Conversion Factors for Tube Characteristics

This Note describes a method for determining the approximate characteristics of an electron tube when all the electrode voltages are changed in the same proportion from the published or measured values. Conversion factors for the principal characteristics are given in a nomograph which is easy to use and provides direct reading. Although these conversion factors have been available in curve form for some time, the nomograph is more convenient to use than the log-log curves.

The conversion factors obtained from the nomograph are applicable to triodes, tetrodes, pentodes, and beam power tubes when the plate voltage, grid-No.1 voltage, and grid-No.2 voltage are changed simultaneously by the same factor. They may be used for any class of tube operation (class A, AB_1, AB_2, B, or C).

CONVERSION FACTOR NOMOGRAPH

The nomograph shown in Fig.1 may be used to determine the proper value for each conversion factor for a specified relationship (F_e) between published or measured values (E_{pub}) and desired values (E_{des}) of operating voltage. Conversion factors for resistance and transconductance (F_r and F_{gm}) are plotted on the scale at the extreme left of the nomograph, and conversion factors for current and power output (F_i and F_p) on the scale at the extreme right. The dashed lines on the nomograph indicate the correct procedure for determining these factors when it is desired to reduce the operating electrode voltage from 250 to 200 volts. The basis of the conversion factors and the formulas for determining each factor as a function of the change in operating voltages are given in the Appendix.

USE OF NOMOGRAPH CONVERSION FACTORS

An example of how the Conversion Factor Nomograph may be used to determine the characteristics of an electron tube when the operating voltages are changed in the same proportion follows:

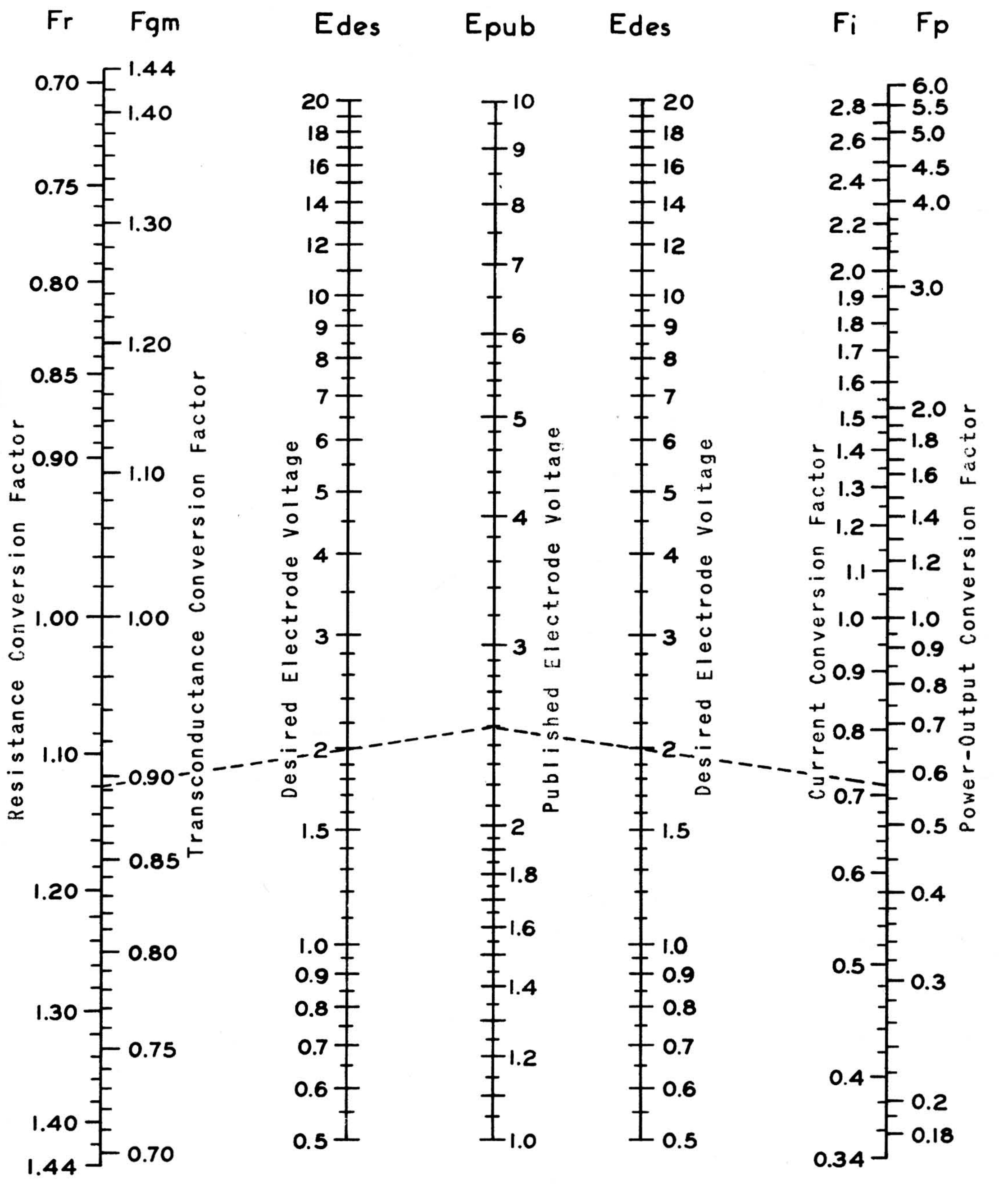

Fig.1 - Nomograph for determining tube-characteristic conversion factors.

The published characteristics for a typical pentode are:

Plate Voltage.	250	volts
Grid-No.2 Voltage.	250	volts
Grid-No.1 Voltage.	-15	volts
Plate Current.	30	ma
Grid-No.2 Current.	6	ma
Plate Resistance (Approx.)	0.13	megohm
Transconductance	2000	μmhos
Load Resistance.	10000	ohms
Total Harmonic Distortion.	10	per cent
Maximum-Signal Power Output.	2.5	watts

If it is desired to determine the characteristics of this tube for a plate voltage of 200 volts, the voltage conversion factor, F_e, is equal to 200/250 or 0.8. The following values for the other conversion factors are obtained from the nomograph:

Current Conversion Factor (F_i)	0.72
Resistance Conversion Factor (F_r).	1.12
Transconductance Conversion Factor (F_{gm})	0.89
Power-Output Conversion Factor (F_p).	0.57

By the use of these factors, the following characteristics values at a plate voltage of 200 volts are obtained from the published characteristics:

Plate Voltage = 200 volts
Grid-No.2 Voltage = 0.8 x 250 = 200 volts
Grid-No.1 Voltage = 0.8 x -15 = -12 volts
Plate Current = 0.72 x 30 = 21.6 ma
Grid-No.2 Current = 0.72 x 6 = 4.3 ma
Plate Resistance = 1.12 x 0.13 = 0.15 megohm
Transconductance = 0.89 x 2000 = 1780 μmhos
Load Resistance = 1.12 x 10000 = 11200 ohms
Total Harmonic Distortion remains unchanged at 10 per cent
Maximum-Signal Power Output = 0.57 x 2.5 = 1.42 watts

COMPARISON OF NOMOGRAPH WITH MEASURED VALUES

Two sets of laboratory measurements were made to determine the relative accuracy obtained by the use of conversion-factor values given by the nomograph. The tubes tested were the RCA-6BH6 sharp-cutoff pentode (tested under class A_1 amplifier conditions) and the RCA-6146 beam power tube (tested under class C telegraphy conditions). Comparative data for these types are given in Tables I and II, respectively.

LIMITATIONS

Because this method for conversion of characteristics is necessarily an approximation, progressively greater errors will be introduced as the voltage conversion factor ($F_e = E_{des}/E_{pub}$) departs from unity. In general, it may be assumed that results obtained will be approximately correct when the value of F_e is between 0.7 and 1.5. When F_e is extended beyond these limits (down to 0.5 or up to 2.0), the accuracy becomes considerably reduced and the results obtained can serve only as a rough approximation.

TABLE I

Type RCA-6BH6 (Class A_1 Amplifier Conditions)

	Measured	Obtained from Nomograph	Measured	Obtained from Nomograph	Measured	Obtained from Nomograph	Measured
Plate Volts (E_b)	250	300	300	200	200	150	150
Grid-No.3 Volts (E_{c_3})	0	0	0	0	0	0	0
Grid-No.2 Volts (E_{c_2})	152	182	182	122	122	91	92
Grid-No.1 Volts (E_{c_1})	-1	-1.2	-1.2	-0.8	-0.8	-0.6	-0.6
Plate Resistance (r_p) - ohms	1.29	1.17	1.16	1.44	1.40	1.67	1.44
Transconductance (g_m) - μmhos	4850	5310	5200	4325	4400	3740	4100
Plate Milliamperes (I_b)	7.3	9.6	9.2	5.3	5.6	3.4	4.1
Grid-No.2 Milliamperes (I_{c_2})	2.8	3.7	3.6	2.0	2.1	1.3	1.6

TABLE II

Type RCA-6146 (Class C Telegraphy Conditions)

	Measured	Obtained from Nomograph	Measured	Obtained from Nomograph	Measured
Plate Volts (E_b)	600	500	500	400	400
Grid-No.2 Volts (E_{c_2})	150	125	125	100	100
Grid-No.1 Volts (E_{c_1})	-56	-46.6	-46	-37.3	-36
Peak RF Grid-No.1 Volts	66.5	55.4	54	44.3	41
Plate Milliamperes (I_b)	112	85.6	85	61.6	61
Grid-No.2 Milliamperes (I_{c_2})	5.4	4.1	4.6	3.0	3.6
Grid-No.1 Milliamperes (I_{c_1})	2.8	2.1	2.1	1.5	1.5
Power Output (P_o) - watts	52.2	33.4	32.0	18.8	19.6

It should be noted that this method does not take into account the effects of contact potential or secondary emission in electron tubes. Contact potential, however, may safely be neglected for most applications because its effects are noticeable only at very low grid-No.1 voltages. Secondary emission may occur in conventional tetrodes at low plate voltages. For such tubes, therefore, the use of conversion factors should be limited to regions of the plate characteristic in which the plate voltage is greater than the grid-No.2 voltage. For beam power tubes, the regions of both low plate currents and low plate voltages should also be avoided.

APPENDIX - Basis of Conversion Factors

The conversion factors for tube characteristics are derived from the well-known "three-halves-power" relationship for current and voltage. For tubes using unipotential cathodes (or filament cathodes provided the plate voltage, E_b, is considerably larger than the filament voltage, E_f), the total plate current, I_b, for positive plate voltages, E_b, under space-charge-limited conditions is given by the following equation:

$$I_b = K E_b^{3/2}$$

where K is a constant determined by the geometry of the tube. When the discussion is limited to a particular tube type, the constant K may be deleted and the expression rewritten to show the direct variation of current with voltage:

$$I_b \propto E_b^{3/2} \qquad (1)$$

This relationship exists for triodes, tetrodes, pentodes, and beam power tubes, provided all electrode voltages (plate, grid-No.1, and grid-No.2) are varied simultaneously in the same proportion.

I. Current Conversion Factor

The factor by which all electrode voltages are varied, F_e, is equal to the ratio between the desired voltages, E_{des}, and the published or measured voltages, E_{pub}:

$$F_e = E_{des}/E_{pub}$$

The new plate current, I_b', therefore, is given by

$$I_b' \propto (F_e \times E_b)^{3/2}$$

This plate current can also be expressed in terms of the published plate current, I_b, as follows:

$$I_b' = F_i \times I_b$$

where F_i is the factor by which the plate current is changed. This value for I_b' can then be substituted in the expression given above:

$$F_i \times I_b \propto (F_e \times E_b)^{3/2} \qquad (2)$$

Equations (1) and (2) can then be combined to show F_i as a function of F_e:

$$F_i = F_e^{3/2}$$

2. Power-Output Conversion Factor

The power output, P_o, is proportional to the product of plate voltage and plate current:

$$P_o \propto E_b \times I_b$$

The new power output, P_o', therefore, is given by

$$P_o' \propto (F_e \times E_b)(F_i \times I_b)$$

or

$$P_o' \propto (F_e \times F_i)(E_b \times I_b)$$

The new value can then be expressed in terms of the published value, P_o, as follows:

$$P_o' \propto (F_e \times F_i)(P_o)$$

The power-output conversion factor, F_p, therefore, is given by

$$F_p = F_e \times F_i = F_e \times F_e^{3/2} = F_e^{5/2}$$

3. Transconductance Conversion Factor

The transconductance, g_m, is equal to the quotient of the change in plate current divided by the change in grid-No.1 voltage. The transconductance conversion factor, F_{gm}, therefore, is given by

$$F_{gm} = F_i/F_e = F_e^{3/2}/F_e = F_e^{1/2}$$

4. Resistance Conversion Factor

The plate resistance, r_p, is equal to the quotient of the change of plate voltage divided by the change of plate current. The resistance conversion factor, F_r, therefore, is given by

$$F_r = F_e/F_i = F_e/F_e^{3/2} = F_e^{-1/2}$$

This conversion factor may be applied to resistance values of output loads and cathode resistors, as well as to plate resistance.