# AMPEREX "COMPUTA-GUIDE"—

# An Aid to the Calculation of Performance of RF Amplifiers, Doublers and Triplers

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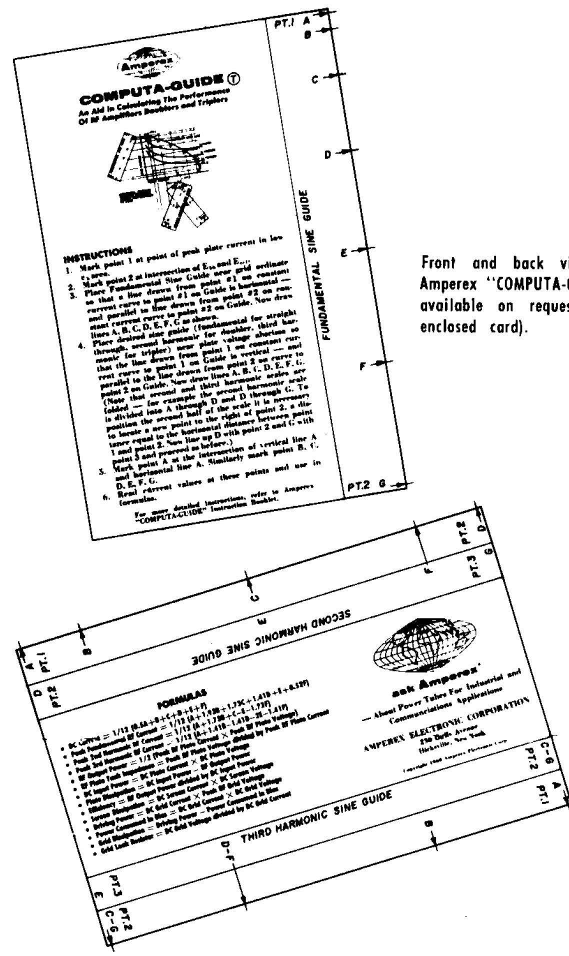
Transmitting and Communication Tube Applications




Front and back view of Amperex "COMPUTA-GUIDE" available on request (use enclosed card).

## INTRODUCTION

The purpose of a nomograph, a graph or other physical computing device, is simply to reduce the amount of tedious and laborious mathematical preparation before getting into the real meat of the problem to be solved. The purpose of the Amperex "COMPUTA-GUIDE" is to facilitate the numerical method of Fourier Analysis which is used to compute the performance of RF amplifiers, both Class B and C, and frequency multipliers.

There are several known numerical processes for calculating the harmonic components of a complex wave form. One of the most accurate is the Chaffee "Simplified Harmonic Analysis" commonly called the "13 point analysis." The conditions under which this analysis can be applied are:

1. The variable Y must be a single valued function of X.
2. The variable X must vary sinusoidally with time.

In an RF amplifier, a sinusoidal voltage is applied to the control grid of the tube. For any of the above mentioned amplifiers, we should expect a sinusoidal plate voltage output. The plate current pulse is the complex wave form, or the variable Y, which we must analyze in order to compute the overall performance of the amplifier.

## CONSTRUCTION AND USE OF "COMPUTA-GUIDE"

~~Figure 1 shows a non-sinusoidal periodic symmetrical~~ wave form. This pulse may be likened to the plate current pulse of an RF amplifier. One-half of the cycle has been divided into 15° increments resulting in 13 points of various amplitudes, A, B, C, D, E, F, G, etc. These amplitudes, used in the first four equations on Table 1, can be used to determine the DC and any of the harmonic components which make up this pulse wave form.

Figure 2 illustrates the constant current curve of a typical triode working as a tripler. Both the grid input voltage and the plate output voltage have been drawn and the points A, B, C, D, E, F, and G projected from both sinusoids to the constant current curves. The points of mutual insersection when joined, make up the line called the operating line. In this particular case, the operating line is the so-called tripler "S" curve. If we prefer, we could now draw a very good replica of the plate current pulse. However, it is unnecessary to do this since we simply use the amplitudes A, B, C, D, E, F, G in the equations to find the components needed for further calculations.

It is also unnecessary to draw the grid sine wave and the plate sine wave each time computations have to be made because the COMPUTA-GUIDE is in a reality a "shorthand" sine wave. This becomes obvious upon examination of Figure 3, which shows the construction of the COMPUTA-GUIDE and its various scales.

The use of the COMPUTA-GUIDE in determining the points A, B, C, D, E, F and G on the constant current curve for the straight through amplifier and multipliers is shown in Figures 4, 5, and 6.

Figure 5 details specifically the step-by-step procedure for establishing the doubler operating line.

In Figure 5A, points 1 and 2 have been arbitrarily established on the constant current curves. Point 2 is the intersection of the grid bias, $E_{cc}$ and the plate battery voltage, $E_{bb}$. The location of Point 1 is based upon a little experience and some trial and error. A good choice is the intersection of a peak current line of six times the average ammeter current for a doubler and a plate voltage line of 20 to 30% of $E_{bb}$. Using the fundamental sine guide scale, horizontal lines parallel to each other are drawn

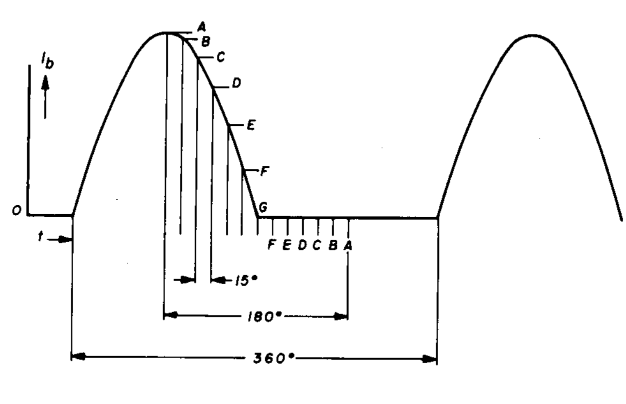



FIG. I

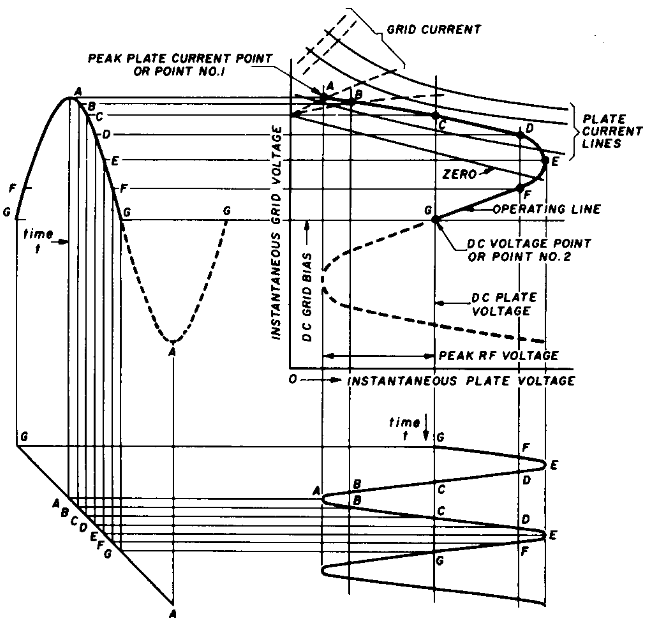
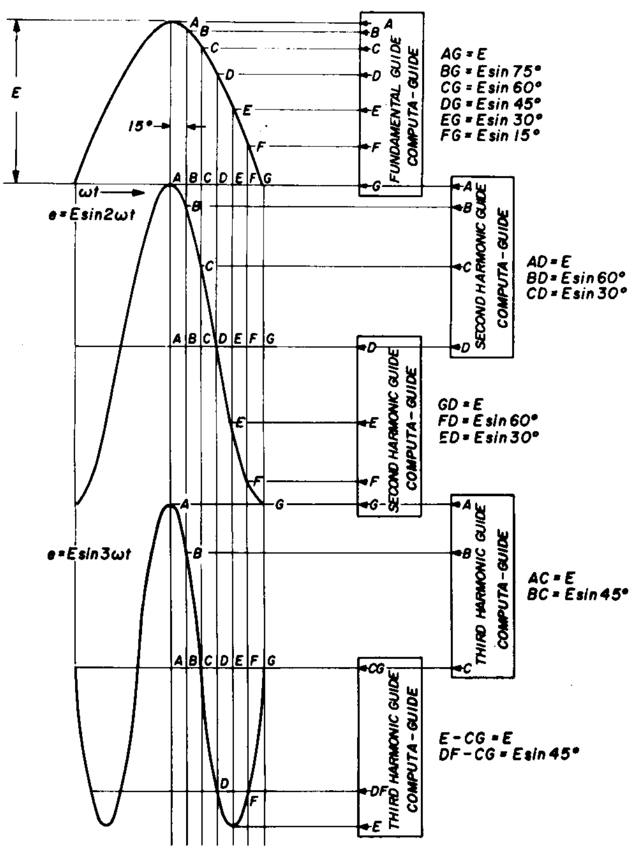



FIG. 2




CONSTRUCTING THE COMPUTA GUIDE

FIG. 3

from Point 1 on the COMPUTA-GUIDE to Point 1 on the constant current curves, and from Point 2 on the sine guide to Point 2 on the constant current curves. Lines B, C, D, E and F are then drawn.

Using the second harmonic sine guide, vertical lines, parallel to each other, are then drawn between Point 1 on the sine guide to Point 1 on the constant current curves, and from Point 2 on the sine guide to Point 2 on the constant current curves (See Figure 5B). Lines B and C are then completed.

In order to draw lines E, F and G, we must first establish Point 3. Point 3 is located so that the horizontal distance between Points 2 and 3 on the constant current curves equals the horizontal distance between Points 1 and 2. Now, using the COMPUTA-GUIDE, draw vertical and parallel lines from Point 2 (D) on the COMPUTA-GUIDE to Point 2 on the constant current curves, and from Point 3 (G) on the COMPUTA-GUIDE to Point 3 on the constant current curves. The lines E and F may now be drawn. (See Figure 5C.)

Figure 5D shows the intersections of the respective lettered horizontal and vertical lines joined to establish the doubler operating line.

The same technique above may be used in drawing the operating line for the tripler. (See Figure 6.)

## SPECIFIC EXAMPLE

Let us now use the COMPUTA-GUIDE to compute the performance of the Amperex tube type 6360. The Amperex tube type 6360 is a dual tetrode. Let us assume that we are going to use it in cascade and that we wish to know the performance of one section used as a doubler. (See Figure 7.)

Let us assume:

a) That the available DC supply voltage is 200 volts,
   Therefore let $E_{bb} = 200\ V_{dc}$
   and let $E_{c2} = 200\ V_{dc}$
b) That the DC Plate Current is about 35 milliamperes
   Therefore $I_b = 35\ mA_{dc}$
c) Then the peak plate current will be about six times this amount or approximately 210 mA.
   Therefore $i_b = 210$ mA
d) That the proper bias for a multiplier should be approximately 3 times the cut-off,
   Therefore $E_{cc1} = -90$ volts
e) That the peak plate swing will be about 120 volts
   Therefore $\hat{E}_p = 120$ and $e_b$ min. = 80 volts.

The previous assumptions have established two points on the constant current curves of Figure 7, Point 1 in the low plate voltage area and Point 2 of the intersection of bias and DC plate voltage. Using the fundamental sine guide scale, we draw horizontal and parallel lines from Point 1 on the COMPUTA-GUIDE to Point 1 on the constant current curves, and from Point 2 on the COMPUTA-GUIDE to Point 2 on the constant current curves. Now we draw horizontal lines A, B, C, D, E, F and G. Note that if this were a straight-through amplifier, the intersection of these lettered lines with a straight operating line drawn between Point 1 and Point 2 on the constant current curve, would be sufficient to determine the respective amplitudes needed for further computation.

For the doubler operating line, we must repeat the previous procedure only this time drawing vertical parallel lines from Points 1 and Points 2, and of course this time using the second harmonic sine guide. Again, we complete the vertical lines, A, B, C, D, E, F and G. To determine points D, E, F and G, it is necessary to use the folded scale of the second harmonic sine guide aligning Points 2 and 3 on the COMPUTA-GUIDE respectively with Points 2 and 3 on the constant current curves. Point 3 is established on the constant current curves as $E_{bb} + \hat{E}_p$ (Horizontal distance between Point 1 and 2). In this case, $200 + 120 = 320$ volts. See Figures 5 and 6.

By designating the intersection of the A vertical with A horizontal lines as point A, and B vertical with B horizontal lines as point B, etc., and joining these intersections we can now observe the doubler operating line that we have chosen. The amplitudes of the intersctions are now tabulated below.

INSTANTANEOUS VALUES OF CURRENT

| Letter | Plate (mA) | Control Grid (mA) | Screen Grid (mA) |
|---|---|---|---|
| A | 210 | 10 | 19 |
| B | 180 | 7 | 16 |
| C | 100 | 2.5 | 9 |
| D | 30 | 0 | 0 |
| E | 0 | 0 | 0 |
| F | 0 | 0 | 0 |
| G | 0 | 0 | 0 |

The DC currents for meter readings may now be determined using the formula DC current $= 1/12\ (\frac{A}{2} + B + C + D + E + F)$. Therefore:

DC Plate Current $= 1/12\ (105 + 180 + 100 + 30) = 34.6$ mAdc

DC Control Grid Current $= 1/12\ (5 + 7 + 2.5) = 1.21$ mAdc.

DC Screen Grid Current $= 1/12\ (9.5 + 16 + 9) = 2.88$ mAdc.

The RF power output may now be determined. First, we must calculate the second harmonic plate peak current ($\hat{I}_{p2}$).

$\hat{I}_{p2} = 1/12\ (A + 1.73B + C - E - 1.73F)$

$\hat{I}_{p2} = 1/12\ (210 + 1.73 \times 180 + 100) = 52$ mA.

Therefore:

Power Output $= \frac{\hat{E}_{p2} \times \hat{I}_{p2}}{2} = 120 \times .052/2 = 3.12$ watts.

~~Input Power $= E_{bb} \times I_b$~~ $= 200 \times .0346 = 6.92$ watts.

Plate Dissipation $=$ DC Input $-$ Power Output $= 6.92 - 3.12 =$ 3.80 watts.

Efficiency $= \frac{\text{input power}}{\text{output power}} = 3.12/6.92 = 45\%$.

Driving Power $= eg\ I_{c1} = 103.5 \times 1.21 \times 10^{-3} = 0.125$ watts.

Control Grid Dissipation $= e^{+}g \times I_{c1} = 13.5 \times 1.21 \times 10^{-3} =$ .0164 watts.

Grid Leak Resistance $R_{g1} = E_{cc1}/I_{c1} = 90/1.21 \times 10^{-3} = 74$ k ohms.

Screen Grid Dissipation $= E_{c2} \times I_{c2} = 200 \times 2.88 \times 10^{-3} =$ .576 watts.

Plate Effective RF Impedance $= \hat{E}_{p2}/\hat{I}_{p2} = 120/.052 = 2300$ ohms.

**SUMMARY OF 6360 SINGLE SECTION DOUBLER PERFORMANCE**

| | |
|---|---|
| DC Plate Voltage | 200 volts |
| DC Grid No. 2 Voltage | 200 volts |
| DC Grid No. 1 Voltage | −90 volts |
| From Grid Resistor | 74 k ohms |
| Peak RF Grid No. 1 Voltage | 103.5 volts |
| DC Plate Current | 34.6 mA |
| DC Grid No. 2 Current | 2.88 mA |
| DC Grid No. 1 Current | 1.21 mA |
| Driving Power (low frequency) | 0.125 watts |
| Plate RF Impedance | 2300 ohms |
| Power Output | 3.12 watts |
| Efficiency | 45% |
| Grid No. 1 Dissipation | 0.016 watts |
| Grid No. 2 Dissipation | 0.576 watts |
| Plate Dissipation | 3.80 watts |
| Plate Power Input | 6.92 watts |

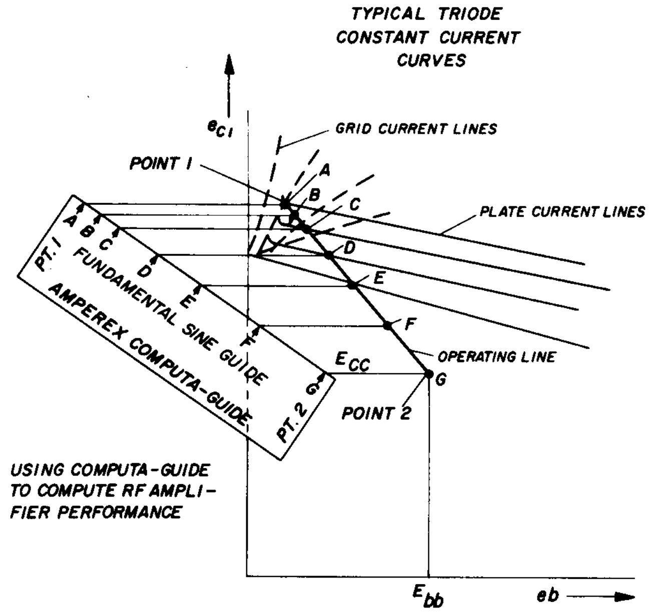



FIG. 4

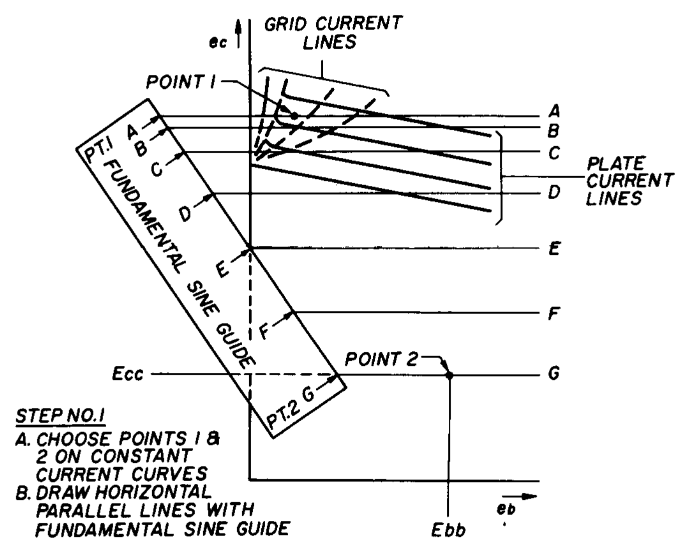



FIG.5a

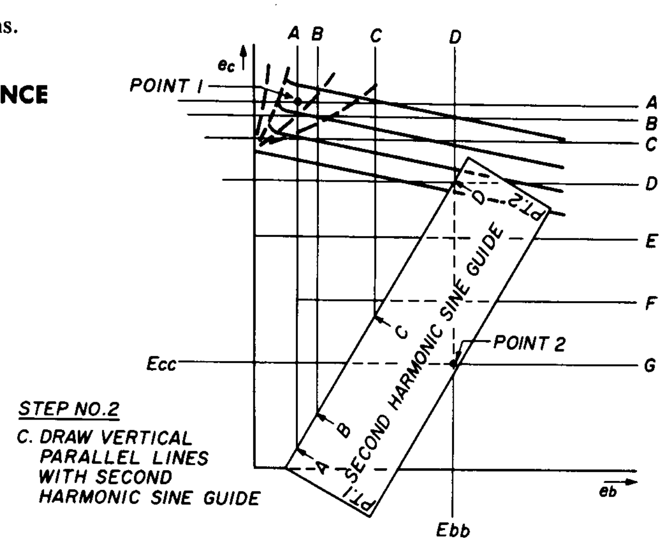



FIG. 5b

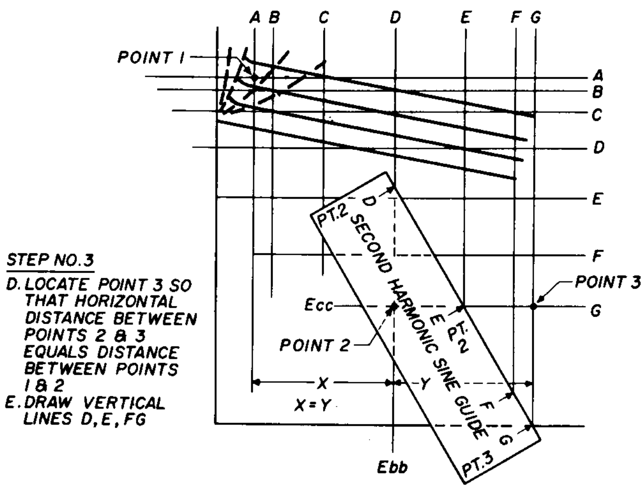



FIG.5c

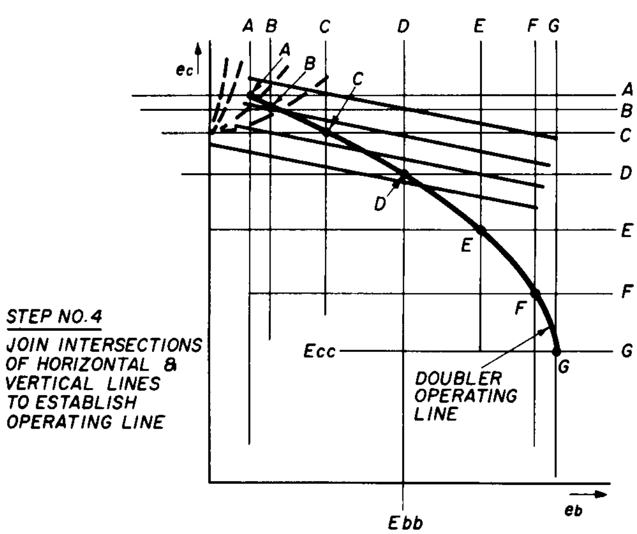



FIG. 5d

## SPECIAL AIDS AND SHORT CUTS IN USING THE COMPUTA-GUIDE

It is not unusual to find a good deal of size variation in the constant current curves from tube to tube. Also the nature of the particular characteristics make it sometimes impossible for the manufacturer to include any room on the graph for very high bias. Examination of the operating lines already discussed above, and the equations used for determining the DC and peak RF currents can give us a better understanding of how to overcome the limitations of various sizes of graph paper. Also, we can reduce the number of trial computations by establishing a few general rules.

TABLE 1

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

Peak Fundamental RF Current $\hat{I}_{p1} = 1/12\ (A + 1.93B + 1.73C + 1.41D + E + 0.52F)$

Peak Second Harmonic RF Current $\hat{I}_{p2} = 1/12\ (A + 1.73B + C - E - 1.73F)$

Peak Third Harmonic RF Current $\hat{I}_{p3} = 1/12\ (A + 1.41B - 1.41D - 2E - 1.41F)$

The object in most cases of computation will be to achieve the highest possible efficiency, i.e., $\frac{\text{power output}}{\text{DC input}}$. Let us examine the equations in Table 1 which will help determine what the best efficiency will be for a straight through amplifier. The object in the first two equations is to get the highest ratio of the individual letter in the RF equation to that which it has in the DC current equation. Notice then, that a high value of A and B and C and D would tend to yield high efficiency. However, any values of E and F tend to lower efficiency. Consequently, it behooves the designer to establish E on the constant current curves so that it coincides approximately with the zero current plate line. Now we can take this one step further. It so happens that E bisects the straight through operating line. The question now is "Can the operating line be plotted from A to E instead of from A to G and still yield sufficient information?" The answer is "Yes." The letter E may be used as Point 2 and the following procedure and equations used to determine $E_{bb}$ and $E_{cc1}$:

a) Locate E horizontally so that it equals $e_b$ min + ½ ($E_{bb} - e_b$ min)

$e_b$ min is the horizontal distance on the abscissa measured from zero plate voltage to Point A.

b) In the same manner, the vertical location of E may be determined by locating point E so that it equals $e^+g - ½\ [e^+g - (-E_{cc1})]$

$e^{+}g$ represents the vertical distance from zero bias to point A. This method allows the designer to use constant current curves plotted on graph paper where the normal Point 2 (G) would have to be located off the bottom of the paper.

c) For the doubler, locate E so that it equals $E_{bb} + \frac{1}{2}(E_{bb} - e_b \min)$

And for the vertical position locate E so that it is equal to $e^{+}g - \frac{1}{2}\left[e^{+}g - (-E_{cc1})\right]$

For the doubler, point E should be located approximately on the zero plate current line for the best efficiency.

The same system may be used for the tripler computations, but this time we must work with letter C which should be located at or about the zero plate current line. Its location can be determined as follows:

a) Locate C horizontally so that it is equal to $E_{bb}$
b) Locate C vertically so that it is equal to $e^{+}g - .134\left[e^{+}g - (-E_{cc1})\right]$

With a little practice, the designer, with the aid of the locating devices given above and the Amperex COMPUTA-GUIDE may shorten the computation time considerably.

## REFERENCES


- Chaffee, E. L., "A Simplified Harmonic Analysis," *Review of Scientific Institute* (October, 1936), p. 384.
- Brown, Robert H., "Harmonic Amplifier Design," *Proceedings of the IRE,* Volume 35 (August, 1947), pp. 771-777.
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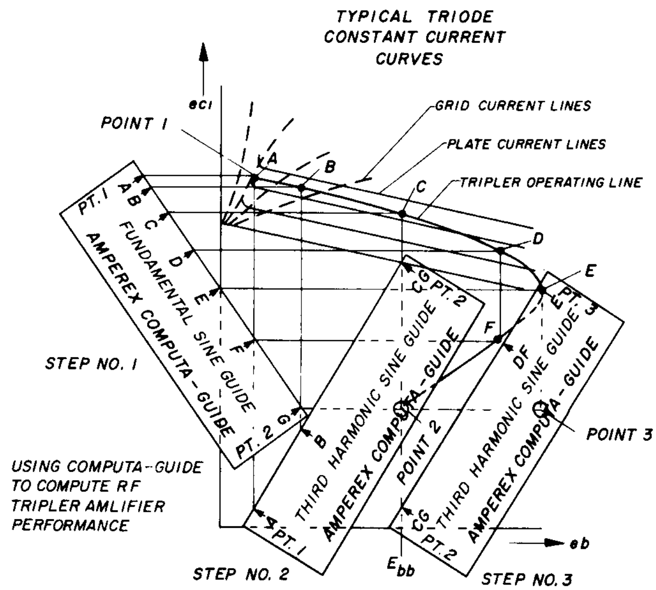


FIG. 6

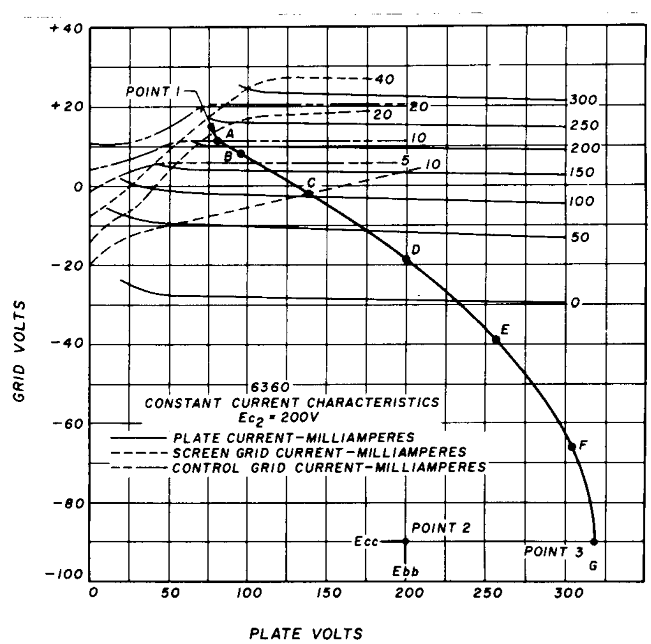


FIG.7

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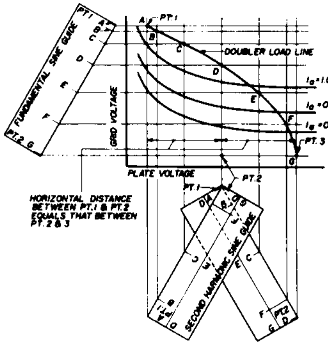
# COMPUTA-GUIDE®

***An Aid in Calculating The Performance Of RF Amplifiers Doublers and Triplers***




## INSTRUCTIONS

1. Mark point 1 at point of peak plate current in low $e_b$ area.
2. Mark point 2 at intersection of $E_{bb}$ and $E_{cc1}$.
3. Place Fundamental Sine Guide near grid ordinate so that a line drawn from point #1 on constant current curve to point #1 on Guide is horizontal — and parallel to line drawn from point #2 on constant current curve to point #2 on Guide. Now draw lines A, B, C, D, E, F, G as shown.
4. Place desired sine guide (fundamental for straight through, second harmonic for doubler, third harmonic for tripler) near plate voltage abscissa so that the line drawn from point 1 on constant current curve to point 1 on Guide is vertical — and parallel to the line drawn from point 2 on curve to point 2 on Guide. Now draw lines A, B, C, D, E, F, G. (Note that second and third harmonic scales are folded — for example the second harmonic scale is divided into A through D and D through G. To position the second half of the scale it is necessary to locate a new point to the right of point 2, a distance equal to the horizontal distance between point 1 and point 2. Now line up D with point 2 and G with point 3 and proceed as before.)
5. Mark point A at the intersection of vertical line A and horizontal line A. Similarly mark point B, C, D, E, F, G.
6. Read current values at these points and use in formulas.

For more detailed instructions, refer to Amperex "COMPUTA-GUIDE" Instruction Booklet.

PT.1 A →
B →
C →
D →
E →
F →
PT.2 G →

FUNDAMENTAL SINE GUIDE

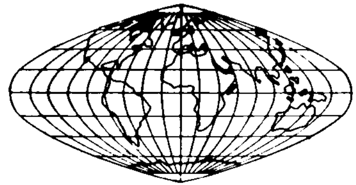
A PT.1 B C PT.2 D

D PT.2 E F PT.3 G

SECOND HARMONIC SINE GUIDE

## FORMULAS

- DC Current = 1/12 (0.5A+B+C+D+E+F)
- Peak Fundamental RF Current = 1/12 (A+1.93B+1.73C+1.41D+E+0.52F)
- Peak 2nd Harmonic RF Current = 1/12 (A+1.73B+C—E—1.73F)
- Peak 3rd Harmonic RF Current = 1/12 (A+1.41B—1.41D—2E—1.41F)
- RF Output Power = 1/2 (Peak RF Plate Current × Peak RF Plate Voltage)
- RF Plate Tank Impedance = Peak RF Plate Voltage divided by Peak RF Plate Current
- DC Input Power = DC Plate Current × DC Plate Voltage
- Plate Dissipation = DC Input Power — RF Output Power
- Efficiency = RF Output Power divided by DC Input Power
- Screen Dissipation = DC Screen Current × DC Screen Voltage
- Driving Power = DC Grid Current × Peak RF Grid Voltage
- Power Consumed in Bias = DC Grid Current × DC Grid Voltage
- Grid Dissipation = Driving Power — Power Consumed in Bias
- Grid Leak Resistor = DC Grid Voltage divided by DC Grid Current







E PT.3 D-F THIRD HARMONIC SINE GUIDE PT.2 C-G

C-G PT.2 B PT.1 A