

Appendix – Formulas used in TANKIT

There are eight key formulas or computer processes which determine the plate operating parameters in Path 1, and just two more for the cathode operating parameters in Path 2. They are listed here for those who are interested.

Formula 1 – Calculate $F01$

As mentioned in the text, $F01$ is central to TANKIT's ability to calculate several of the plate and cathode circuit parameters. $F01$ is a factor which is the ratio of the peak fundamental component of plate current, $i_{1\max}$, to the maximum-signal DC plate current, $I_{b\max}$. It is calculated from the ratio of $I_{b\max}$ to the no-signal (idling) plate current, I_{bo} , using this power series formula:

$$F01 = a + \frac{b}{x} + \frac{c}{x^2} + \frac{d}{x^3} + \frac{e}{x^4} + \frac{f}{x^5} \quad (\text{Eq 1})$$

where: $a = 1.5708342$, $b = -0.12247733$, $c = -0.40135184$, $d = 1.1419976$, $e = -1.5216604$, $f = 0.33265683$ and $x = I_{b\max}/I_{bo}$.

Equation 1 defines the curve in **Figure A1** for values of x in the range of 1 to 1000. However, its greatest usefulness lies in the range from approximately 1.8 to 50. Above $x = 50$, the curve flattens out and the $F01$ values don't change very much. When x is below 1.8, I_{bo} is more than half the value of $I_{b\max}$ and plate efficiency would be rather poor. For this and other reasons, it is recommended that you do not attempt to use TANKIT with ratios lower than 1.8.

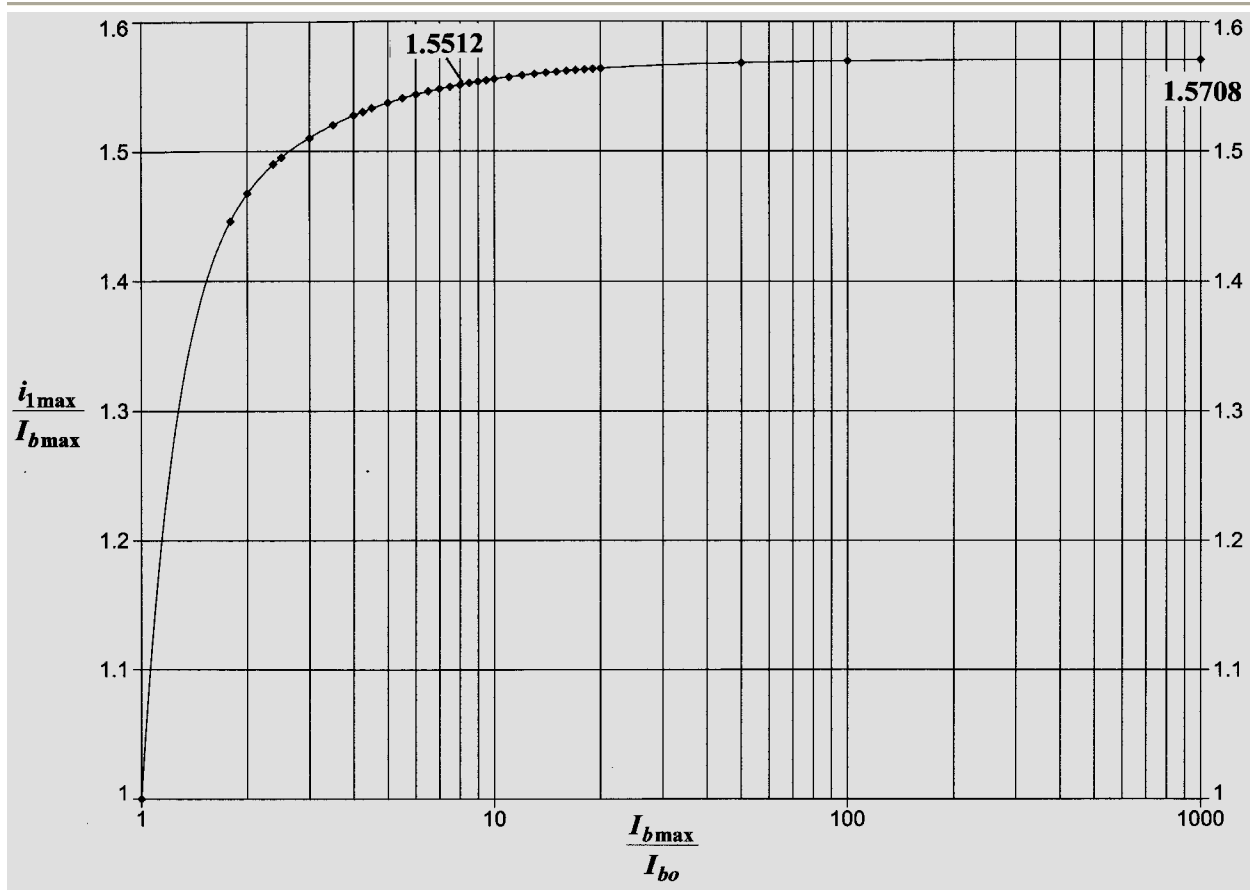


Figure A1 - Graph of Eq. 1. The F01 value that was obtained in the Path 1 walk-through is marked. The dots along the curve mark the coordinates that were input to the curve-fitting program

A similar curve has appeared for well over 30 years in the Radio Society of Great Britain’s *Radio Communication Handbook* in the chapter “Electronic Tubes and Valves,” where it is designated curve F8.¹ According to the text, the curves in that chapter were originally developed “by applying factors derived from a Fourier analysis of sine and sine squared pulses of appropriate angles of flow.” Although the value of curve F8 in making the TANKIT program possible was quite apparent, this cryptic explanation didn’t offer any hints as to how the curve could be incorporated into a computer program. The RSGB could not provide information about the original author nor the mathematics he used to

define the curve without “mining” their archives, and apparently there was no time for this. Therefore, a decision was made to “reverse engineer” the curve in order to derive Equation 1 from it. This was done by first manually converting the curve into a list of about 30 X-Y coordinate points, striving to maintain 5% or better accuracy while taking readings from the plotted curve (this is possible due to the excellent draftsmanship in the RSGB's publications). Then, several more points from the *RCA Transmitting Tubes Technical Manual*² were added to the list to cross check the other coordinate points. Finally, the complete list was processed through a remarkable curve-fitting program called *TableCurve 2D*^{TM,3}, the output of which is a listing of over 3000 potential equation solutions that define the curve with a greater or lesser degree of accuracy; fortunately, they are listed in order of “goodness of fit!” Although the equation above ranked eleventh in the list, it was selected because it not only fits the original curve extremely well (better than 99.995%, according to *TableCurve*), but also because it completely lacks any sign of oscillations or gyrations in the portion of the curve lying just outside the limits of the input coordinates (for values of x between 1 and 0, for instance); some of the higher-ranked equation solutions exhibited this disturbing behavior in their graphs and in practical terms they were no more accurate than number 11 in the list.

Despite the valuable contributions of this powerful curve-fitting program, full credit for the mathematical principles underlying the formula must be given to the (as yet) unidentified genius who laid down its foundations so many years ago.

Formula 2 – Calculate peak RF plate voltage swing

The formula for $e_{p\max}$ has two forms:

$$e_{p\max 1} = \frac{2 \times P_o}{i_{1\max}} \quad (\text{Eq 2a})$$

where P_o is power output *at the plate*; $i_{1\max} = F01 \times I_{b\max}$. Also,

$$e_{p\max 2} = \frac{2 \times \left(\frac{P_o}{Eff} \right)}{i_{1\max}} \quad (\text{Eq 2b})$$

where Eff is the user-specified overall plate output circuit efficiency as a decimal fraction; P_o is converted from load power to the equivalent power output at the plate.

Formula 3 – Calculate RF plate load resistance

R_L is the load resistance at the output of the pi or pi-L plate tank network *transformed* to the optimum plate load resistance presented at the network's input, all things being ideal. As for Equation 2, the calculation for R_L also has two versions:

$$R_{L1} = \frac{e_{p\max 1}}{i_{1\max}} \quad (\text{Eq 3a})$$

and

$$R_{L2} = \frac{e_{p\max 2}}{i_{1\max}} \quad (\text{Eq 3b})$$

where $e_{p\max}$ is the peak RF voltage developed *across* R_L and $i_{1\max}$ is the peak fundamental current flowing *through* R_L .

This method for calculating R_L is significantly more accurate than the usual “shortcut” formulas given in the amateur radio handbooks. The shortcuts, however, are adequate for Class C design work where plate current linearity is not so important.

Formula 4 – Calculate plate current conduction angle

Formula 4 isn't actually an equation; it's a computer procedure—namely, a loop. The idea behind this is simple: Given that it is possible to solve for the theoretical maximum plate efficiency for any plate current conduction angle (as demonstrated by Robert Craiglow in *QEX* for January/February, 2005⁴), and given that the theoretical plate efficiency (as a decimal number) can be determined by $F01/2$ (explained later under Formula 8), a programmed loop can be constructed to compare the two efficiency values while decrementing the angle (starting at 360° , or 2π radians). When the efficiencies match, the angle at that moment is the plate current conduction angle, θ_b . The key statements in

PowerBASIC are:

```

EffTest=F01/2
Rads=2*pi                '360 DEGREES IN RADIANS
DO UNTIL EffTheo=>EffTest  (Eq 4 IS A LOOP)
EffTheo=.5*(Rads-SIN(Rads))/(2*SIN(Rads/2)-Rads*COS(Rads/2))
  IF Rads>pi THEN          'LIMIT LOOP TO => 180 DEGREES
    Rads=(Rads-.0001)
  ELSE

```

```

EXIT LOOP
END IF
LOOP
Deg=Rads*180/pi           'PLATE CURRENT CONDUCTION ANGLE

```

The central equation for EffTheo(etical) comes right from Craiglow's article, referenced above.

Formula 5 – Calculate peak RF plate current

The calculation for $i_{p\max}$ comes from another gem found in Craiglow's *QEX* article.⁵ This time Robert's equation was arranged to solve for $i_{p\max}$, given the plate current conduction angle θ_b (from Equation 4) and $I_{b\max}$:

$$i_{p\max} = 2 \times I_{b\max} \times \pi \times \frac{\left(-1 + \cos\left(\frac{\theta_b}{2}\right) \right)}{\left[-2 \times \left(\sin\left(\frac{\theta_b}{2}\right) \right) + \theta_b \times \cos\left(\frac{\theta_b}{2}\right) \right]} \quad (\text{Eq 5})$$

Formula 6 – Calculate two-tone equivalent DC plate current

Formula 6 is derived from one used back in the '50s at Penta Laboratories, a maker of power tubes, for calculating peak tube currents. It was brought to the attention of the amateur radio community by Leigh Norton, W6CEM.⁶ But, the old equation seems to be accurate only near the Class B plate conduction angle of 180°; as the angle increases for Class AB operation the results become less accurate. Equation 6 is an attempt to update Norton's equation by taking into account the changing relationship between peak and DC plate currents at

increasing plate current conduction angles. As set up here, the equation solves for two-tone DC plate current given $F01$, $I_{b\max}$ and I_{bo} :

$$I_{b2tone} = \frac{(-I_{b\max} - \pi \times z \times I_{bo} + F01 \times z \times I_{bo})}{(-\pi + F01)} \quad (\text{Eq 6})$$

where $z = (F01 - 1) / F01$.

The new equation seems to give accurate results in limited testing against several tube manufacturers' data where two-tone DC plate currents are specified.

Formula 7 – Calculate single-tone DC plate current from two-tone DC plate current

As mentioned in the text, TANKIT uses single-tone DC plate current in many of its calculations. When the user has only two-tone data available it must be converted to the equivalent single-tone value. Here, as in Equation 4, a programmed loop is used to arrive at the equivalent single-tone plate current.

Note that Equations 1 and 6 are imbedded in this *PowerBASIC* loop:

```
F01trial = 1.001           'INITIALIZE STARTING F01 VALUE
WHILE F01trial <= 1.5708  'CONFINE LOOP TO CLASS AB OR B
  z = (F01trial - 1)/F01trial
  Ibltone = (Pi - F01trial)*(Ib2tone - z*Ibo)  (Eq 7)
  '*****
  'x1 = RATIO OF MAXIMUM SIGNAL PLATE CURRENT Ibltone
  '   TO NO-SIGNAL (IDLING) PLATE CURRENT Ibo
  '*****
  x1 = Ibltone/Ibo
  IF x1 > 1000 THEN x1 = 1000  'x1 LIMITS ARE 1 TO 1000
  '*****
  'F01 = RATIO OF PEAK FUNDAMENTAL COMPONENT OF PLATE
```

```

' CURRENT ilmax TO MAXIMUM SIGNAL PLATE CURRENT Ib1tone
'*****
F01 = a1+b1/x1+c1/x1^2+d1/x1^3+e1/x1^4+f1/x1^5 'Eq 1
IF F01 = 1.0 THEN F01 = 1.001 'PREVENT ZERO FACTOR BELOW
z = (F01 - 1)/F01
Ib22 = (-Ib1tone - Pi*z*Ibo + F01*z*Ibo)/(-Pi+F01) 'Eq 6
IF Ib22 <= Ib2tone THEN
    EXIT LOOP '2-TONE/SINGLE-TONE CONVERSION COMPLETE
END IF
F01trial = F01trial + .0001
WEND
Ibmax = Ib1tone 'SET Ibmax TO LAST SINGLE-TONE VALUE IN LOOP

```

The loop continually compares a sample two-tone plate current (obtained by converting a closely-spaced series of single-tone values to two-tone) with the user's two-tone plate current. When they match, the single-tone value at that moment becomes $I_{b\max}$.

Formula 8 – Calculate theoretical maximum plate efficiency

The simplest way to calculate the theoretical maximum plate efficiency is:

$$Eff_{(theoretical)} = \frac{F01}{2} \quad (\text{Eq 8a})$$

This works because $F01$ is the ratio of the peak fundamental component of plate current, $i_{1\max}$, to the maximum-signal DC plate current, $I_{b\max}$. If we may mathematically paraphrase Orr from his *Radio Handbook*, 23rd edition,⁷ this ratio can be expressed as:

$$F01 = \frac{2 \times N_p \times E_b}{e_{p\max}} \quad (\text{Eq 8b})$$

where N_p is the actual plate efficiency as a decimal fraction. However, in the case of the *theoretical* maximum plate efficiency, $e_{p\max} = E_b$ (the impossible condition discussed in the *TANKIT User’s Guide*), so this equation then becomes:

$$F01 = 2 \times N_{p(\text{theoretical})} \quad (\text{Eq 8c})$$

and solving for N_p we get:

$$N_{p(\text{theoretical})} = \frac{F01}{2} \quad (\text{Eq 8d})$$

The theoretical efficiency may also be found with Craiglow’s Equation 11, as referenced and used in Formula 4.

Formula 9 – Calculate cathode drive “feed-through” power

This may not be the most important of all of TANKIT’s numbers, but here’s how it is estimated:

$$P_{ft} = \frac{e_{k\max} \times i_{1\max}}{2} \quad (\text{Eq 9})$$

where $e_{k\max}$ is the peak cathode drive voltage; dividing the product by 2 gives RMS power. The actual P_{ft} will be a little less due to losses within the tube and its socket, etc. Note that if P_{ft} ever exceeds about 95% of your cathode driving power p_d (as measured at the cathode), a condition which often indicates bad data was entered somewhere along the line, P_{ft} will be flagged in a magenta color, both on the screen and in the printed report. This is the only TANKIT parameter so flagged.

Formula 10 – Calculate cathode drive resistance

To enable a reasonably well-centered cathode input tank design to be achieved it is important to know the cathode's driving resistance. However, be aware that the cathode resistance estimated by TANKIT is not exact, and furthermore this value is affected by any mistuning in the plate tank network as well as by tube manufacturing tolerances. Nevertheless, since the cathode's driving resistance is usually fairly low and since the cathode tank usually has a rather low operating Q of about 3 or so, the tank response should be broad enough such that your driver doesn't see a severe mismatch anywhere in the band, given proper tuning and operation. The formula is simple:

$$R_k = \frac{e_{k \max}^2}{2 \times p_d} \quad (\text{Eq 10})$$

where p_d is the driving power *at the cathode*; the actual driving power needed at the input to the cathode tank will be somewhat more than this due to various losses in the tank and in the tube itself.

References

¹ *Radio Communication Handbook*, 7th Edition, Radio Society of Great Britain, 1999, p. 4.13, Fig. 4.21.

² *RCA Transmitting Tubes Technical Manual TT-5*, Radio Corporation of America, 1962, Table I, p. 46

³ *TableCurve 2D™*, a product of Systat Software, Inc, www.systat.com

⁴ R. L. Craiglow, "RF Power Amplifier Output Impedance Revisited," *QEX*, Jan/Feb 2005, Equation 11, p. 31

⁵ Op. cit., Equation 7, p.31

⁶ L. Norton, W6CEM, "Power Ratings," Technical Correspondence, *QST*, Oct 1957, p. 49, and *Single-Sideband for the Radio Amateur*, 2nd edition, ARRL, 1958, p. 149

⁷ W. I. Orr, W6SAI, *Radio Handbook*, 23rd Edition, Howard W. Sams & Co., 1987, Equation 8, p. 15-6