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GENERAL ELECTRIC COMPANY
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Title: Amplification Factor Charts For Triodes

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FN-460-E (11-43)

AMPLIFICATION FACTOR CHARTS FOR TRIODES

1. INTRODUCTION

The charts presented here are intended to aid the designer in developing new tubes. There is also included a chart to be used when making changes in existing tubes.

2. FORMULAE USED IN CONSTRUCTION OF CHARTS

The charts are based upon the amplification factor formula of Salzberg (1)* which is:

$$\mu = \frac{2\pi nS - \ln(\cosh \pi nd)}{\ln(\coth \pi nd) + \ln\left[1 - e^{-4\pi nS}(\cosh^2 \pi nd)\right]} \qquad \text{(I)}$$

in which n = grid turns per unit length

d = grid wire diameter

S = effective grid-plate spacing

The effective grid-plate spacing is given for a plane structure tube by the actual grid-plate spacing, measured from the center line of the grid wires, and for a circular structure tube by

$$S = r_g \ln\left(\frac{r_p}{r_g}\right) = \frac{D_g}{2} \ln\left(\frac{D_p}{D_g}\right) \qquad \text{(II)}$$

where

$r_g = \frac{D_g}{2}$ = radius of grid to center line of grid wires

$r_p = \frac{D_p}{2}$ = inside radius of plate

The dimensions may be measured in any consistent set of units.

For large values of nS and small values of nd eq. (I) reduces to the Vodges and Elder (2) formula

$$\mu = \frac{2\pi nS - \ln(\cosh \pi nd)}{\ln(\coth \pi nd)} \qquad \text{(III)}$$

*Number in parentheses refer to items in bibliography.

Formulae (I) and (III) were derived for both plane structure tubes and tubes of circular construction in which the grid wires are parallel with the cathode. The validity of the formulae when used with other types of grid structure was demonstrated by Y. Kusunose (3). A set of empirical form factors was developed by E. R. Jervis (4) which extended the use of the formulae to tubes of non-circular cylindrical construction.

3. DESCRIPTION AND USE OF CHARTS

Drawing M-69087-1A179 is a plot of formula (I) with nS and μ as arguments and nd as a parameter.

The primary use of this plot is to determine the values of nS and S for existing tubes, which may not be of circular or plane construction. It is only necessary that μ, n, and d be known to determine S.

The value of S thus found is the same for any tube having the same plate and grid cross-section.

If all of the cross-sectional dimensions are changed in the same ratio, the value of S will also be changed in that ratio.

Example A:

Find S for the type 6SF5 triode

In this tube

$n = 72.5$ TPI

$d = 0.0041$ inches

$\mu = 100$

$nd = 72.5 \times 0.0041 = 0.297$

From chart at $\mu = 100$, $nd = 0.297$

$nS = 5.1$

$$S = \frac{5.1}{72.5} = 0.0704 \text{ inches.}$$

This chart may also be used to find the amplification factor of tubes when the dimensions are specified.

Drawing K-69087-1A173 is a plot of equation (II) combined with a nomogram to determine the value of nS for circular element tubes.

With the values of Dg/Dp and Dp known, S is determined. A straight line is then passed through the point on the S scale and the grid turns per unit length on the n scale. nS is then read at the intersection of the straight line and the nS scale.

Example B

Find the value of nS for a cylindrical triode with

$Dg = 0.085"$

$Dp = 0.253"$

$n = 72.5$ TPI

$$\frac{Dg}{Dp} = \frac{0.085}{0.253} = 0.336$$

From chart

$S = 0.0465$

$nS = 3.36$

The nomogram may also be used to find the value of nd. This is done by substituting d for S and dividing the numbers on the S and nS scales by ten. From the above example, let d = 0.00465 in. (4.65 mils), then nd = 0.335.

Drawing K-69087-1A174 gives the effective value of nd for square mesh grid (3) from which the effective value of n can be determined.

Example C

Find the effective values of nd and n for an 80 mesh 2 mil square mesh grid

$n'd = 80 \times 0.002 = 0.16$

From chart

$nd = 0.295$ $\qquad n = \frac{0.295}{0.002} = 147.5$

Drawings K-69087-1A175, 1A176, and 1A177 are plots of formula (I) for specific grid wire sizes, namely 0.002 in., 0.003 in., and 0.004 in. These curves are plotted with S and n as arguments and with μ as a parameter. Thus if the value of S is known, the necessary t.p.i. for the desired μ can be quickly found.

In designing a new tube the value of S for a known tube with the same grid-plate cross-section can be determined from drawing M-69087-1A179. The grid wire size and t.p.i. of the new tube can then be determined from drawing K-69087-1A175, 1A176, or 1A177.

Example D

What is the t.p.i. for a tube with the same grid-plate cross-section as the type 6SF5, but with an amplification factor of 50 and with 3 mil grid wire.

From Example A, the value of S for the 6SF5 is

$$S = 0.0704 \text{ inches.}$$

From drawing K-69087-1A176, for $\mu = 50$, $S = 0.0704$,

$$n \cong 67.5 \text{ t.p.i.}$$

Drawing K-69087-1A178 is a combination of a set of curves and a nomogram which gives the necessary change in grid turns per unit length to effect a given change in μ.

The value of nd for the tube can be found from the n, d, nd nomogram by connecting n and d with a straight line and reading nd. With the values of nd and μ known, nS may be found from drawing M-69087-1A179. These values of nd and nS determine Q.

The point on the Q axis is then joined with the grid wire diameter d with a straight edge. The intersection of the straight edge and the Qd axis is used as an alignment point with the change in μ on the $\Delta\mu$ axis.

The straight line through Qd and $\Delta\mu$ gives Δn, the required change in grid turns per unit length. The change in n has the same sign as the change in μ, i.e., an increase in μ requires an increase in n.

Example E

What change in grid t.p.i. should be made to give a 6SF5 tube an amplification factor of 90?

In this case we have

$\Delta\mu = 90 - 100 = -10$

From Example A

nd = 0.297

nS = 5.1

d = 0.0041 inches

original n = 72.5 t.p.i.

From curve and nomogram

Q = 985

Δn = -2.5 t.p.i.

n = New grid t.p.i. = 72.5 - 2.5 = 70 t.p.i.

4. LIMITATIONS

The formulae used are subject to appreciable error when the grid-cathode spacing is less than the grid wire spacing. This error increases as the grid-cathode spacing decreases. Therefore the charts should not be used when the grid cathode distance is less than the grid wire spacing. The error is due to the assumption made in deriving formulae (I) and (III) that, in plane structure tubes, the cathode is far removed from the grid, and, for the case of circular structure, that the cathode is of filamentary size.

A further limitation is imposed by the assumptions, namely that the value of S be greater than d.

The solution of drawing 69087-1A178 is subject to an inherent deviation. This is due to the fact that the function Q is a function of n as well as S and d. The magnitude of this deviation is given approximately by

$$\text{Deviation} = \frac{(\Delta n)^2}{n} \qquad \text{(IV)}$$

The sign of the deviation is always positive, i.e., the correction should be subtracted from Δn when $\Delta\mu$ is positive, and added to Δn when $\Delta\mu$ is negative.

Example F

From Example E

$$\text{Deviation} = \frac{(2.5)^2}{72.5} = 0.0086 \text{ or } 0.01$$

Since $\Delta\mu$ is negative the corrected Δn is:

$$\Delta n' = 2.5 + 0.01 = 2.51$$

and $n'' = 72.5 - 2.51 = 69.99$ t.p.i.

5. JERVIS FORM FACTORS

The Jervis Form Factors (4) are empirical constants which are intended to give the amplification factor of tubes which are of neither plane nor circular structure. A series of constants, K, ranging from unity to zero are given, the value depending upon the cross-sectional geometry of the grid, plate, and cathode. The value of unity applies to a circular structure tube without grid side rods, while the zero applies to essentially plane structure tubes such as the 2A3.

The formula given by Jervis for the amplification factor is

$$\mu = (1 - K)\,\mu_p + K\mu_c \qquad \text{(V)}$$

Where K is the Jervis form factor

u_p is the amplification factor for plane structure.

u_c is the amplification factor for circular structure.

The amplification factors are calculated with the Vodges and Elder formula (2), for which Jervis presented a nomogram.

In calculating the value of u_p the grid-plate spacing is taken as that measured along a line perpendicular to the plane of the grid side rods, and passing through the center line of the tube; i.e., along minor O.D. The original formula is based upon measurement made from the center line of the grid wires, but little error is introduced by using the outside dimension of the grid.

Similarly, when calculating u_c, the grid and plate radii are measured perpendicular to the grid side rod plane.

Because these form factors are empirical, the accuracy in the results of their use is open to question. It is therefore advisable in design work, to derive form factors from existing tubes with cross-sectional geometry similar to that desired. This can be done by calculating u_p and u_c for the known tube, and then finding K from formula (V) which can be rearranged as

$$K = \frac{up - u}{up - uc} \qquad \text{(V-a)}$$

Example C

Find the form factor for the 6SF5 tube.

The dimensions of this tube were used in Example B, from which, for the circular case

$$nSc = 3.35$$

From Example A

$$nd = 0.297$$

From drawing M-69087-1A179

$u_G = 66$

For the plane case

$$S_p = \frac{0.253 - 0.085}{2} = 0.084"$$

$$nS_p = 0.084 \times 72.5 = 6.1$$

From drawing M-69087-1A179

$u_p = 120$

Then, from formula (V-a)

$$k = \frac{120 - 100}{120 - 66} = 0.371$$

The factor given by Jervis for an elliptical grid and a circular plate corresponding to the 6SF5 is 0.66, which indicates the desirability of finding a form factor in each special case.

Study of formula (III) indicates that in the region in which this formula is effective, which includes most practical cases, S has a form factor which should be equal to the Jervis factor.

For the above example

$$K_s = \frac{S_p - S}{S_p - S_c} = \frac{0.084 - 0.0704}{0.084 - 0.0465} = 0.363$$

The difference between K and Ks is 0.008 which is only 2.2% of K. This difference is no greater than the error involved in reading the curves.

We can now use form factors based upon S rather than μ, and can somewhat simplify calculations since it is no longer necessary to calculate u_p and u_G, but rather S_p and S_G. The proper form factor then gives the effective S, and only one calculation of μ is necessary.

Formula ?

Countersigned E. F. Peterson E F Peterson
Tube Division Sept. 26, 1946

J. E. Fowler J E Fowler
Tube Division Sept. 26, 1946

Nomenclature

μ - amplification factor

u_p - amplification factor for tube considered as a plane structure.

u_c - amplification factor for tube considered as a circular structure.

Δu - change in u

n - grid turns per unit length (TPI)

Δn - change in n

d - grid wire diameter

S - effective grid-plate spacing

= grid-plate spacing in plane structure

$= r_g \ln\left(\frac{r_p}{r_g}\right)$ in circular structure

r_g - radius of grid to center line of grid wire

r_p - inside radius of plate

D_g - diameter of grid

D_p - inside diameter of plate

Q - $\frac{1}{d}\frac{\partial \mu}{\partial n}$

ln - logarithm to base e

K - Jervis form factor

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(1) Bernard Salzberg

"Formulas for the Amplification Factor for Triodes". Proc. I.R.E. - Vol. 30, p. 134, March, 1942.

(2) F. B. Vodges and F. R. Elder

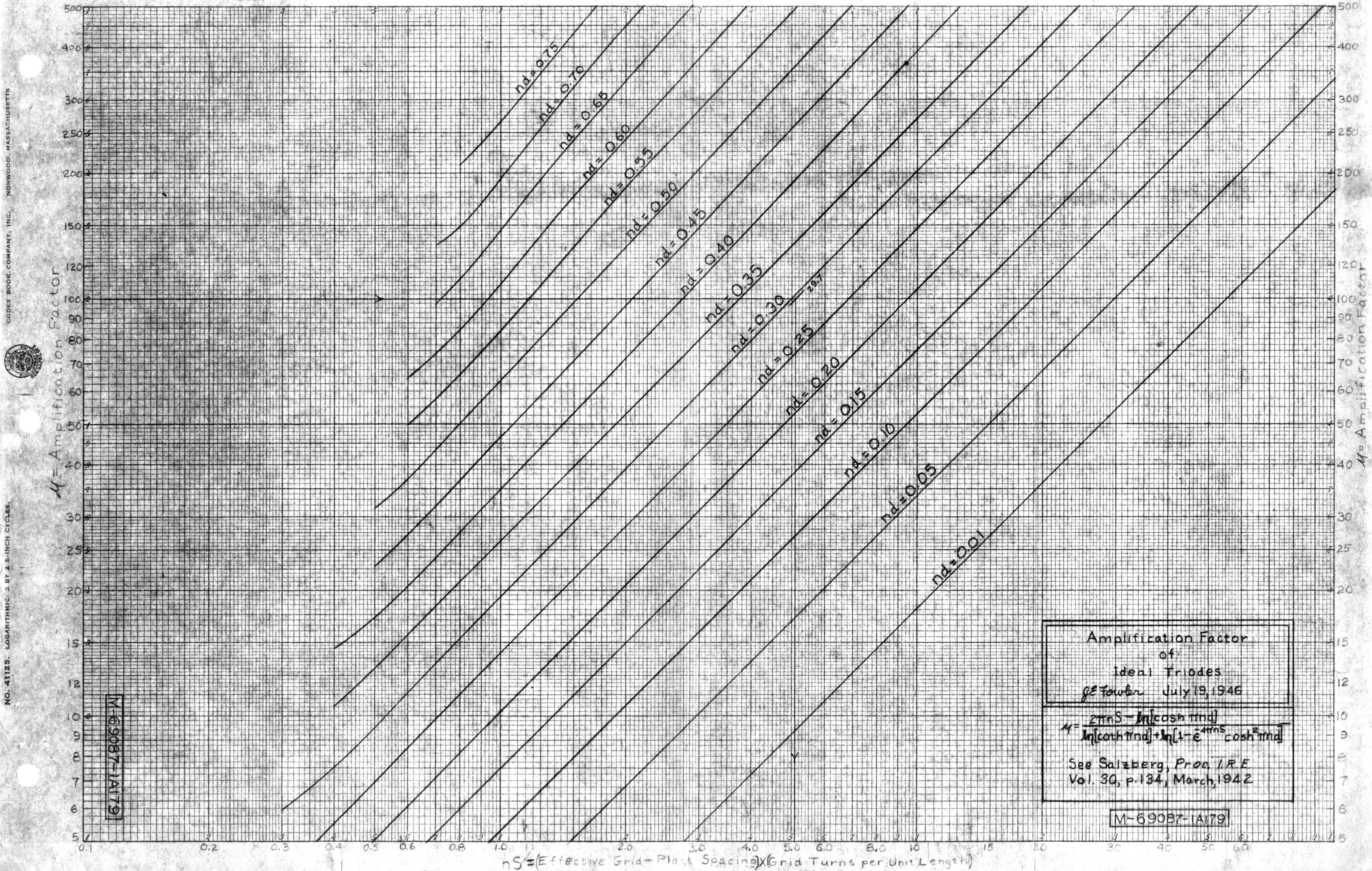
"Formulas for the Amplification Constant for Three Element Tubes." Phys. Rev. - Vol. 24, p. 683, December, 1924. See also F. E. Terman "Radio Engineers' Handbook" 1st. Edition, McGraw-Hill Book Co., 1943, p. 304.

(3) Y. Kusunose

"Calculation of the Characteristics and the Design of Triodes." Proc. I.R.E. Vol. 17, No. 10, p. 1706-1749, October, 1929. See also Terman, p. 305.

(4) E. R. Jervis

"Amplification Factor Chart" Electronics Vol. 12 - p. 45, June 1939. See also Terman, p. 307.


μ = Amplification Factor
nS = (Effective Grid-Plate Spacing) X (Grid Turns per Unit Length)
nd = 0.75
nd = 0.70
nd = 0.65
nd = 0.60
nd = 0.55
nd = 0.50
nd = 0.45
nd = 0.40
nd = 0.35
nd = 0.30
nd = 0.25
nd = 0.20
nd = 0.15
nd = 0.10
nd = 0.05
nd = 0.01
28.7
Amplification Factor
of
Ideal Triodes
J.E. Fowler July 19, 1946
μ = [2πnS − ln(cosh πnd)] / [ln(coth πnd) + ln(1 − e^(−4πnS) cosh² πnd)]
See Salzberg, Proc. I.R.E.
Vol. 30, p. 134, March, 1942
M-69087-1A179
NO. 41125. LOGARITHMIC: 3 BY 2.5-INCH CYCLES. CODEX BOOK COMPANY, INC., NORWOOD, MASSACHUSETTS

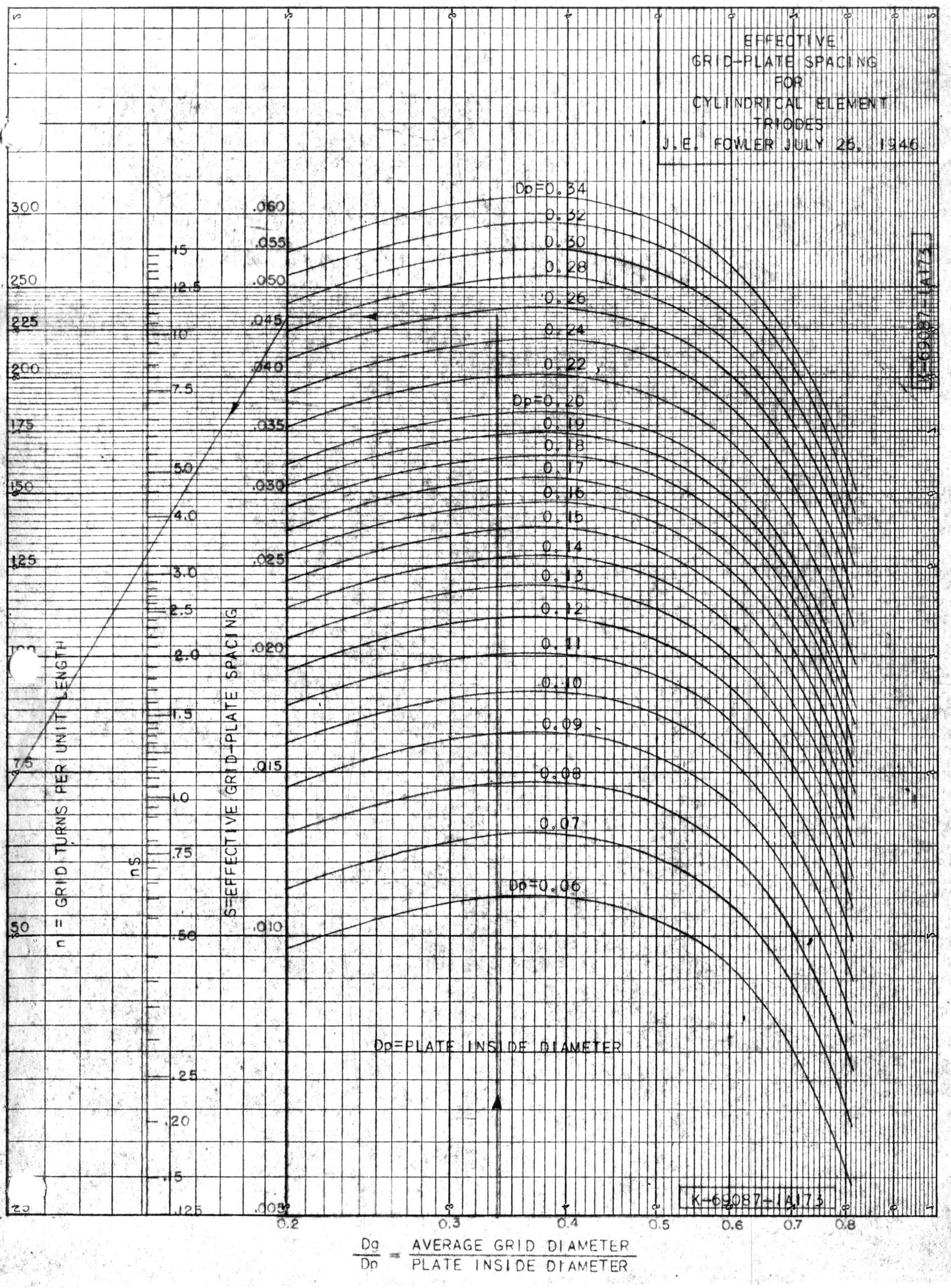

EFFECTIVE
GRID-PLATE SPACING
FOR
CYLINDRICAL ELEMENT
TRIODES
J.E. FOWLER JULY 26, 1946
n = GRID TURNS PER UNIT LENGTH
nS
S=EFFECTIVE GRID-PLATE SPACING
Dp=0.34
0.32
0.30
0.28
0.26
0.24
0.22
Dp=0.20
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
Dp=0.06
Dp=PLATE INSIDE DIAMETER
$\frac{Dg}{Dp}$ = $\frac{\text{AVERAGE GRID DIAMETER}}{\text{PLATE INSIDE DIAMETER}}$
K-69087-1A173

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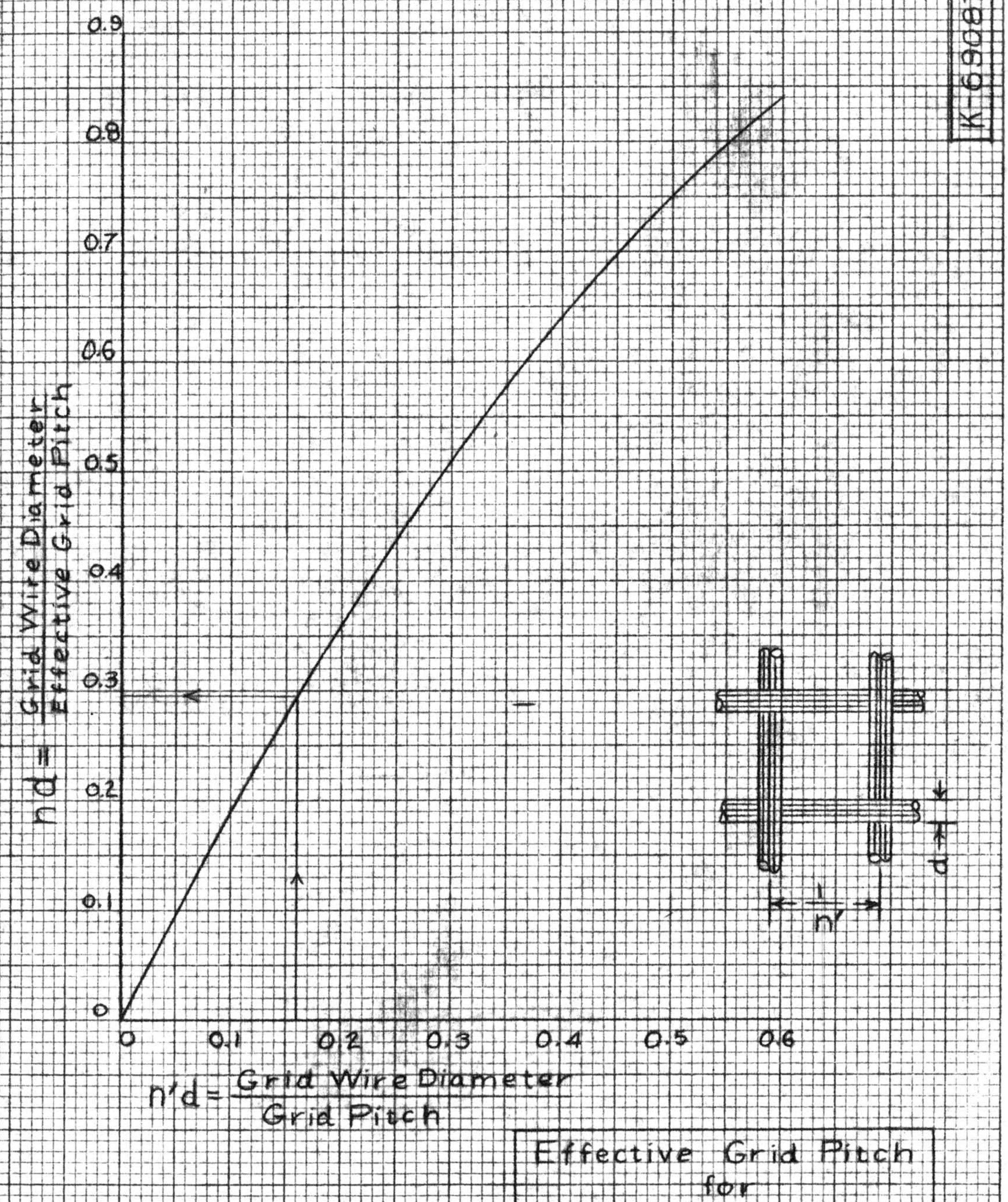
FIG.

FILE DATE



Effective Grid Pitch
for
Square Mesh Grids

J. E. Fowler July 11, 1946

K-69087-1A174

RTD-363-G (6-45) new (100-140-B)

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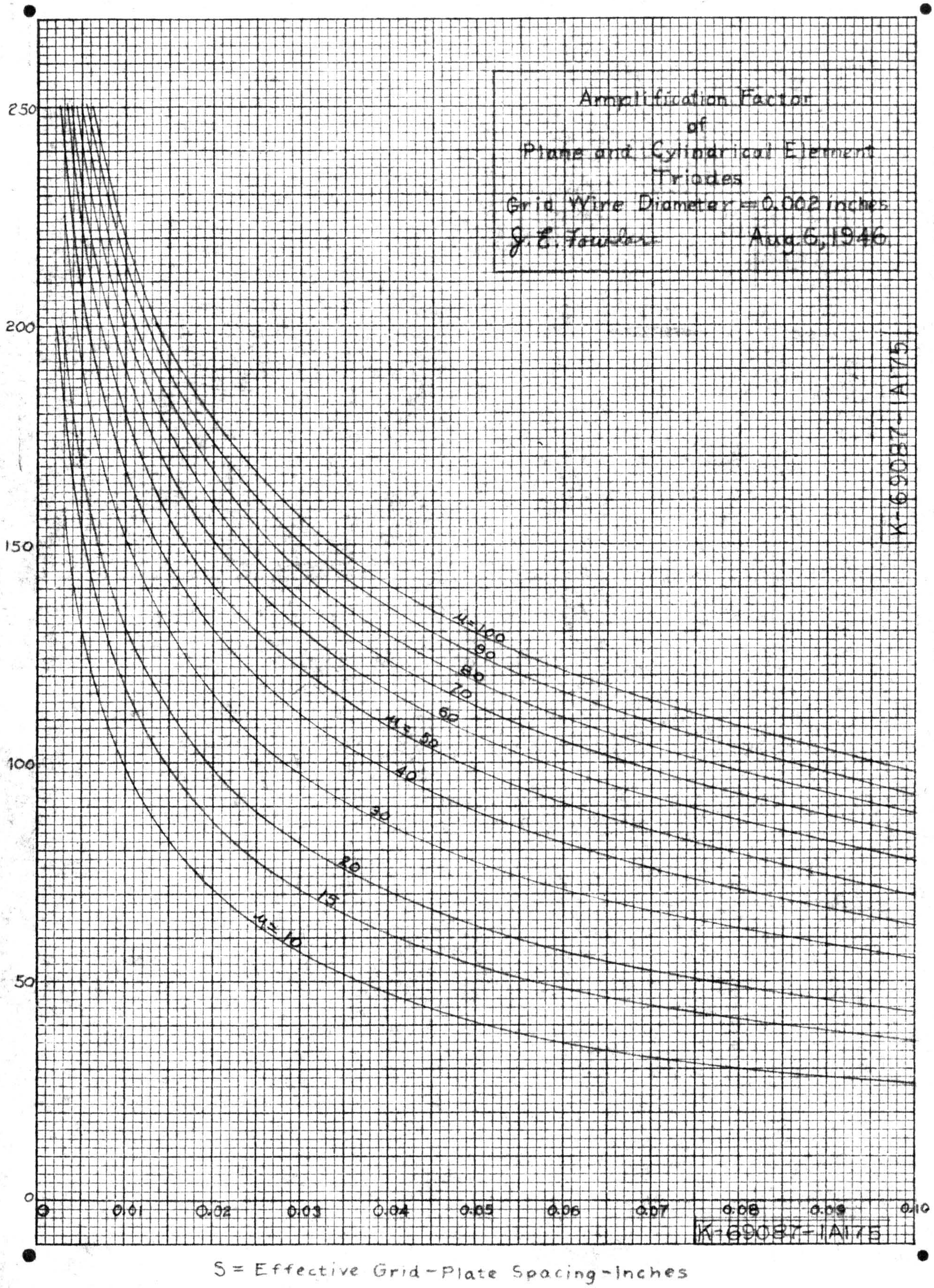
FIG.

FILE DATE



RTD-363-G (6-45) new (100-140-B)

ELECTRONICS DEPARTMENT
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ASSIGNED BY SEPT 27-46 RJL
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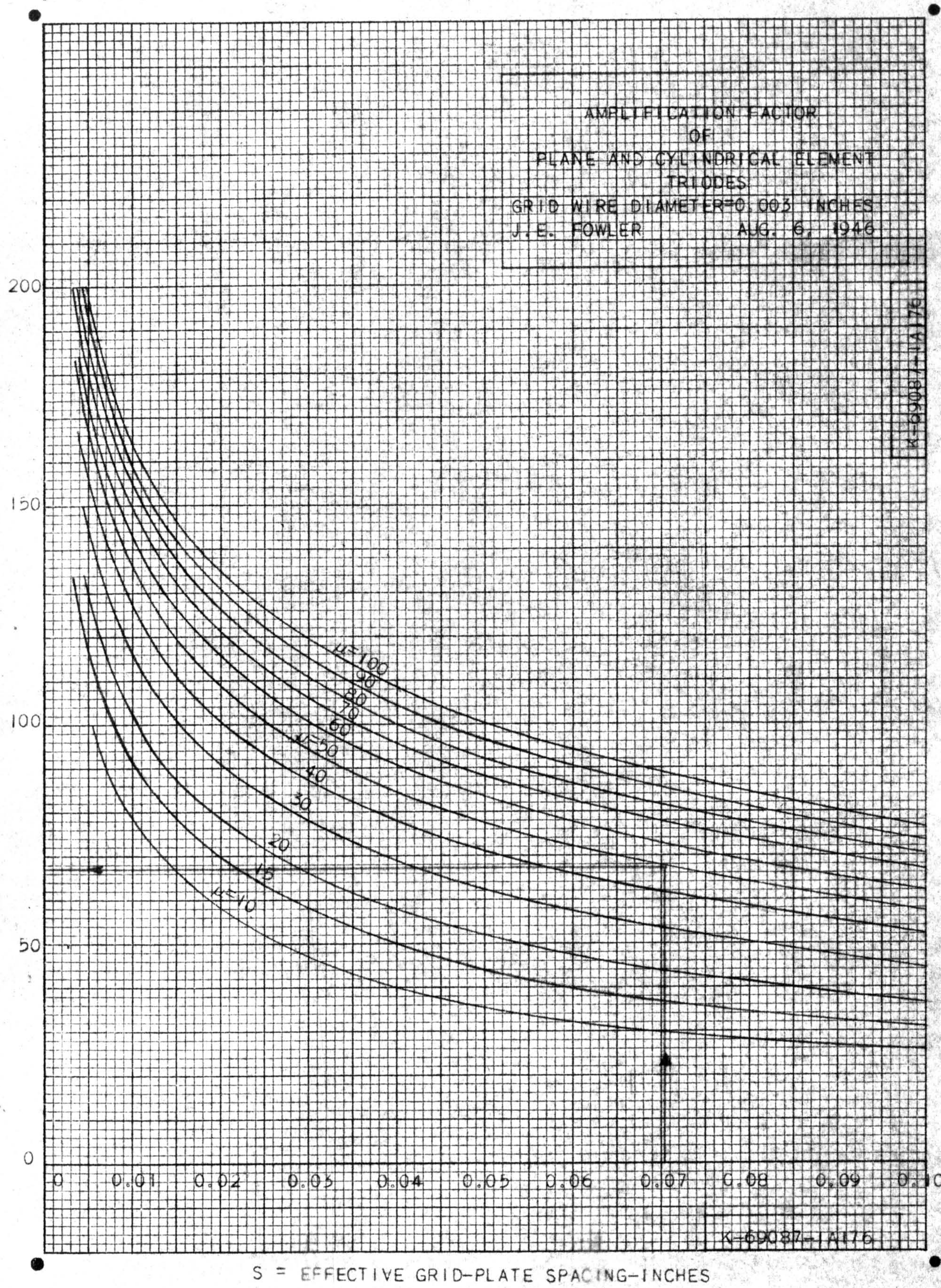
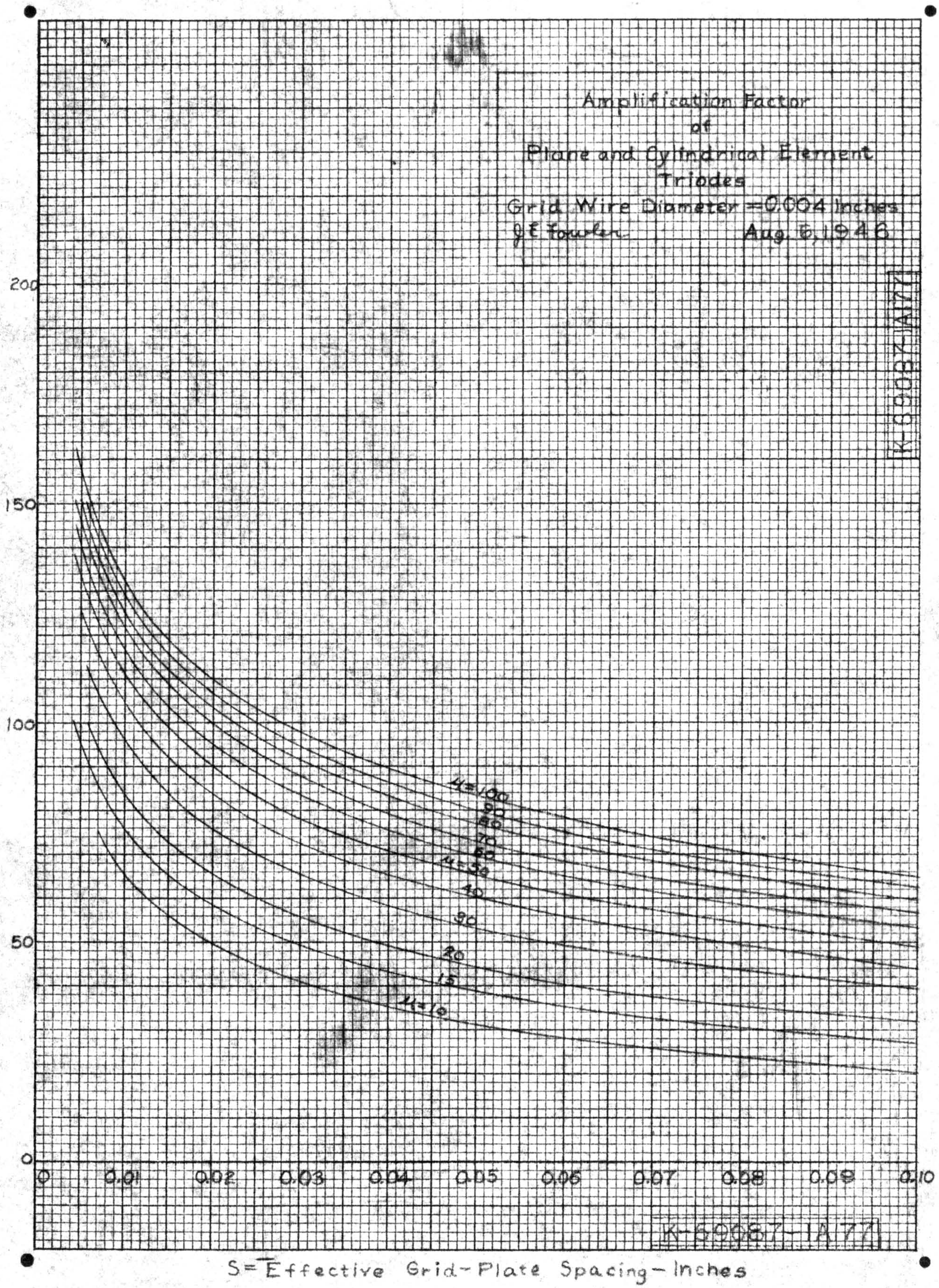
JK-9406

FIG. ______

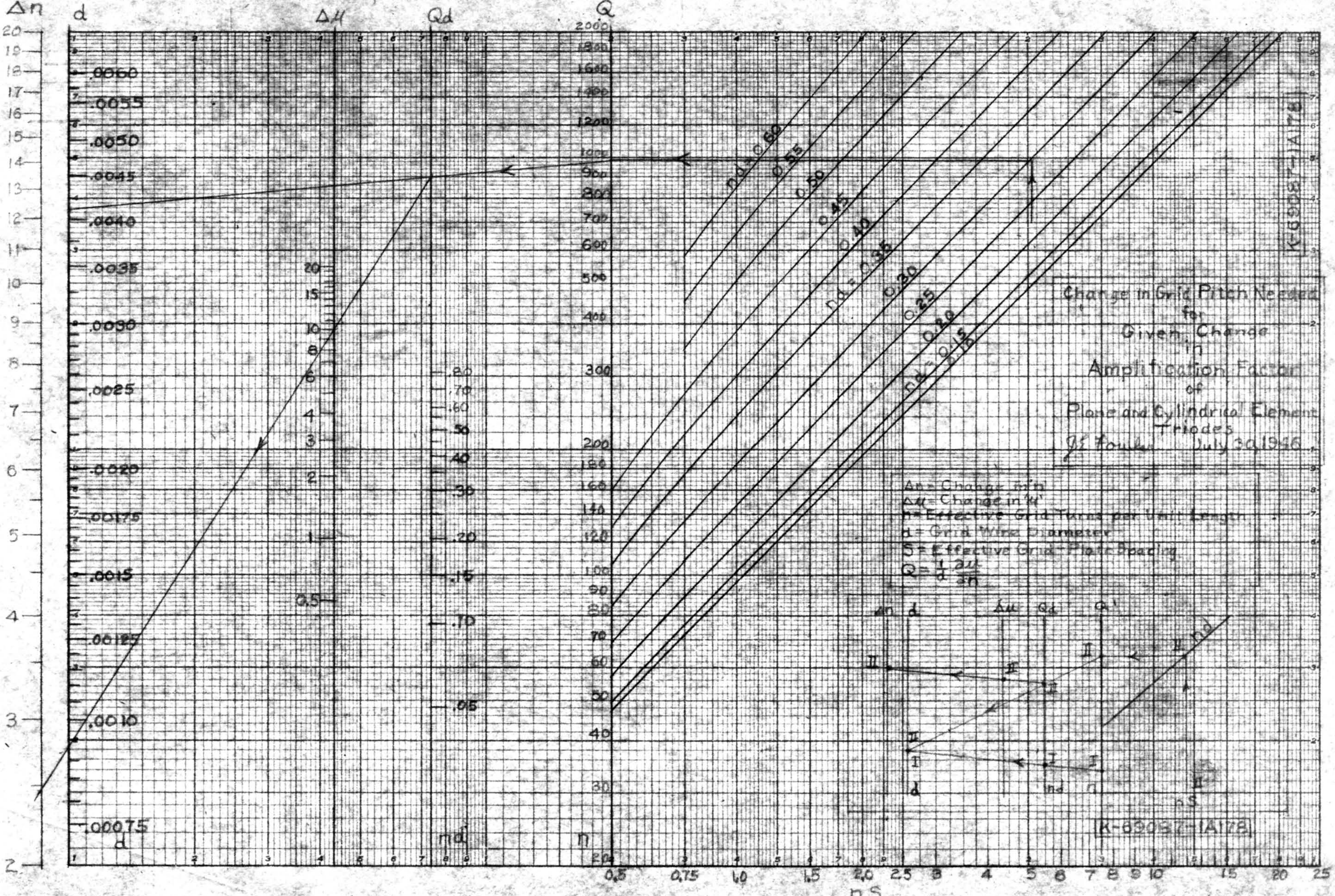
FILE ______ DATE ______



RTD-363-G (6-45) - new (100-140-B)


Amplification Factor
of
Plane and Cylindrical Element
Triodes
Grid Wire Diameter = 0.004 Inches
J E Fowler
Aug. 6, 1946
K-69087-IA77
n = Grid Turns per Inch
200
150
100
50
0
μ=100
90
80
70
60
μ=50
40
30
20
15
μ=10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.10
S = Effective Grid-Plate Spacing - Inches

K-69087-IA77



Change in Grid Pitch Needed
for
Given Change
in
Amplification Factor
of
Plane and Cylindrical Element
Triodes
July 30, 1946
Δn = Change in n
Δμ = Change in μ
n = Effective Grid Turns per Unit Length
d = Grid Wire Diameter
S = Effective Grid-Plate Spacing
Q = 1/d ∂μ/∂n
Δn
d
Δμ
Qd
Q
n
nd
nS
K-69087-1A178

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