


Fig. 3.

fig. 2 and those calculated from another known method³ as against actual experimental data. The first three columns give the excitation ratio, load resistance and grid leak resistance taken from our experimental data. These are chosen from many sets of data. To insure better comparison, we have chosen only those for which the path of operation is approximately a straight line. The fourth column is the calculated value of amplitude of oscillation using Record and Stiles' method assuming an idealized tube characteristic without saturation. The fifth column is also calculated using Record and Stiles' method assuming an idealized tube characteristic with saturation. This amounts to assume that the tube characteristic can be broken up into two straight lines, one for the linear region and the other for the saturation region. The sixth column gives the results obtained from the graphs described in the present paper. The last column gives the actual measured amplitude of oscillation. The close agreement between the last two columns seems to be very encouraging. The large percentage difference between the results

12. P. C. Feng & P. F. Hsu, "Phase Compensation in Power Oscillators" *Chinese J. Phys.* 7 (1950), 396.

given in columns four and five and those in the last column shows how dangerous it is to use "idealized" conditions in practical problems.

TABLE 1.

χ	$(R_b)\omega$ (Ω)	R_c (Ω)	$\widehat{E}_p(\nu)$			
			Record's method		present method	experimental
			without saturation	with saturation		
0.213	3180	9715	230	200	850	796
0.221	7980	13800	698	1520	960	966
0.339	6160	16550	433	1055	940	922
0.364	4630	13800	400	1064	930	896
0.475	3870	13800	287	568	920	858