APPLICATION BULLETIN

EITEL-McCULLOUGH, INC.

SAN BRUNO, CALIFORNIA

NUMBER 1

CRYSTAL CONTROLLED DIATHERMY

THE APPLICATION OF CRYSTAL CONTROL TO DIATHERMY

The obvious advantages of operating diathermy and r-f heating equipment within the frequency bands recently assigned for this service by the FCC makes the use of crystal control attractive, if economically feasible. This bulletin describes a 400 to 500-watt crystal-controlled diathermy unit employing an Eimac 4-250A tetrode as a power amplifier in the output stage. The unit provides for the necessary frequency stability, control of output, circuit simplicity and safety to both operator and patient. Due to the low driving power requirements of the 4-250A, a minimum of equipment is needed for adequate frequency control. The exciter unit consists mainly of receiving type tubes and small parts. The complete unit is no larger than many existing outmoded self-controlled oscillators serving the same purpose. As the frequency is controlled within a band assigned for diathermy use, shielding is not required to prevent interference with communication services.

CIRCUIT

The circuit (Fig. 5) employs a crystal having a fundamental frequency one-fourth the output frequency of 27.32 Mc. This scheme would be applicable to either of the other two assigned diathermy frequencies, 13.66 Mc. or 40.98 Mc., as crystals having fourth harmonics within this range are available.[1] The oscillator stage employs a 6AG7 operating as a Pierce oscillator in the grid-screen section, and doubling in the plate circuit. This is followed by a 6L6 doubler stage. With approximately 425 volts plate supply for these two tubes, the 6L6 easily delivers adequate grid excitation to the 4-250A.

The plate of the 4-250A is shunt-fed through an r-f choke, to allow d-c grounding of the plate tank circuit, as a safety measure. The maximum plate voltage applied to the 4-250A is 3000 volts. Power is taken from the output circuit via a matching network which allows an efficient transfer of energy for various forms of application. A small pilot lamp inductively coupled to the output leads indicates presence of maximum output to the patient, while a plate-current meter indicates the degree of loading.

The 4-250A does not require neutralization at the frequency on which this unit operates, if reasonable precautions are taken regarding by-passing and shielding. All r-f circuits preceeding the 4-250A have been placed under the chassis, to prevent capacitive coupling around the power amplifier stage. The 6L6 in the doubler stage is of the metal-envelope type, with the envelope grounded via a short lead, to prevent capacitive coupling between the plate of the 4-250A and the plate of the 6L6. The filament and screen by-pass capacitors in the 4-250A stage are returned to ground by short, direct leads.

It has been found that the 4-250A plate circuit, once set for resonance, needs no further adjustment with changes in loading. The plate tank capacitor control might well be placed behind the panel out of immediate reach, as it is not required as an operating control.

A SERVICE OF THE APPLICATION ENGINEERING DEPARTMENT OF EITEL-McCULLOUGH, INC.

PRINTED IN U.S.A.

CONSTRUCTION

A wooden cabinet 16 by 22 by 48 inches houses the equipment. Space is available for the storage of cords and pads in a small cupboard below the control panel. Two chassis 17 by 13 by 3 inches, one for the r-f section, the other for the low and high power supplies, provide ample space for construction. The power supply chassis rests on cleats provided at the base of the unit, while the r-f section is situated behind the control panel to which it is attached. The two units may be removed through the rear of the cabinet, which is normally covered with a single partition. As air cooling of the 4-250A base structure is required, and envelope cooling is advisable, a unique ventilating system has been incorporated in the diathermy unit to provide both types of cooling. A 15 by 20 by 2 inch glass-type dust filter is located in the bottom of the cabinet, below the power supply. Air is drawn by a 6-inch fan through the filter, around the power supply chassis, up behind the storage space, and exhausted through a screened opening six inches in diameter behind the r-f section. The fan is centered in this opening but is attached to the side of the cabinet, allowing easy removal of the rear partition when desired. Air, in passing into the upper section of the cabinet, is also drawn under the r-f chassis and through the socket in sufficient quantity to provide adequate cooling of the 4-250A base structure. The r-f chassis does not completely block the flow of air into the upper section containing the fan and outlet opening, as the entire volume of air is not required to cool the tube base.

CONTROLS

The output to the applicator pads is smoothly controlled by a continuously variable autotransformer in the high voltage transformer primary. Since the 4-250A screen voltage is obtained by means of a series dropping resistor from the plate supply, no separate control is required for screen voltage, and the voltage on the screen due to changes in the loading preliminary to or during treatment is self-regulating to the extent that no adjustment is necessary. The main controls for adjustment to the patient are a time switch as a guard against overdose due to unintentional duration of treatment, the autotransformer power adjustment, and the output load matching control. As a precaution against maladjustment, an overload relay protects the equipment. A reset button for the overload relay is provided on the control panel.

RESULTS

The output has been found to be more than ample for normal therapeutic treatment. In many cases a smaller tube such as the Eimac 4-125A in the amplifier would deliver adequate power, with a resulting saving in the cost of the tube and certain components.

Tests on frequency stability indicate that there is no appreciable change in frequency either from varying load conditions or from drift due to temperature changes. The frequency drift during the first ten minutes from a cold start measured approximately 800 cycles at the output frequency of 27.32 Mc. The frequency shift from changes in loading and power was so slight as to be inconsequential. Stability of this sort is a great improvement over self-controlled oscillator devices, many of which shift frequency violently, often rendering whole bands of communications frequencies completely useless.

---

[1] The sixth harmonic, using the combination of 3X in the 6AG7 and 2X in the 6L6, would lower the crystal frequency still further, if desired and yet provide ample excitation for the 4-250A.

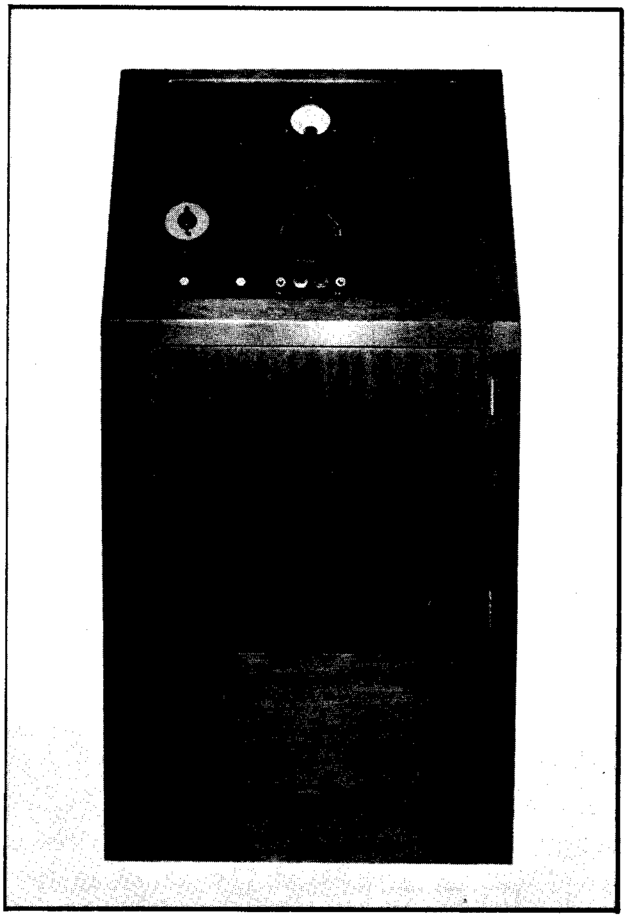


FIG. 1—Front view of the experimental crystal-controlled diathermy unit. Apparatus on the panel includes, autotransformer control, PA plate meter, output tuning control, interval timer, PA plate tuning control, output jacks, output indicator lamp, oscillator and doubler tuning controls (screwdriver adjustment), power switches and pilot lamps.

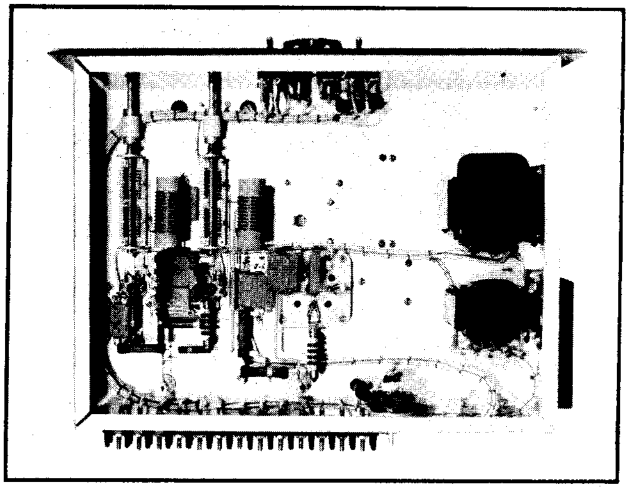


FIG. 4—Bottom view of the r-f section chassis. All r-f circuits preceeding the 4-250A plate circuit are placed under the chassis, to prevent unwanted feedback around the power amplifier stage. Holes in the 4-250A socket allow adequate circulation of air through the tube base, with the aid of the exhaust fan above the chassis.

FIG. 2 Complete r-f section of the diathermy unit. The two tuning capacitors for the output network are visible at the upper left of the panel. One of the capacitors is used as a fixed padding capacitor, the other is adjustable from the front panel.

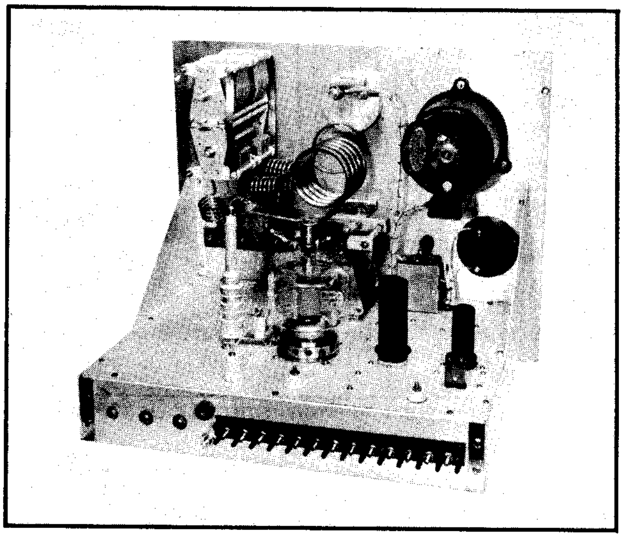
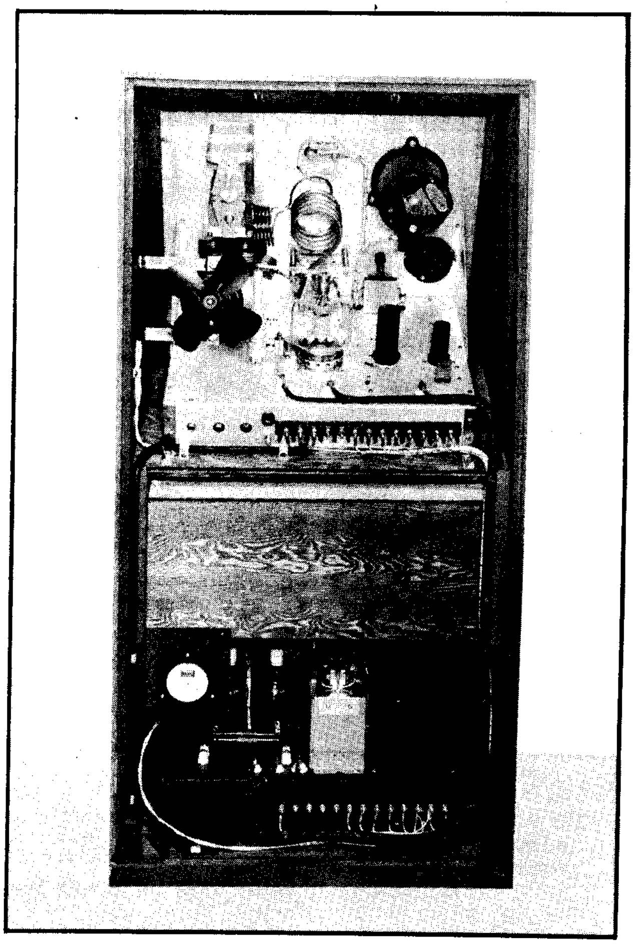
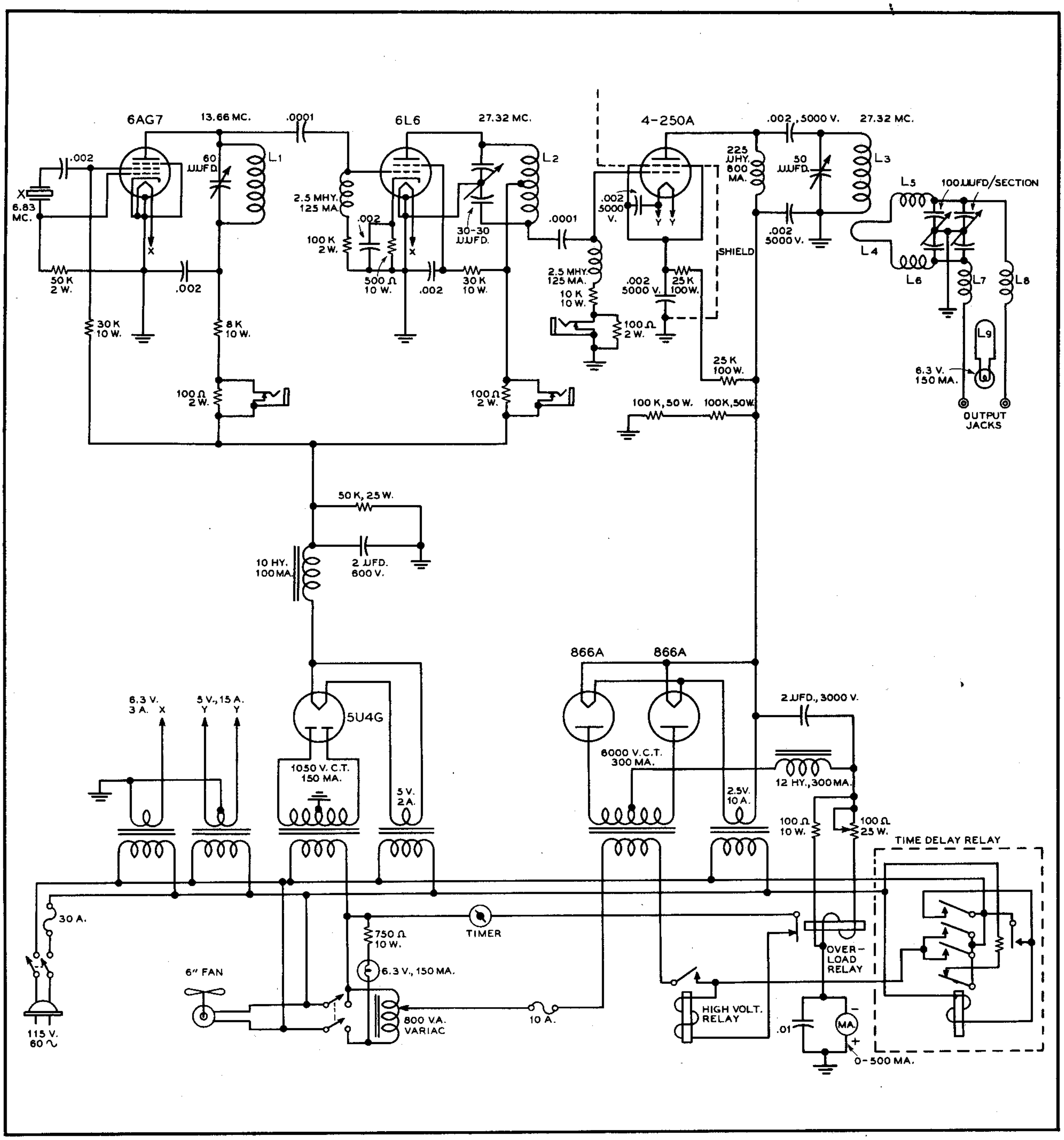


FIG. 3—Rear view of diathermy unit (rear partition removed). Removing the rear partition allows access to exciter-section metering jacks, fuses, and overload relay shunt. Note exhaust fan supported from left side of cabinet.





CIRCUIT DIAGRAM OF THE CRYSTAL CONTROLLED DIATHERMY UNIT

(Figure 5)

APPLICATION BULLETIN

EITEL-McCULLOUGH, INC.

SAN BRUNO, CALIFORNIA

NUMBER 3

PULSE SERVICE NOTES

REVISED 1-19-53

PULSE SERVICE NOTES

In pulse service, where the "on-time" is small compared to the "off-time," Eimac tubes with their ample reserve of filament emission and freedom from internal insulators can be run to a much higher peak-power than is permissible in continuous services. In continuous service, the published voltage and current maxima of Eimac tubes are generally set at values considerably less than the inherent limitations of the design, due to the need to consider the average power dissipated on the anode, grids, and entire tube structure. In pulse service, it is usually reasonable to increase the applied electrode voltages and resulting pulse currents above the maximum values shown for continuous service on the data sheets.

Because of the wide variety of operating conditions in pulse service, it seems advisable to indicate possibilities of tube performance rather than specific operating conditions. It is the user's responsibility to see that no basic limitations of the tubes are exceeded and to introduce factors of safety according to the needs of the particular application.

The principal basic limitations of the tube are given below:

1. **Average Electrode Dissipation.** The dissipation limits of the electrodes are given on the tube data sheet and usually under Radio Frequency Power Amplifier or Oscillator Service. The dissipation must be average over a full repeated pulse cycle. The length of the applied pulse must not be so great that the temperature rises excessively on any one pulse. Pulse times as high as 0.1 second are often not unreasonable. Above about 0.1 seconds the rise in temperature of the electrodes rather than the average power during the pulse becomes the basic limitation and this type of service is discussed under Item 5, "Long Pulse Operation."

   Usually, the average electrode dissipation is the product of the dissipation on the element during the on-time, multiplied by the duty cycle (ratio of on-time to a full cycle time). This assumes that the pulse is essentially a square wave. The dissipation may be considerably greater if intermediate values of current between zero and the maximum value flow for appreciable time. Sometimes uneven heating of an element may be a further limitation. In the case of a radiation-cooled anode, this effect is apparent and the temperature of the hottest spot should not be allowed to exceed the normal maximum anode temperature.
2. **Envelope and Seal Temperatures.** The temperature requirements of the bulb and seals will be met if the ordinary cooling instructions are followed. In continuous radio frequency service, a limiting upper frequency is usually specified above which operation at reduced ratings or increased cooling is recommended. In pulse service above this frequency, care should be taken to see that the heating of the leads due to rf charging currents will not be greater than normal.
3. **Available Cathode Emission.** In continuous service, the tube currents are usually limited by dissipation of the electrodes and for convenience are given in terms of dc components read on a meter external to the tube. In pulse service, one needs to know the available total cathode emission in order to engineer the application.

   With thoriated tungsten filaments operating at rated voltage in Eimac tubes, the available emission throughout life is above 80 milliamperes per watt of filament power. By raising the filament voltage 10%, this figure can be approximately doubled. Above 10%, the emission will not be further increased, except for short periods of time due to the failure to maintain the optimum emitting surface conditions.

   With oxide coated cathodes, the available peak emission is not clearly defined or as easily generalized as in the case of thoriated tungsten fila-

PRINTED IN U.S.A.

When, in 1936, government engineers first tried Eimac tubes as pulsed oscillators, radar became a reality in the United States. The ability of standard Eimac tube types to withstand voltages many times in excess of their maximum CW ratings and to deliver high orders of emission current over relatively long periods of time made possible the attainment of the high peak power required for a practical radar system.

Throughout the years since 1936, the development of improved pulse equipment has been paced by new Eimac tubes and the continual improvement of existing types for better and more reliable operation under pulsed conditions.

Important milestones in the use of Eimac tubes in pulse service are:

> **Eimac 100T tubes used as pulsed VHF oscillators in the Navy's first radar tests at sea aboard the USS New York in 1938.**
>
> **Eimac VT-127's, a modification of the 100T used as oscillators and Eimac 304T's used as modulators in the SCR-268, one of the Army's first radar sets.**
>
> **Eimac 15E and 15R miniature transmitting tubes developed for and used as pulsed oscillators and high voltage rectifiers in ASB airborn search radar.**
>
> **Eimac 327A and 227A tubes developed for use as pulsed oscillators in Navy search radar sets of the SC and SK series.**
>
> **Eimac 527 tube developed for and used in SK-1M and SR radar for high-power search.**
>
> **Eimac 1000T, later modified for mass production and designated 6C21, used as modulator for the Armys famous SCR-584 radar.**

During World War II Eimac produced nearly 2 million tubes of its own design for pulse service. In the process of developing and producing these tubes Eimac has gained "know how" about the pulse operation of tubes which is unequaled in the vacuum tube industry. This knowledge has made it possible to develop new tubes having outstanding characteristics for pulse operation. Among these tubes are oscillators and amplifiers capable of delivering pulse powers from a few tens of kilowatts to megawatts and modulators which will key currents from a few amperes to hundreds of amperes.

Years of experience have been gained regarding the pulse capabilities of standard Eimac types. Some of this information is presented on the following pages. However, many pulse applications are so specialized in nature that they do not lend themselves to general rules or tabular presentation. If your problem is of this sort, avail yourself of the services of the Eimac Field Engineering Department.

ments. It appears that the available emission for pulse work in typical oxide coated cathodes used in Eimac tubes can conservatively be estimated as 500 ma. per watt of heater power. This figure assumes that the pulse duration is not over about 3 micro-seconds. There is some evidence that above 3 micro-seconds, the maximum usable space current may have to be reduced.

4. VOLTAGE INSULATION. The breakdown voltage of Eimac tubes is usually well above the values given for continuous service. The basic limit is related to the maximum instantaneous voltage applied to the anode of the tube at any instant. It is also somewhat affected by the regulation of the supply voltage and length of time the voltage is applied. The accompanying table is a rough guide to the values of dc anode voltage that can be applied to the tube.

5. LONG PULSE OPERATION. When the length of the applied pulse exceeds about 0.1 seconds (100 milliseconds) the power limitation is no longer the average power dissipated on the electrodes and one must consider the temperature rise of the electrodes (principally the grid wires) during the time the pulse is on. If the pulse duration is in excess of 2.5 seconds the tube must be treated as in continuous service and the normal data sheet ratings apply.

   The maximum capabilities of a thoriated tungsten tube in pulse service when the pulse duration is between 0.1 seconds and 2.5 seconds can be computed by using the accompanying curve and table.

   As long as the off-time between pulses is 5 seconds or more the pulse may be repeated even though the maximum tube capability for a given pulse length is utilized. Because the grid dissipation is the principal limitation, the curve and table give factors to compute the permissible grid dissipation during the pulse. The product of the two factors is the number of times the rated grid dissipation can be exceeded for a given pulse duration. The factor from the curve is to be used directly for the plate and screen dissipation.

When first running up the voltage on a tube in pulse service, or after the tube has been idle for some time occasional internal flash breakdowns in a tube are to be expected. The circuit should be designed so that the high rush of current and resulting high transient voltage surges will not be destructive to equipment. The transients, due to momentary breakdown of the insulation of the vacuum space, have very high frequency components. As a consequence, high voltages will develop across small lead inductances. Spark gaps, bypass capacitors and inductance filters are often used to dissipate or divert this energy into harmless channels.

Protective devices should be designed to remove the applied voltage quickly when a breakdown occurs. If overload protective action is fast, and the regulation of the source voltage poor enough, no damage to the tube will result and operation can be resumed.

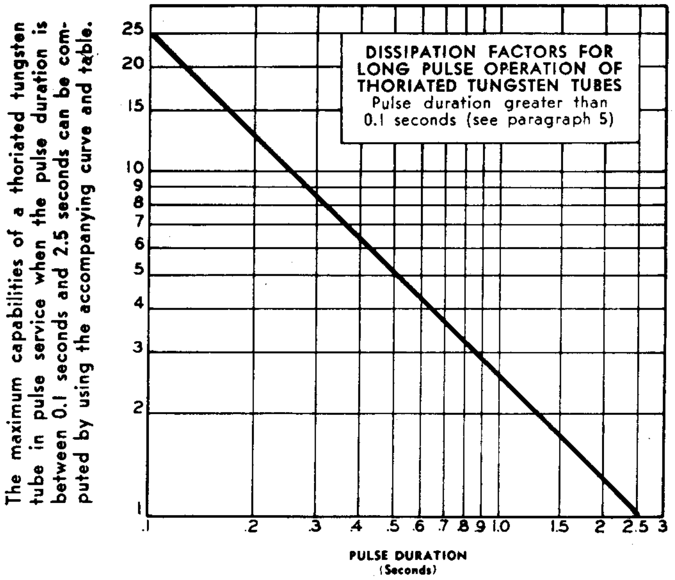
No guarantee is made that the tube will not break down at the voltages given on the chart. It is estimated from considerable experience that these are approximately safe maximum values to be considered in design work.

▶Indicates Revision

MAXIMUM RATINGS FOR PULSED SERVICE

Tube Type	MAXIMUM PLATE VOLTAGE RF Service Plate Pulsed Kilovolts	MAXIMUM PLATE VOLTAGE RF Service Grid Pulsed Kilovolts	MAXIMUM PLATE VOLTAGE Pulse Modulator Service Kilovolts	Max. Screen Voltage Kilovolts	Grid Factor Long Pulse Operation*
▶ 2C39A	3.5	....	....	....	....
3C24	10	7.5	15	....	.68
3X2500A3	15	10	25	....	.68
3X2500F3	15	10	25	....	.68
▶ 3W5000A3	15	10	25	....	.68
▶ 3W5000F3	15	10	25	....	.68
4E27A/5-125B	12	9	18	2.0	1.68
4-65A	10	7.5	15	2.0	.57
4-125A	12	9	18	2.0	1.87
4-250A	15	10	20	2.5	2.7
4-400A	15	10	20	2.5	2.7
4-1000A	20	15	30	2.5	1.54
4PR60A	....	....	20	1.5	....
4X150A	2	....	3	1.0	....
▶ 4X150D	2	....	3	1.0	....
4X150G	2	....	3	1.0	....
4X500A	10	7.5	15	2.0	.95
4X500F	10	7.5	15	2.0	.95
6C21	20	15	30	....	....
15E	12.5	10	15	....	....
25T	10	7.5	15	....	.77
35T	10	7.5	15	....	.84
35TG	10	7.5	15	....	.84
UH-50	5	4	7.5	....	....
75TH	12	9	17	....	.67
75TL	12	9	17	....	.62
100TH	15	10	20	....	1.01
100TL	15	10	20	....	1.11
152TH	12	9	18	....	.71
152TL	12	9	18	....	.65
250TH	18	15	25	....	1.03
250TL	18	15	25	....	.89
304TH	12	9	18	....	.71
304TL	12	9	18	....	.65
327A	20	15	30	....	....
450TH	20	15	30	....	1.09
450TL	20	15	30	....	1.0
527	20	18	30	....	....
592/3-200A3	18	15	25	....	.80
750TL	20	15	30	....	1.09
1000T	20	15	30	....	1.1
1500T	20	15	30	....	1.61
2000T	20	15	30	....	1.8

*Combine with factor taken from curve for various pulse duration times.



PULSE

Eimac
TUBES

APPLICATION BULLETIN

EITEL-McCULLOUGH, INC.

SAN BRUNO, CALIFORNIA

NUMBER 4

CLASS C AMPLIFIER CALCULATIONS

CLASS C AMPLIFIER CALCULATIONS WITH THE AID OF CONSTANT CURRENT CHARACTERISTICS

In calculating and predicting the operation of a vacuum tube as a class-C radio frequency amplifier, the considerations which determine the operating conditions are plate efficiency, power output required, maximum allowable grid and plate dissipation, maximum allowable plate voltage and maximum allowable plate current. The values chosen for these factors will depend both on the demands of a particular application and the tube selected to do the job.

The plate and grid currents of a class-C amplifier are periodic pulses, the durations of which are always less than 180 degrees. For this reason the average plate and grid currents, power output, driving power, etc., cannot be directly calculated but must be determined by a Fourier analysis from points selected along the line of operation as plotted on the constant-current characteristics. This may be done either analytically or graphically. While the Fourier analysis has the advantage of accuracy, it also has the disadvantage of being tedious and involved.

An approximate analysis which has proven to be sufficiently accurate for most purposes is presented in the following material. This system has the advantage of giving the desired information at the first trial. The system, which is an adaption of a method developed by Wagener[1], is direct because the important factors, power output, plate efficiency and plate voltage may be arbitrarily selected at the beginning.

In the material which follows, the following set of symbols will be used. These symbols are illustrated graphically in Figure 1.

Symbols

P_i = Plate power input
P_o = Plate power output
P_p = Plate dissipation
n = Plate efficiency expressed as a decimal
E_{bb} = D-c plate supply voltage
E_{pm} = Peak fundamental plate voltage
e_{bmin} = Minimum instantaneous plate votage
I_b = Average plate current
I_{pm} = Peak fundamental plate current
i_{bmax} = Maximum instantaneous plate current
θ_p = One-half angle of plate current flow
E_{cc} = D-c grid bias voltage (a negative quantity)
▶ E_{c2} = D-c screen voltage
E_{gm} = Peak fundamental grid excitation voltage
e_{cmp} = Maximum positive instantaneous grid voltage
I_c = Average grid current
i_{cmax} = Maximum instantaneous grid current
P_d = Grid driving power (including both grid and bias losses)
P_g = Grid dissipation
▶ μ = Amplification factor of triode
μ_{12} = Grid-screen amplification factor of tetrode

Method

The first step in the use of the system to be described is to determine the power which must be delivered by the class-C amplifier. In making this determination it is well to remember that ordinarily from 5 to 10 per cent of the power delivered by the amplifier tube or tubes will be lost in well-designed tank and coupling circuits at frequencies below 20 Mc. Above 20 Mc. the tank and coupling circuit losses are ordinarily somewhat above 10 per cent.

The plate power input necessary to produce the required output is determined by the plate efficiency:

$$P_i = \frac{P_o}{n}$$

For most applications it is desirable to operate at the highest possible efficiency. High-efficiency operation usually requires less expensive tubes and power supplies, and the amount of artificial cooling needed is frequently less than for low-efficiency operation. On the other hand, high-efficiency operation often requires more driving power and higher ▶ operating plate voltages. Eimac triodes and tetrodes will operate satisfactorily at 80 per cent efficiency at the highest recommended plate voltages and at 75 per cent efficiency at medium plate voltages.

The first determining factor in selecting a tube or tubes for any particular application is the maximum allowable plate dissipation. The total plate dissipation rating for the number of tubes used must be equal to or greater than that calculated from

$$P_p = P_i - P_o$$

After selecting a tube or tubes to meet the power output and plate dissipation requirements it becomes necessary to determine from the tube characteristics whether the tube selected is capable of the required operation and, if so, to determine the driving power, grid bias and grid current.

---

[1] W. G. Wagener "Simplified Methods for Computing Performance of Transmitting Tubes," Proc. I.R.E., Vol. 25, p. 47, (Jan. 1937).

(Reprinted from the Eimac News Industrial Edition, March 1945)

▶ Indicates Revision 11-10-49

PRINTED IN U.S.A.

The complete procedure necessary to determine the class-C-amplifier operating conditions is as follows[2]:

1. Select plate voltage, power output and efficiency.
2. Determine plate input from

$$P_i = \frac{P_o}{n}$$

3. Determine plate dissipation from

$$P_p = P_i - P_o$$

P_p must not exceed maximum rated plate dissipation for tube or tubes selected.

4. Determine average plate current from

$$I_b = \frac{P_i}{E_{bb}}$$

I_b must not exceed maximum rated plate current for tube selected.

5. Determine approximate i_{bmax} from

$$i_{bmax} = 4.5\ I_b \text{ for } n = 0.80$$
$$i_{bmax} = 4.0\ I_b \text{ for } n = 0.75$$
$$i_{bmax} = 3.5\ I_b \text{ for } n = 0.70$$

6. Locate the point on constant-current characteristics where the constant plate current line corresponding to the approximate i_{bmax} determined in step 5 crosses the line of equal plate and grid voltages ("diode line") ▶ in the case of triodes; or in the case of tetrodes where the plate current line turns rapidly upward.
Read e_{bmin} at this point.[3]
7. Calculate E_{pm} from

$$E_{pm} = E_{bb} - e_{bmin}$$

8. Calculate the ratio $\frac{I_{pm}}{I_b}$ from

$$\frac{I_{pm}}{I_b} = \frac{2n\ E_{bb}}{E_{pm}}$$

9. From the ratio of $\frac{I_{pm}}{I_b}$ calculated in step 8 determine the ratio $\frac{i_{bmax}}{I_b}$ from Chart 1.
10. Calculate a new value for i_{bmax} from ratio found in step 9.

$$i_{bmax} = (\text{ratio from step 9})\ I_b$$

11. Read e_{cmp} and i_{cmax} from constant current characteristics for values of e_{bmin} and i_{bmax} determined in steps 6 and 10.
12. Calculate the cosine of one-half the angle of plate current flow from

$$\cos\theta_p = 2.3\left(\frac{I_{pm}}{I_b} - 1.57\right) \quad [4]$$

13. Calculate the grid bias voltage from

$$E_{cc} = \frac{1}{1 - \cos\theta_p}\left[\cos\theta_p\left(\frac{E_{pm}}{\mu} - e_{cmp}\right) - \frac{E_{bb}}{\mu}\right], \text{ for triodes;}$$

▶ or $$E_{cc} = \frac{1}{1 - \cos\theta_p}\left[- e_{cmp}\cos\theta_p - \frac{E_{c2}}{\mu_{12}}\right], \text{ for tetrodes.}$$

14. Calculate the peak fundamental grid excitation voltage from

$$E_{gm} = e_{cmp} - E_{cc}$$

15. Calculate the ratio $\frac{E_{gm}}{E_{cc}}$ for values of E_{cc} and E_{gm} found in steps 13 and 14.
16. Read ratio $\frac{i_{cmax}}{I_c}$ from Chart 2 for ratio $\frac{E_{gm}}{E_{cc}}$ found in step 15.
17. Calculate average grid current from ratio found in step 16 and value of i_{cmax} found in step 11.

$$I_c = \frac{i_{cmax}}{\text{ratio from step 16}}$$

18. Calculate approximate grid driving power from

$$P_d = 0.9\ E_{gm} I_c \quad [5]$$

19. Determine grid dissipation from

$$P_g = P_d + E_{cc} I_c$$

P_g must not exceed the maximum rated grid dissipation for the tube selected.

Example

A typical application of this procedure is shown in the example below.

1. Desired power output.............. 1250 watts
Desired plate voltage.............. 4000 volts
Desired plate efficiency.......... 75 per cent (n=0.75)

2. $$P_i = \frac{1250}{0.75} = 1670 \text{ watts}$$

3. $$P_p = 1670 - 1250 = 420 \text{ watts}$$

Try type 450TL; Max. P_p=450W; μ =18

4. $$I_b = \frac{1670}{4000} = 0.417 \text{ ampere}$$

(Max. I_b for 450TL=0.600 ampere)

5. Approximate $i_{bmax} = 4.0 \times 0.417 = 1.67$ ampere

6. $$e_{bmin} = 315 \text{ volts (see figure 2)}$$

7. $$E_{pm} = 4000 - 315 = 3685 \text{ volts}$$

8. $$\frac{I_{pm}}{I_b} = \frac{2 \times 0.75 \times 4000}{3685} = 1.63$$

9. $$\frac{i_{bmax}}{I_b} = 3.45 \text{ (from Chart 1)}$$

10. $$i_{bmax} = 3.45 \times 0.417 = 1.44 \text{ amperes}$$

11. $$e_{cmp} = 280 \text{ volts}$$

$$i_{cmax} = 0.330 \text{ amperes}$$

(see figure 3)

12. $$\cos\theta_p = 2.32\ (1.63 - 1.57) = 0.139$$

13. $$E_{cc} = \frac{1}{1 - 0.139}\left[0.139\left(\frac{3685}{18} - 280\right) - \frac{4000}{18}\right]$$

$$= -270 \text{ volts}$$

14. $$E_{gm} = 280 - (-270) = 550 \text{ volts}$$

15. $$\frac{E_{gm}}{E_{cc}} = \frac{550}{-270} = -2.04$$

16. $$\frac{i_{cmax}}{I_c} = 5.69 \text{ (from Chart 2)}$$

17. $$I_c = \frac{0.330}{5.69} = 0.058 \text{ amperes}$$

18. $$P_d = 0.9 \times 550 \times 0.058 = 28.7 \text{ watts}$$

19. $$P_g = 28.7 + (-270 \times 0.058) = 13.0 \text{ watts}$$

(Max P_g for 450TL=65 watts)[6]

---

[2] In the case of push-pull or parallel amplifier tubes the analysis should be carried out on the basis of a single tube, dividing P_i, P_o and P_p by the number of tubes before starting the analysis and multiplying I_b, I_c and P_d by the same factor after completing the analysis.

▶ Indicates Revision 11-10-49

[3] In a few cases the lines of constant plate current will inflect sharply upward before reaching the diode line. In these cases e_{bmin} should not be read at the diode line but at the point where the plate current line intersects a line drawn from the origin through these points of inflection.

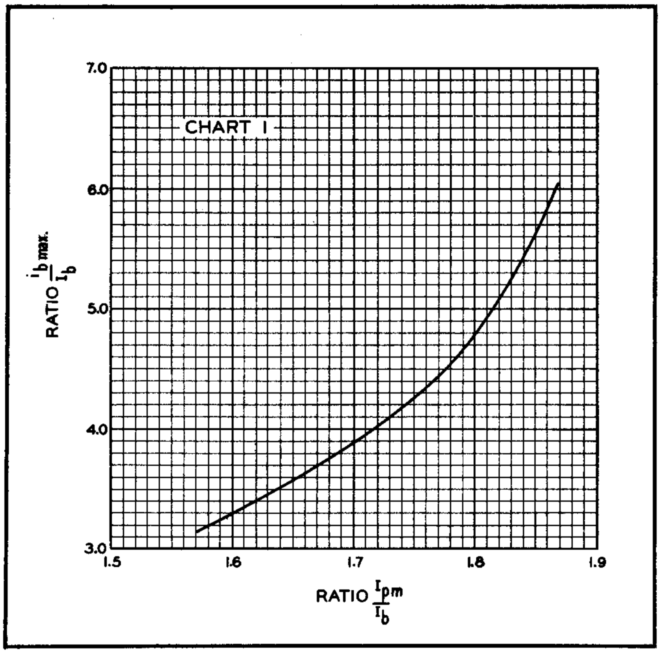


Chart 1

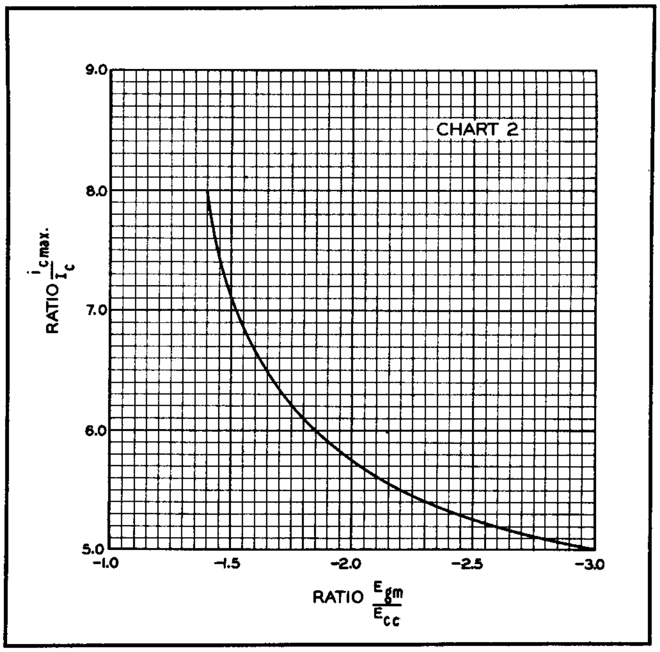


Chart 2

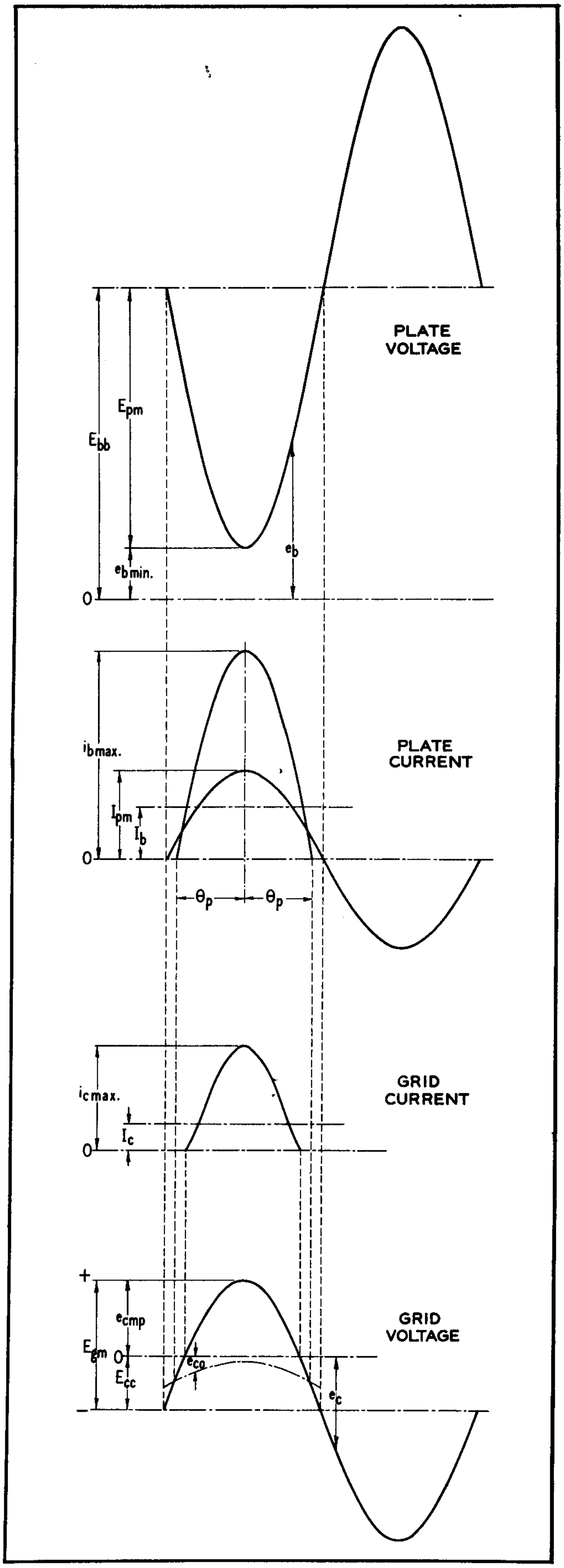


Figure 1. Symbols

---

[4] If this calculation gives Cos θ_p as zero or a negative quantity class-B operation is indicated and new operating conditions should be chosen on a basis of higher efficiency (less plate dissipation, more power output or less power input).

[5] The calculated driving power is that actually used in supplying the grid and bias losses. Suitable allowance in driver design must be made to allow for losses in the coupling circuits between the driver plate and the amplifier grid.

[6] "Vacuum Tube Ratings" Eimac News, Industrial Edition, Jan. 1945.

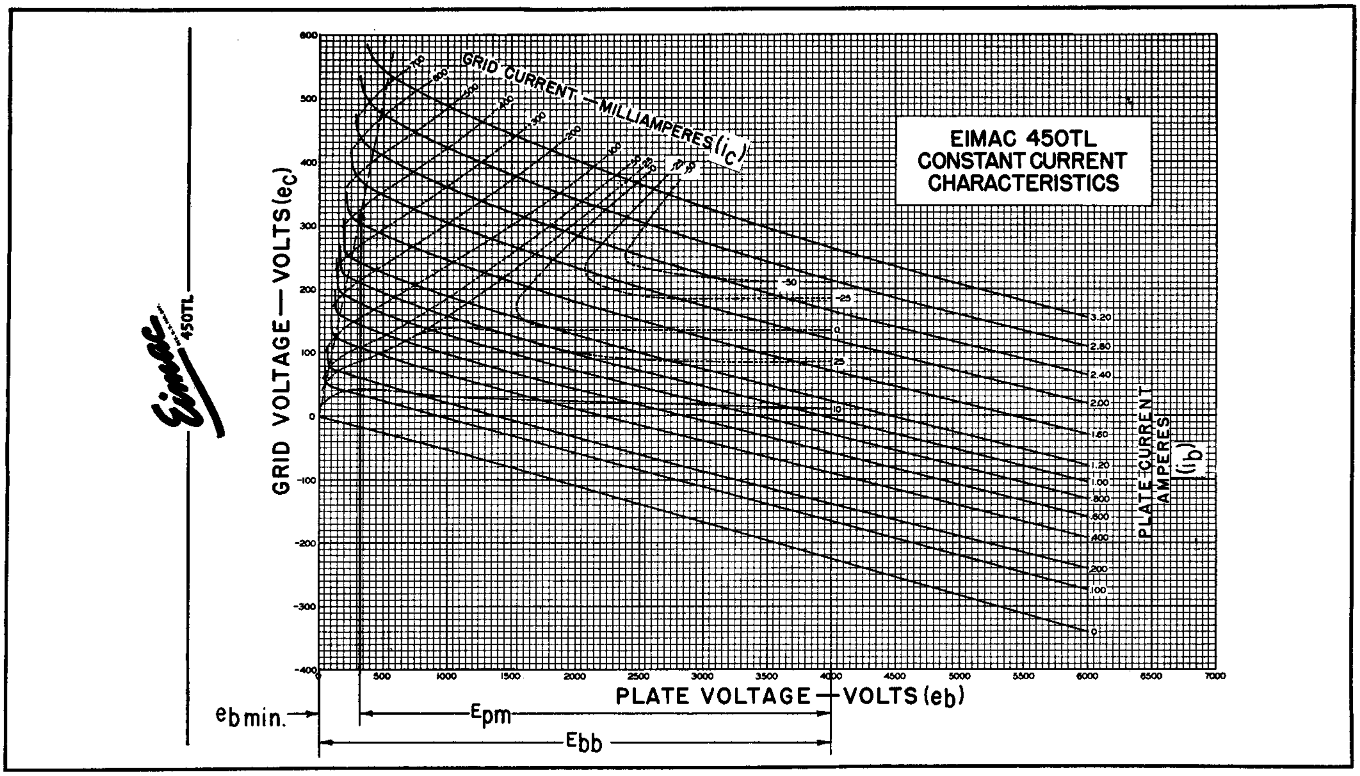


Figure 2. 450TL constant-current characteristics showing method of determining e_{bmin} and E_{pm} in steps 6 and 7 from value of i_b obtained in step 5.

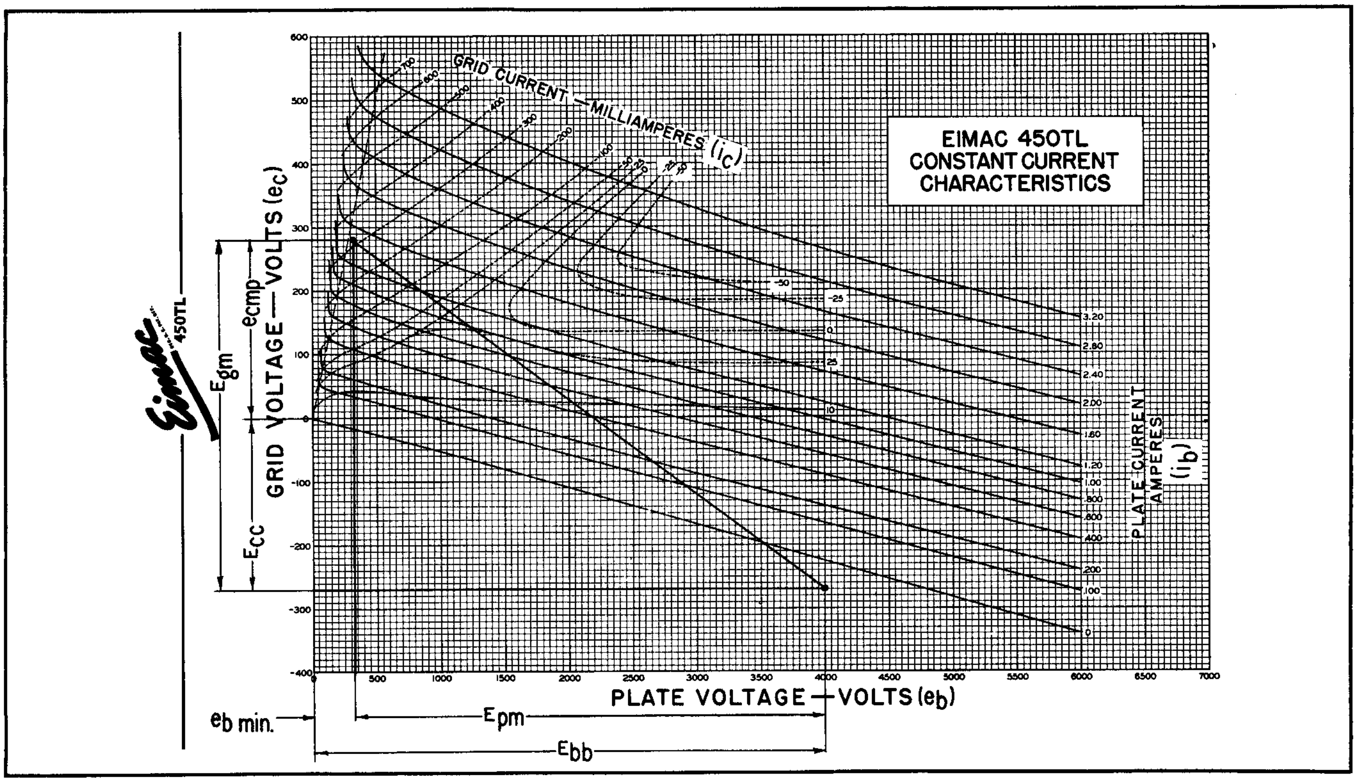


Figure 3. Method of determining e_{cmp} and i_c on 450TL constant-current characteristics from values of e_{bmin} and E_{pm} found in steps 6 and 7 and value of i_b found in step 10. The value of E_{cc} and E_{gm} from steps 13 and 14 and the operating line are also shown.

APPLICATION BULLETIN
EITEL-McCULLOUGH, INC.
SAN BRUNO, CALIFORNIA

NUMBER 5

TUBE PERFORMANCE COMPUTOR

DETAILED INSTRUCTIONS

TUBE PERFORMANCE COMPUTOR FOR RF AMPLIFIERS (CLASS B, C, AND FREQUENCY MULTIPLIERS)

It is quite easy to make a close estimate of the performance of a vacuum tube in radio frequency power amplifier service, or an approximation in the case of harmonic amplifier service. Such estimates will give RF output power, DC input power, grid driving power and all DC current values.

These estimates can be made easily by using the Eimac Tube Performance Computor and the characteristic curves of a tube, plotted on plate voltage/grid voltage curves (constant current curves). Only the ability to multiply out figures taken from the curves by means of the computor is required.

By graphically laying out the trace of the plate and grid voltages as they rise and fall about the applied DC plate voltage and DC grid bias a clearer understanding is possible of the action taking place within a tube. With such an understanding the operating conditions can be altered readily to suit one's particular requirements.

Simple Action in Class C RF Amplifiers

In an amplifier a varying voltage is applied to the control grid of the tube. Simultaneously the plate voltage will vary in a similar manner, due to the action of the amplified current flowing in the plate circuit. In radio frequency applications with resonant circuits these voltage variations are smooth sine wave variations, 180° out of phase (as the grid voltage rises and becomes *more* positive, the plate voltage falls and becomes *less* positive) as indicated in Fig. 1. Note how these variations center about the DC plate voltage and the DC control grid bias.

Let us now see how such variations of the plate and grid voltages of a tube appear on the constant current curve sheet of a tube. In Fig. 2 these variations have been indicated next to the plate voltage and grid voltage scales of a typical constant current curve. At some instant of time, shown as "t" on the time scales, the grid voltage has a value which is the point marked "eg" on the grid voltage sine wave. At this same instant of time the plate voltage has a value which is the point "ep" marked on the plate voltage sine wave. If now one finds the point on the tube curve sheet corresponding to these values (where a line drawn from "eg" and a line drawn from "ep" cross) he will be at point A in Fig. 2. As the values of grid voltage "eg" and plate voltage "ep" vary over the RF cycle, the point A moves up and down a line, which in the case of the normal RF power amplifier is a straight line. This line is called the "Operating Line."

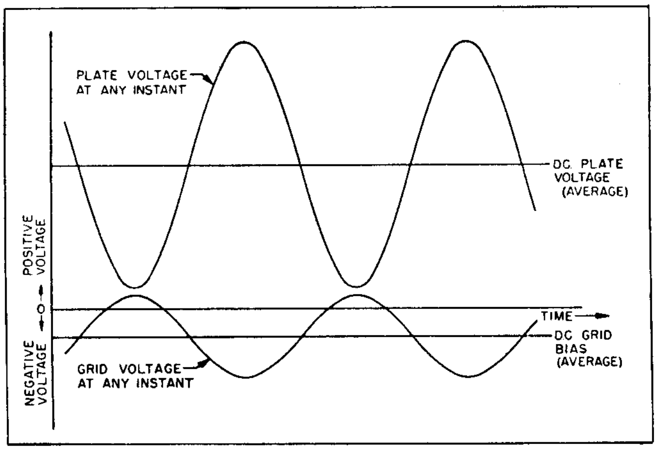


Figure 1

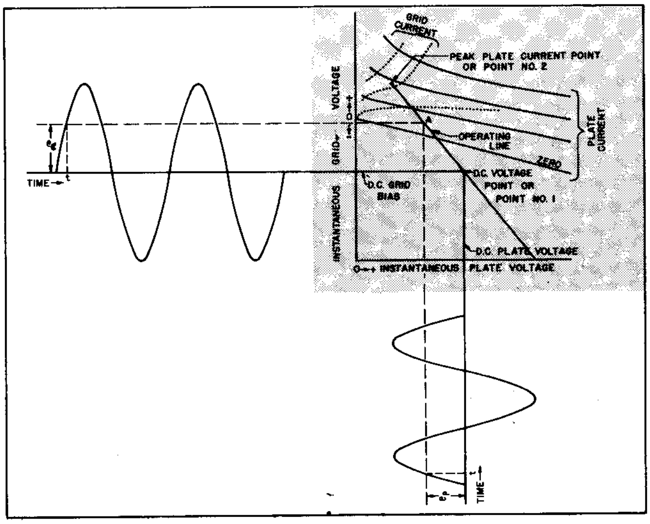


Figure 2

Any point on the operating line (when drawn on a curve sheet as in Fig. 2 or Fig. 4) tells the instantaneous values of plate current, screen current, and grid current which must flow when those particular values of grid and plate voltage are applied to the tube. Thus by reading off the values of the currents and plotting them against the time, t, one can obtain a curve of instantaneous values of plate and grid current. See Fig. 3.

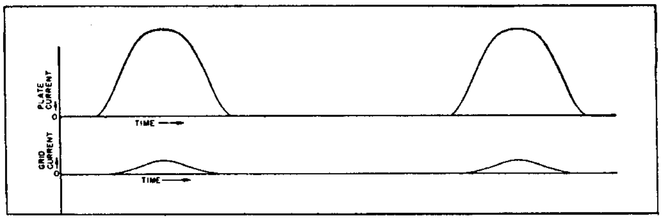


Figure 3

If we analyze the plate and grid current values shown, we can predict that they will cause a DC ammeter to show a particular reading. This is called the DC component of the current. Also, we can predict that if the plate current flows through a properly loaded resonant RF circuit a certain amount of radio frequency power will be delivered to that circuit. If the circuit is tuned to the fundamental frequency (same frequency as the RF grid voltage) the power delivered will be due to the fundamental (or principle radio frequency) component of plate current. If the circuit is tuned to a harmonic of the grid voltage frequency (for instance, two, or three times the frequency) the power delivered will be due to a harmonic component of the plate current.

The Eimac Tube Performance Computor gives us the means to make these simple calculations. It is a means with which to determine the DC component, the fundamental RF component, or the approximate harmonic component of the current flowing in a tube when the tube is operating as a radio frequency amplifier, and enables one to state what all meter readings will be and to predict the RF output power and the required driving power. With these factors known we are then able also to forecast what will happen if any of the operating conditions are changed.

Use of the Eimac Tube Performance Computor

The Eimac Tube Performance Computor is a simple aid to enable one to select suitable values from the characteristic curves of a tube, and by means of simple calculations to forecast the performance of the tube in radio frequency power amplifiers.

The basic steps are outlined under "Instructions" on the computor. This requires selecting DC plate and grid bias voltages, being guided by the typical operating values given on the technical data sheet for the tube type and by general experience. Next, a suitable "Operating Line" must be chosen on the constant current curves for the tube type (plotted on grid voltage/plate voltage scales).

The computor when properly placed over this operating line enables one to obtain instantaneous values of the currents flowing at every 15° of the electrical cycle. The formulas given on the computor were derived by Chaffee[1] to give the various average and harmonic components of the resulting currents. Knowing these current component values and the radio frequency voltage values which are indicated by the use of the computor, one can readily calculate the complete performance of the tube.

The fundamental methods of making such computations, and the considerations necessary to stay within ratings of the tube types, and accomplish various forms of modulation have been covered in the literature.[2,3,4,5,6,7] The method for the case of harmonic amplifier service is approximate and should be used only for tetrode and pentode tubes, where the plate voltage has little effect on the amount of plate current flowing. A more exact method, showing that for harmonic operation the operating line is a simple Lissajou figure, has been described by Brown.[8]

The results of using this computor for power amplifier service can be applied in combination with the other methods given in the literature to give good accuracy with simpler procedues. The resulting accuracy is well within the normal variation of tube characteristics due to the normal variation in manufacturing dimensions of a tube. Since the published tube curves are only typical of the characteristics to be expected from a particular tube type, the calculated performance is well within the values expected when different tubes of a given tube type are operated under the assumed conditions.

Example Showing Detailed Use of the Eimac Tube Performance Computor

Radio Frequency Power Amplifier, Class C (Telegraphy or FM)

Let us say we have an Eimac 4-65A tetrode and want to make it work effectively. Also let us say we have a 2000 volt DC plate power supply available.

Within frequency limits, we know a tube should be able to run in class-C amplifier service with about 75% efficiency, or, in other words, to convert 75% of the DC plate input power into RF output power. The difference, or 25% of the input power, is dissipated or lost as heat on the plate of the tube. The DC plate input power is then about four times the power dissipated on the plate.

The 4-65A tetrode has a maximum rated plate dissipation of 65 watts, so, to illustrate performance near the maximum rating, we'll choose an input power four times the plate dissipation, or 260 watts per tube. At 2000 volts the plate current per tube must then be 130 ma. It is usual practice, in the case of tetrodes and the medium or low mu triodes in class-C amplifier service for the DC grid bias voltage to be roughly two or three times the grid voltage necessary to cut off the flow of plate current. By referring to the curves of the 4-65A we decide to use a DC grid bias voltage of—120 volts.

Let us now locate the "Operating Line" on the constant current curves of the 4-65A. See Fig. 4. First mark the point where the DC grid bias and DC plate voltage cross. The "Operating Line" must go through this point. Call it point No. 1. Next, we must decide what the peak value of plate current of the tube must be and how low we can let the instantaneous value of plate voltage go when the tube is passing this much current. This is necessary in order to locate the other end of the "Operating Line," point No. 2.

The peak value of plate current usually runs about four times the DC plate current. The minimum value of instantaneous plate voltage is usually set by the fact that if the voltage is too low the grid and screen currents will be needlessly high, and also little will be gained as far as output power is concerned. The minimum value of plate voltage is usually in the region where the plate constant current curves bend upward. See Fig.

4. (In the case of the triode this is near the "diode line" or line where the instantaneous grid and plate voltages are equal.) The practical procedure in calculating tube performance is to arbitrarily choose point No. 2 and complete the calculations. Then try other locations of point No. 2, complete the calculations, and compare the results.

In the case of the 4-65A let us choose a peak value of plate current about four times the DC plate current of 130 ma, or 500 ma. Let us choose a minimum instantaneous plate voltage of 250 volts and thus fix the upper end of the "Operating Line." Next, locate this point on the tube curves. This is point No. 2 on Fig. 4. (The plate currents which flow at various combinations of plate and grid voltages are shown by the plate current lines. The value of current for each line is noted. In-between values can be estimated closely enough for our purposes.) Now draw a straight line between points No. 1 and No. 2. This line is the "Operating Line" and shows the current and voltage values for each part of the RF cycle when current is being taken from the tube. (The non-conducting half of the RF cycle would be shown by extending this line an equal distance on the opposite side of point No. 1. However, there is little use in so doing because no current flows during this half of the cycle.)

The Eimac Tube Performance Computor can now be used to obtain the meter readings and power values from this "Operating Line." Place the computor on the constant current curve sheet so that the "guide lines" of the computor are parallel with the operating line. Now slide the computor about without turning it until the line OG passes through the DC voltage point No. 1 and line OA passes through the peak current point No. 2. *Make sure the guide lines are still parallel to the "Operating Line."*

Note that the lines OB, OC, OD, OE and OF of the computor all cross over the "Operating Line."

At each point where the lines OA, OB, etc., cross the "Operating Line" we need to determine the instantaneous values of plate current and grid current (and screen current if a tetrode or pentode is used) which is flowing at that particular moment in the RF cycle. Later, from these key values of current, we will calculate the values of DC plate current and grid current (and screen current) as well as the RF components of the plate current.

At each of these points, where the instantaneous current values are to be determined, a mark should be made on the constant current curve sheet of the tube. By noting where this mark lies with respect to the plate current curves, one can estimate the value of plate current flowing at this part of the cycle. Next, the location of this mark with respect to the control grid curves is noted and a value of grid current is estimated. Finally, by referring the mark to the screen grid curves, if the tube is a tetrode or pentode, a value of screen current is noted. These current values should be listed for each

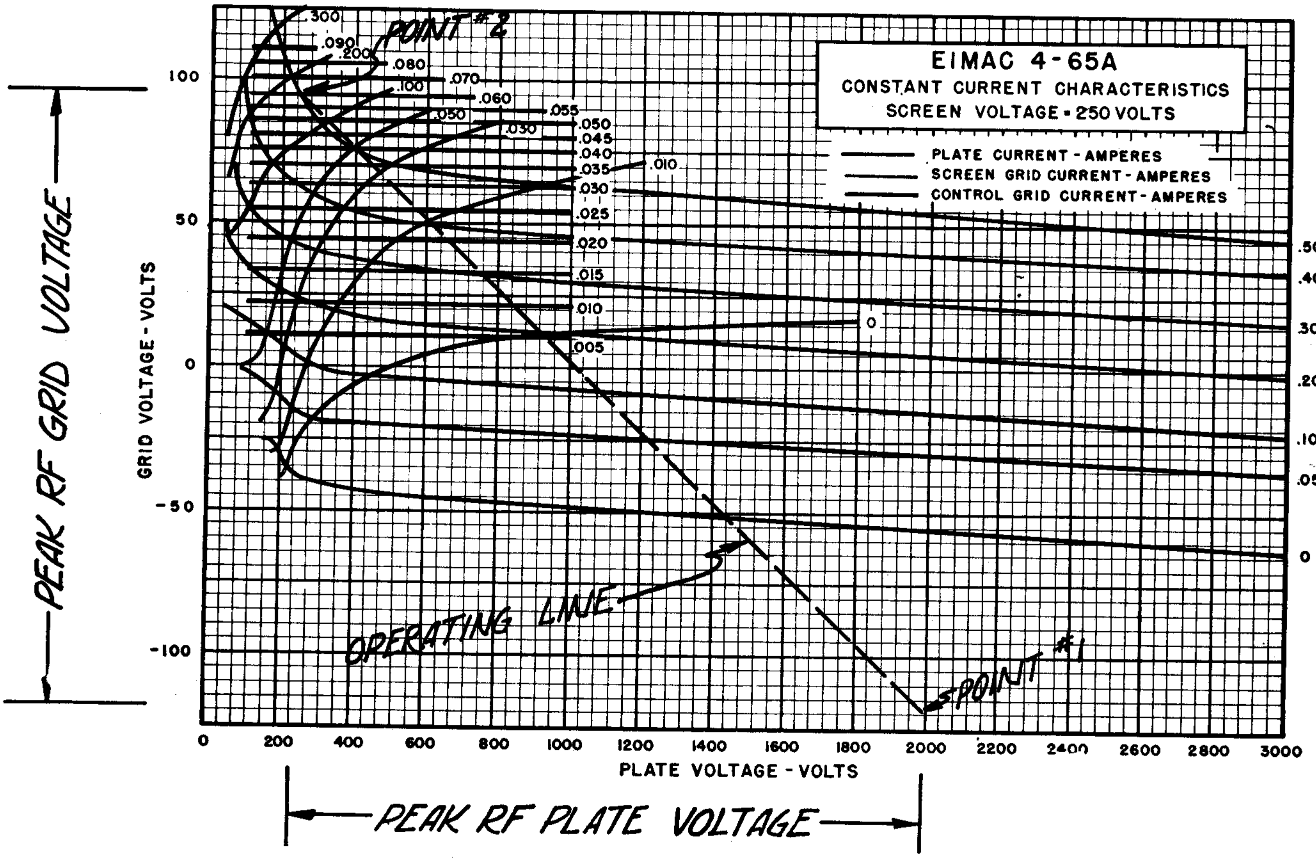


Figure 4

point where the lines OA, OB, etc., cross the operating line so that they can be combined later to calculate the various tube currents. At points where OF and OE cross, the current values are often zero.

Now in the example chosen, let us read off the instantaneous plate current values where these lines cross the "Operating Line." At the point where the line OA crosses the "Operating Line" the plate current is 500 ma. Where OB crosses the operating line the plate current can be estimated as 510 ma since the point is about 1/10 of the way from the 500 ma line to the 600 ma line. At OC the plate current is 460 ma, OD 290 ma, OE 75 ma, OF and OG 0 ma. Similarly we can estimate the instantaneous screen current at the crossing of OA and the "Operating Line" as 165 ma, and the instantaneous grid current at 60 ma. Values are read for the other crossings and written down. These values are put in simple columns for calculating:

Crossing of line	Simplified Name in Formulas	Instantaneous Values of Currents		
		Plate	Screen	Control Grid
OA	A	500 Ma	165 Ma	60 Ma
OB	B	510	100	50
OC	C	460	25	30
OD	D	290	5	14
OE	E	80	0	0
OF	F	0	0	0

Now in order to obtain the DC value of plate, screen, and control grid currents the formula (see computor) says to add up the above values but use only one-half of the A values (giving 250 ma for plate, 82 ma for screen, and 30 ma for grid), and then divide by 12, as follows:

DC Meter Reading = 1/12 (0.5 A+B+C+D+E+F)

Plate	Screen	Control Grid
250 Ma	82 Ma	30 Ma
510	100	50
460	25	30
290	5	14
80		
Total 1590 Ma	212 Ma	124 Ma
DC Current = 1/12 Total =		
132 Ma	18 Ma	10 Ma

Now to calculate the RF output power it is necessary to use the formula for the peak RF current which is present in the tube plate current. Since we are using the tube as a straight RF power amplifier we use the formula for "Peak Fundamental RF" as shown on the computor. (If we were estimating the performance of a doubler or tripler we would use the formula for "Peak 2nd Harmonic RF" or "Peak 3rd Harmonic RF".)

From the computor we see that the formula for the peak fundamental RF current is:

1/12 (A+1.93 B+1.73 C+1.41 D+E+0.52 F)
A = 500 = 500 Ma
1.93 B = 1.93x 510 = 985
1.73 C = 1.73x 460 = 796
1.41 D = 1.41x 290 = 409
E = 80 = 80
Total = 2770 Ma
Peak fundamental current = 1/12 Total
= 2770/12 = 230 Ma

We now have the various current values. In order to calculate the powers involved it is necessary to know, not only the DC voltage values, but the greatest amount each voltage swings away from the DC value. This is known as the peak value of the RF voltage. Because the plate voltage swings from 2000 volts down to 250 volts the peak RF voltage is the difference, or 1750 volts. Similarly the grid voltage must rise and fall between the operating points No. 1 and No. 2, or from −125 volts to +95 volts. This is a peak swing of 220 volts and the peak RF grid voltage is 220 volts.

Let us now use the formulas for output power and driving power:

Output power = ½ peak RF plate current x peak RF plate voltage.

We found the peak RF plate current to be 230 ma or .230 amperes, and the peak RF plate voltage to be 1750 volts.

So; Output Power = ½ x .230 x 1750 = 201 watts,
and Input Power = DC Plate Current x DC Plate Voltage
= .132 x 2000 = 264 watts
Plate Dissipation = DC Input Power—RF Output Power
= 264 − 201 = 63 watts
Efficiency = RF Output Power divided by DC Input Power
= 201/264 = 76%
Driving Power = DC Grid Current x Peak RF Grid Voltage
So the Driving Power = .010 x 220 = 2.2 watts

The power consumed by the bias source is simply the product of the DC grid current and the DC grid voltage, or .010 x 120 = 1.2 watts.

The difference between the driving power and the power consumed by the bias source is the power dissipated on the control grid, or 2.2 − 1.2 = 1.0 watts.

The power dissipated on the screen grid is simply the product of the DC screen current and the DC screen voltage, because the screen grid has no impedance between it and the DC screen supply. Thus it is .018 x 250 = 4.5 watts.

The performance of the tube can now be summarized:

DC Plate Voltage	2000 Volts	Driving Power	2.2 Watts
DC Screen Voltage	250 Volts	Grid Dissipation	1.0 Watts
DC Grid Voltage	—120 Volts	Screen Dissipation	4.5 Watts
DC Plate Current	132 Ma	Plate Power Input	264 Watts
DC Screen Current	18 Ma	Plate Power Output	201 Watts
DC Grid Current	10 Ma	Plate Dissipation	63 Watts
Peak RF Grid Voltage	220 Volts		

REFERENCES

1. E. L. Chaffee, "A Simplified Harmonic Analysis," Review Sci. Inst. 7, page 384, October 1936
2. H. P. Thomas, "Determination of Grid Driving Power in Radio Frequency Power Amplifiers," Proc. IRE, Vol. 21, pp. 1134-1141; August 1933
3. W. G. Wagener, "Simplified Methods for Computing Performance of Transmitting Tubes," Proc. IRE; January 1937
4. R. I. Sarbacher, "Graphical Determination of PA Performance," Electronics; December 1942
5. R. I. Sarbacher, "Performance of Self Biased Modulated Amplifier," Electronics; April 1943
6. "Class C Amplifier Calculations With The Aid of Constant-Current Characteristics," Eimac Application Bulletin Number 4
7. "Vacuum Tube Ratings," Eimac Application Bulletin Number 6
8. Robert H. Brown, "Harmonic Amplifier Design," Proc. IRE, Vol. 35 pp. 771-777; August 1947

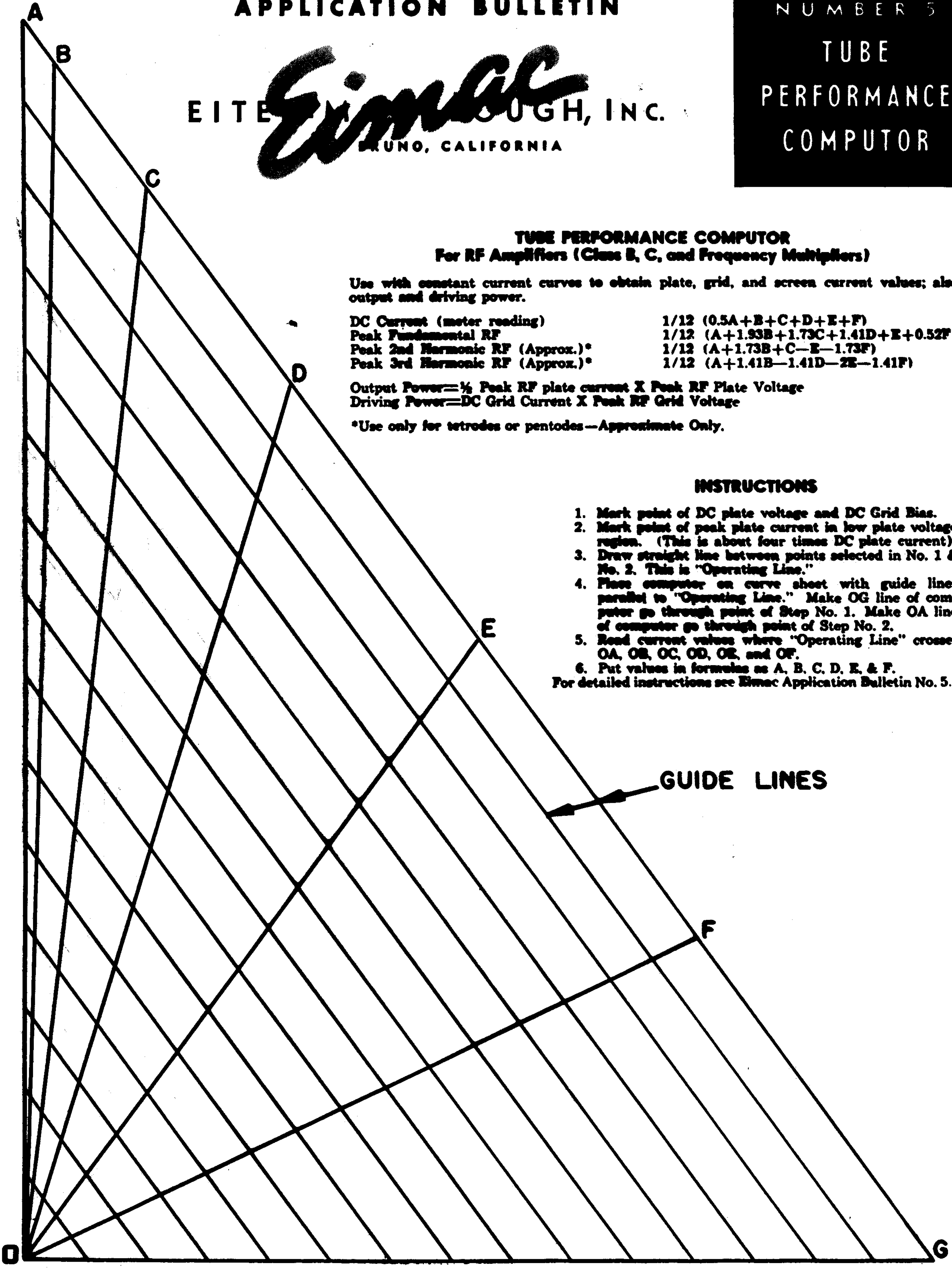
PRINTED IN U.S.A. 3-68139

APPLICATION BULLETIN

EITE Eimac OUGH, INC.
BRUNO, CALIFORNIA

NUMBER 5

TUBE PERFORMANCE COMPUTOR



TUBE PERFORMANCE COMPUTOR
For RF Amplifiers (Class B, C, and Frequency Multipliers)

Use with constant current curves to obtain plate, grid, and screen current values; also output and driving power.

DC Current (meter reading)	$1/12\ (0.5A+B+C+D+E+F)$
Peak Fundamental RF	$1/12\ (A+1.93B+1.73C+1.41D+E+0.52F)$
Peak 2nd Harmonic RF (Approx.)*	$1/12\ (A+1.73B+C-E-1.73F)$
Peak 3rd Harmonic RF (Approx.)*	$1/12\ (A+1.41B-1.41D-2E-1.41F)$

Output Power = ½ Peak RF plate current X Peak RF Plate Voltage
Driving Power = DC Grid Current X Peak RF Grid Voltage

*Use only for tetrodes or pentodes—Approximate Only.

INSTRUCTIONS

1. Mark point of DC plate voltage and DC Grid Bias.
2. Mark point of peak plate current in low plate voltage region. (This is about four times DC plate current).
3. Draw straight line between points selected in No. 1 & No. 2. This is "Operating Line."
4. Place computer on curve sheet with guide lines parallel to "Operating Line." Make OG line of computer go through point of Step No. 1. Make OA line of computer go through point of Step No. 2.
5. Read current values where "Operating Line" crosses OA, OB, OC, OD, OE, and OF.
6. Put values in formulas as A, B, C, D, E, & F.

For detailed instructions see Eimac Application Bulletin No. 5.

PRINTED IN U. S. A.