# TANKIT – A Design Aid for Vacuum Tube Linear RF Power Amplifiers
## >>> Description and User's Guide <<<

By Keith A. Kunde, K8KK

Originally, the TANKIT program was intended to be just a calculator for determining a transmitting tube's RF plate load resistance ($R_L$) and the corresponding component values for an all-band pi or pi-L plate tank network. Its design goals seemed simple: Calculate $R_L$ with a degree of accuracy comparable to an expertly-performed graphical analysis of a tube's constant-current plate characteristic curves, then design a tank network to reflect that load resistance using Elmer Wingfield's (W5FD) tank design equations, including support for $C_{\min}$. Furthermore, it was to do this without requiring any special expertise on the part of the radio amateur user.

Although achieving these goals turned out to be not so simple, when they finally had been realized (after several years of part-time effort) it was noticed that a factor in the load resistance calculation could also be used to develop several other plate circuit operating parameters. With the addition of these new values, TANKIT can now give interested amateurs quick and easy access to the kind of technical operating data for power tubes that was formerly utilized chiefly by electronics professionals or technically advanced amateurs. This data makes it possible to predict the full range of plate circuit operating conditions for a new linear amplifier design *before* construction has begun, potentially leading to a better design result and better operating performance. The data can also help the amateur to better understand a tube's plate circuit operating parameters and how they interact with the operation of the grid and screen. Of course, as its name suggests, TANKIT also provides a very fast and easy way to design new or replacement pi or pi-L tank circuits for almost any tube-based amateur power amplifier project.

## Overview of TANKIT

The TANKIT program has three main functional blocks, called *paths*:

### Path 1. Calculate Plate Circuit Operating Parameters

This function path may be used for any type of tube operating in Class AB or B linear amplifier service, whether grid- or cathode-driven. It calculates several important plate circuit operating parameters which aren't ordinarily available except by performing a laborious graphical analysis of the tube's constant-current characteristic curves. In just a few moments, an amateur using TANKIT can determine:

$i_{1\max}$, peak fundamental component of RF plate current

$e_{p\max}$, peak RF plate voltage swing

$R_L$, RF plate load resistance

$\theta_b$, plate current conduction angle

$i_{p\max}$, peak RF pulse plate current

$I_{b2tone}$, the DC plate current, under two-tone modulation, which produces a PEP output signal having the same peak level as a specified single-tone PEP output signal (this is very handy for tuning up; TANKIT also supports the reverse of this function)

$N_{p\max}$, the *theoretical* maximum plate efficiency at plate conduction angle $\theta_b$, for comparison against actual plate efficiency

(Note: The symbols used throughout the text are chiefly as defined in Orr's *Radio Handbook*;[1] see the chapter titled "Radio-Frequency Power Amplifiers.")

All of the above information is developed from the typical operating data for a power tube without the need to perform a graphical analysis of the tube's characteristic curves. To run this path, only three operating parameters are needed as input:

$I_{bo}$, the tube's no-signal (idling) DC plate current, in mA

$I_{b\max}$, the tube's maximum-signal (single- or two-tone) DC plate current, also in mA

$P_o$, maximum-signal (PEP) output power, in watts

Sources for these parameters include the tube manufacturer's data sheets, handbook tube tables, or even the internet. You may also find such data given in the text of articles on linear amplifiers.

**Path 2. Calculate Cathode Circuit Operating Parameters**

This function path applies only to grounded-grid (cathode-driven) amplifier designs. It provides an estimate of two cathode circuit operating parameters:

$P_{ft}$, converted drive power or "feed-through" power

$R_k$, cathode drive resistance

This information is developed using either (but preferably both) the peak cathode driving power, $p_d$, and/or the peak cathode driving voltage, $e_{k\,\max}$. The peak fundamental component of plate current, $i_{1\max}$, is also used here; it is either passed through from Path 1 or it is calculated within Path 2 itself.

**Path 3. Design a Pi or Pi-L Tank Circuit**

This path may be run in conjunction with the above function paths or it can be run separately if, for example, you wish to design a tank for a Class C amplifier. If Path 3 is started immediately following Paths 1 or 2, the RF plate load resistance, $R_L$, (for a plate output tank) or the cathode drive resistance, $R_k$, (for a cathode input tank) is passed through to the tank design path automatically—you do not need to enter these values. If you decide to run this path by itself then you must enter the appropriate input and load resistance values manually, along with the desired tank operating Q.

The output from Path 3 is a table of tank capacitance and inductance values for every amateur band from 160 meters through 6 meters (with the exception of 60 meters). Wingfield's tank design equations are used and minimum circuit capacitance, $C_{\min}$, is supported.[2,3] The effect which $C_{\min}$ has on tank operating Q as the operating frequency increases is instantly apparent.

**Printing TANKIT's Reports**

Each path produces an output report which may be printed on any *Windows* printer accessible from your computer. Line printers (LPT1, etc.) are not supported.

## A "Walk" Through TANKIT

Although TANKIT is a modern 32-bit *Windows* application program (written in *PowerBASIC Console Compiler 4.03*[4]), it uses a mouse-free screen interface that will be familiar to anyone who once used the old DOS BASIC. That interface is simple to program and serves very well for this application. In the following "walk" through TANKIT's functions (for a grounded-grid, Class $AB_2$, 2 kW linear utilizing the venerable *Eimac* 3CX1500A7 / 8877 ceramic-metal triode) all input screen fields are shown filled in with example values.

Note that plate current values must be entered in ***milliamperes***. Some input fields have default values which can be recalled by entering a question mark (**?**) in the blank field. When your data entry is complete, you may continue on to the output report screen or go back and edit the data. The edit function starts the input screen over but leaves your previously entered data in place—just hit enter to keep it, or type your new data right over the old (ignore any old data that sticks out beyond the new). You may also switch paths at this point by returning to the main menu. Terminate TANKIT by clicking the "X" in the upper right corner of TANKIT's window.

Now, let's see how simple it is to use TANKIT as we "walk" through its functions. Start the program and select Path 1 to begin collecting data for the plate circuit operating parameter calculations.

## Path 1 – Plate parameters

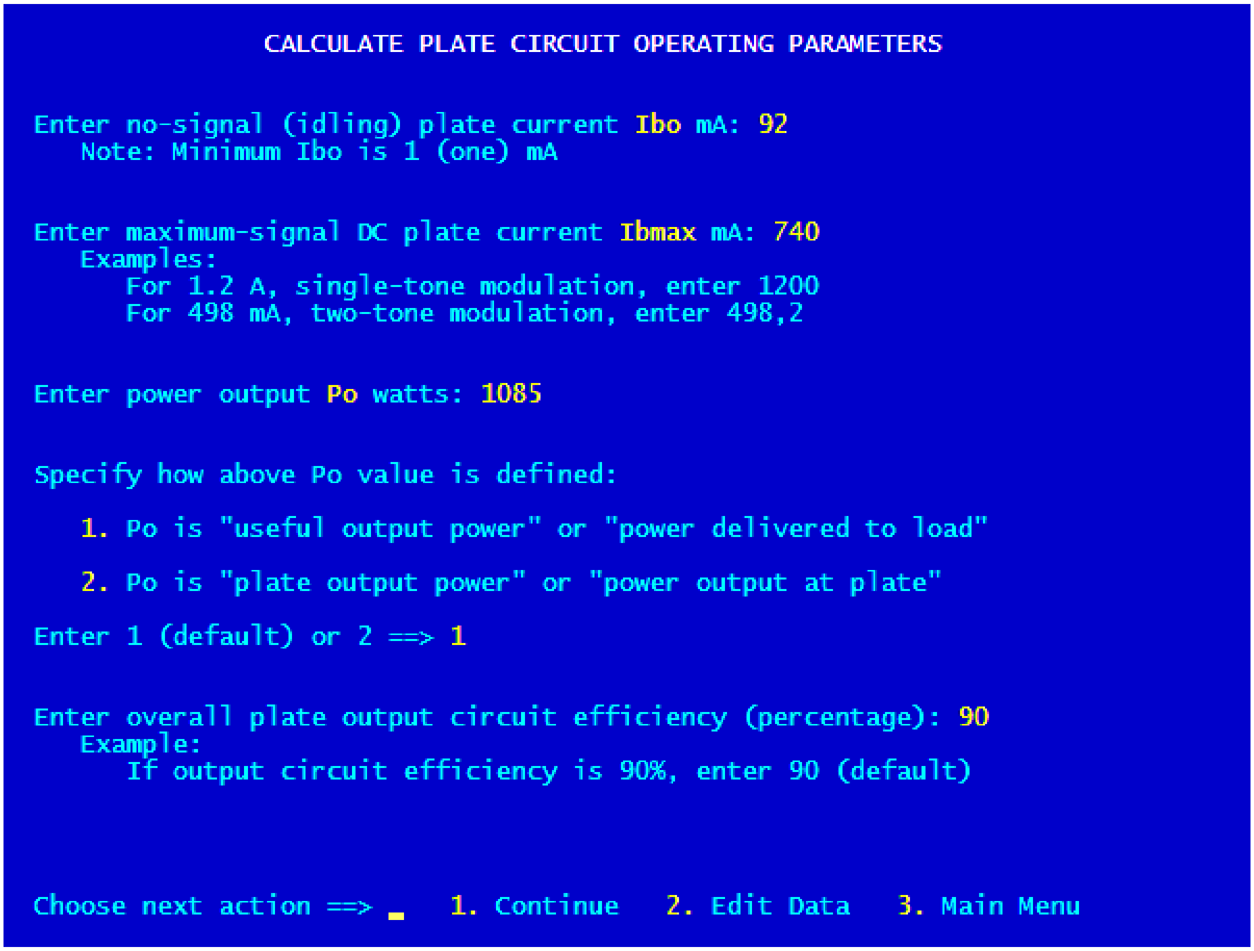


**Figure 1 -- A complete path 1 input screen with sample data**

**Figure 1** shows a completely filled-in Path 1 input screen. Since a tube's power output can be specified either "at the plate" or "at the load," TANKIT needs to know which point of reference to use. If the specification is "power delivered to the load" (a.k.a., "useful output power"), then an estimate of the percentage of plate output circuit efficiency must also be entered; this is the percentage of plate output power which actually reaches the load, and it typically ranges from nearly 95% at the lower amateur band frequencies to 85% or less at 6 meters (power loss occurs in the tank due to removal of harmonic energy from the plate output pulse, as well as from losses in the tank components and other plate circuitry). Since "power delivered to the load" is specified in our example, an overall plate output circuit efficiency must also be entered; the 90% used here is typical of the average tank circuit efficiency across the amateur HF frequencies. The efficiency prompt is omitted when power output "at the plate" is specified.

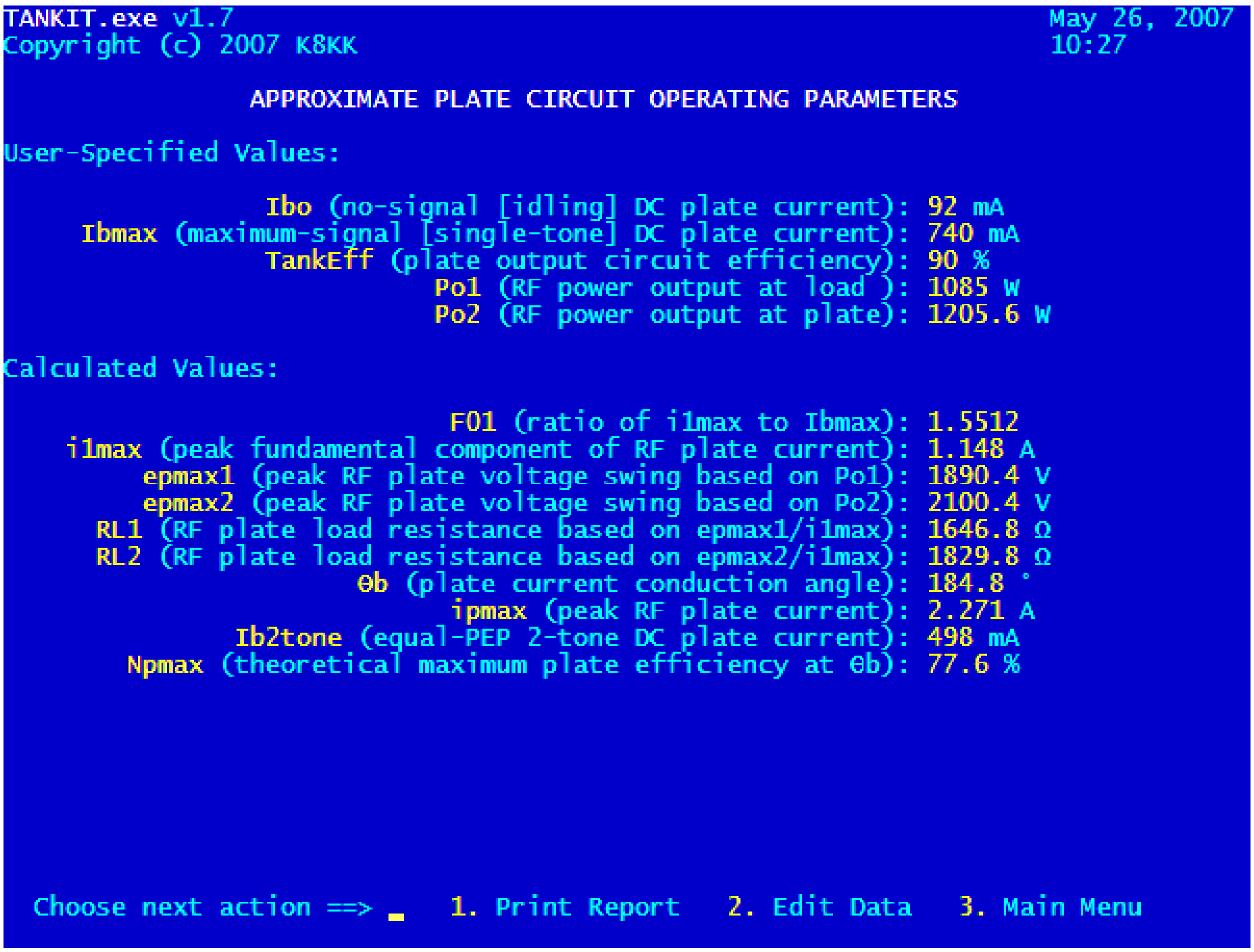


**Figure 2 - Plate Circuit Operating Parameters report**

After hitting the enter key to continue (next action 1 in Figure 1), the plate parameters are calculated and the report screen in **Figure 2** is displayed.

The top section summarizes your input data, including a new figure for power output at the plate, $P_{o2}$, which is derived from the "delivered to the load" power output figure that you entered. Many of TANKIT's internal calculations require the plate output power. If you specify power output "at the plate" both $P_o$ numbers will be the same.

The lower section of the report lists the calculated plate circuit operating parameters described below (the major formulas used are listed in the appendix).

$\boldsymbol{F01}$**:** This parameter is a factor which is central to TANKIT's ability to calculate the other plate circuit parameters, but it has no immediate application here; please refer to the appendix of formulas if you wish to see how this parameter is calculated and used.

$\boldsymbol{i_{1\max}}$**:** Next comes $i_{1\max}$, the peak fundamental component of plate current which flows in $R_L$, the input impedance of the resonant tank circuit. It's called the fundamental component because it's at the same frequency as the driving signal; there are also many harmonic components present in the pulses of RF plate current. The tank's "flywheel effect" transforms the pulses of fundamental-frequency plate current into sine waves which are passed through to the output load, while simultaneously the tank's low-pass filtering action bypasses the harmonic components to ground.

$\boldsymbol{e_{p\max}}$**:** The fundamental frequency RF plate voltage reaches peaks as it swings in both the positive-going and negative-going directions across $R_L$, as referenced to the DC plate supply voltage, $E_b$ (i.e., the sine wave of RF plate voltage is centered on the DC plate voltage level); either peak may be designated $e_{p\max}$. The negative-going peak is the one used in a graphical analysis of tube operating characteristics. Together with $i_{1\max}$, $e_{p\max}$ accounts for the tube's maximum-signal (PEP) output:

$$P_{o(plate)} = \frac{i_{1\max} \times e_{p\max}}{2} \qquad \text{(Eq 1)}$$

The product of these peak sine wave values is divided by 2 in order to obtain the RMS plate power output.[a]

Notice that two figures are given for $e_{p\max}$ in the report: one is based on $P_{o1}$, the other on $P_{o2}$. The purpose for showing both of these values is to allow you to verify that $e_{p\max 2}$, the figure normally used, is "reasonable"; that is, you should verify that the peak swing of RF plate voltage doesn't approach the tube's full DC plate supply voltage $E_b$ too closely, or perhaps even exceed it. If the calculated $e_{p\max 2}$ swing crowds or exceeds the DC plate supply voltage while $e_{p\max 1}$ seems to be the one that is more reasonable, perhaps the tube's $P_o$ figure was misstated as being "at the load" when it was actually "at the plate"? Otherwise, it is likely that one of the other input values is faulty, or perhaps the $E_b$ supply voltage you have in mind for your amplifier is not high enough to support the stated input conditions. On the other hand, insufficient RF plate voltage swing will result in reduced power output and plate efficiency.

[a] A peak sine wave value may be converted to RMS by multiplying by .707. Since two peak values are being multiplied, the conversion is .707 x .707 ≈ .5, the same as dividing by 2.

Looking at our example (please refer to the plate voltage scale along the bottom of the graph in **Figure 3**, below), the plate supply voltage $E_b$ is to be 2700 V (according to the manufacturer's data sheet), so the negative-going $e_{p\max 2}$ swing of 2100 V leaves 600 V of instantaneous DC plate voltage (called $e_{b\min}$) remaining. As long as our peak grid driving voltage stays well below $e_{b\min}$, grid current should stay within ratings and plate output distortion products should also be low. If the peak grid and/or screen voltage is crowded too much by the peak downward swing of RF plate voltage, the grid or screen currents may become excessive (depending on the tube's internal design, or "geometry" as it is often called) and it is likely that splatter-producing distortion products in your output signal would rise to intolerable levels (note: in a "grounded-grid" amplifier the effective grid voltage is equal to the cathode voltage, but opposite in polarity). The RF plate voltage swing can become excessive in actual operation if the amplifier's output loading is too light or if the drive level is too high. These conditions can result in high grid currents, reports of splatter on your signal and shortened tube operating life.

$\boldsymbol{R_L}$**:** Next comes what TANKIT was intended for in the first place: the calculation of the optimum RF plate load resistance, $R_L$, which allows the tube to produce its greatest power output with the least signal distortion for that power level. Again two figures are given, with $R_{L2}$ being the one normally used. It is interesting to make small adjustments to the input data and watch the effects on $R_L$ and the other plate operating parameters—everything moves! This points up the importance of operating your linear amplifier as closely as possible to the design operating conditions which you specify.

$\boldsymbol{\theta_b}$**:** Each pulse of plate current flows during some fraction of a 360-degree cycle of the input driving signal. The plate current conduction angle is designated $\theta_b$ (theta-b). A pure Class B amplifier has a $\theta_b$ of 180° because the bias is set just at the point of plate current cutoff (i.e., there is very little or no idling plate current). The sine wave driving waveform can only produce a pulse of RF plate current that is 180° in duration when it drives the grid positive with respect to the cathode. Practical linear amplifiers operating in Class AB (i.e., with bias set at *less* than the point of plate current cutoff, meaning there is some static plate current) may have conduction angles ranging up to 210°, or thereabouts. Beyond that point plate efficiency is rather poor and there is little advantage to the amateur in such operation. The conduction angle is usually controlled by adjustment of the tube's operating bias.

$\boldsymbol{i_{p\,\mathrm{max}}}$**:** The plate current at the peak of the RF pulse, $i_{p\,\mathrm{max}}$, is a useful figure if you *optionally* decide to plot an operating line (commonly called a load line) on a chart of constant-current plate curves for your tube. **Figure 3** shows a portion of Eimac's *Curve #4250* for the 3CX1500A7 / 8877 in grounded-grid service.

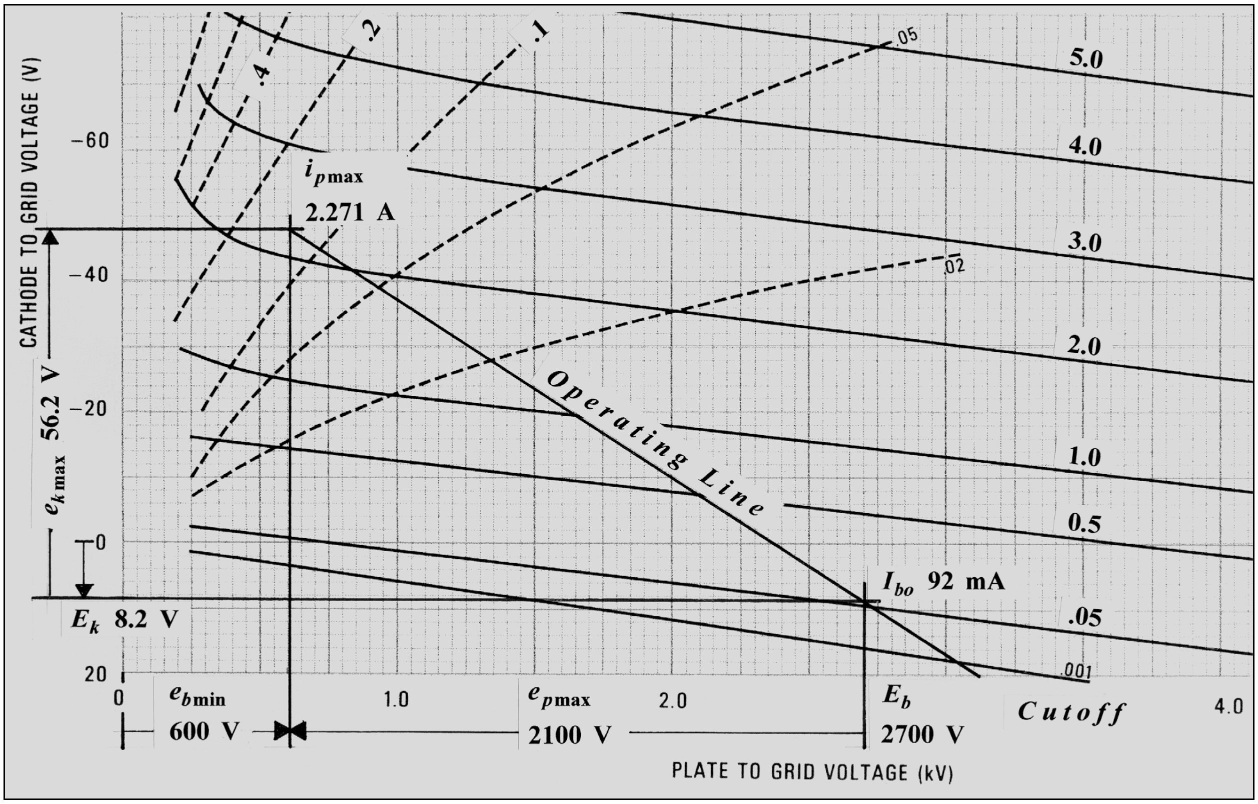


**Figure 3 - Constant-current chart for the *Eimac* 8877 in grounded-grid service; an operating line per the text example is shown. The solid curves represent plate current while the dashed curves are grid current (both given in amperes).**

Note that the upper end of the operating line begins where $i_{p\,\max}$ and the instantaneous minimum plate voltage with respect to ground, $e_{b\,\min}$, intersect. From there, the line extends downwards through the intersection of the idling (no signal) DC plate current, $I_{bo}$, and the plate supply voltage, $E_b$. The line continues past that point all the way down to plate current cutoff. If this was a Class B amplifier, $I_{bo}$ would be zero (i.e., at plate current cutoff) and the line would end right there. Since the line extends *below* the $I_{bo}$ level, we know that $I_{bo}$ is not zero and the plate current conduction angle is greater than 180°; therefore, this is a Class AB amplifier.

$I_{bo}$ is set by the cathode bias voltage, $E_k$, indicated on the left-hand vertical scale; + 8.2 V in this case (reading downwards from the zero (0) volts mark). The peak cathode driving voltage, $e_{k\max}$, is found by *adding* the bias voltage to the "Cathode to Grid Voltage" indicated on the scale directly to the left of the $i_{p\max}$ point you marked earlier; that voltage is about – 48 V in this example (reading upwards from zero (0) volts). The peak, or total swing, of the driving voltage (ignoring signs) is 8.2 V + 48 V, or 56.2 V (in other words, the sine wave of the driving signal is centered on the bias level). This swing, by the way, is the peak voltage *at the cathode*, not at the input of the cathode tank network.

$\boldsymbol{i_{g\max}}$**:** The value of $i_{g\max}$, the peak grid current, may be interpolated from the dashed grid current curves—visualize another dashed curve passing through the $i_{p\max}$ point at approximately 0.14 A (140 mA) of peak grid current. This tells us that our tube is operating in Class $AB_2$ since considerable grid current is drawn at the peak of the driving waveform. TANKIT doesn't directly calculate any grid current values but they may be easily discerned on a chart of constant-current curves—the grid and screen curves which pass through the intersection of $i_{p\max}$ and $e_{b\min}$ are the peak current values for those elements.

You can learn more about tube theory and the graphical analysis methods by visiting Eimac's website—some excellent material on power tubes is available free for downloading there.[5] If you're already skilled in the graphical analysis technique, you may wish to know how TANKIT can assist you in that process—see "Special procedure for graphical analysis users" on page 24.

We are finished with Figure 3 for now. Continuing with the remaining plate circuit operating parameters in the report, we come to:

$\boldsymbol{I_{b2tone}}$**:** Some tubes are rated for SSB PEP output levels that, if sustained, will result in greatly shortened tube life. Such tubes may have their maximum-signal DC plate currents specified only for *two-tone* modulation conditions. The manufacturer is warning you that it is inadvisable to operate the tube under full-power single-tone (or carrier) conditions for more than a few seconds; if you exceed this limitation you may damage or destroy the tube. TANKIT can help you here, in two ways:

First, if the manufacturer gives only a two-tone DC plate current specification, you may enter that figure *directly* as your $I_{b\max}$ input value in Path 1. Simply follow the plate current with **,2** (comma 2—no space); for example, **498,2**. This tells TANKIT that $I_{b\max}$ is a two-tone value of 498 mA and it must be converted into the equivalent-PEP single-tone value before any internal calculations are done. Be aware that the plate parameters report will show the *converted* single-tone $I_{b\max}$ value in the "User-Specified" section of the report, while the two-tone value which you actually entered will be in the $I_{b2tone}$ field in the "Calculated Values" section.

The second way TANKIT can help is illustrated using the case of the *Eimac* 3CX1500A7 / 8877. Although this manufacturer gives single-tone DC plate current in the typical operating data, during tune-up you may prefer to use a two-tone test signal to reduce plate dissipation and the power dissipated in your dummy load. Remember that *average* two-tone power output is only half of single-tone output, while *PEP* output (i.e. the peak level of the modulation envelope) is the same as for single-tone. But, what should the DC plate current be to assure that full PEP output is being reached with two-tone modulation?

Simply refer to the $I_{b2tone}$ field in TANKIT's plate parameters report. Assuming you first ran Path 1 using a single-tone DC plate current of 740 mA in the $I_{b\max}$ field, $I_{b2tone}$ will be 498 mA. To tune up, apply your two-tone test signal and tune for a plate current of 498 mA. Briefly switch to single-tone modulation and your plate meter should read close to 740 mA—the full power single-tone value.

**Important!** Remember that the amplitude of your single-tone test signal must be set to exactly *twice* the amplitude of either tone of your two-tone test signal, or the single-tone / two-tone plate currents will not hold their proper relationship.

For example, if your single-tone test signal's amplitude is 100 millivolts peak-to-peak (at the driver's mic input) when the DC plate current is 740 mA, then each tone of your two-tone test signal should be set to exactly 50 millivolts peak-to-peak. Your two-tone DC plate current should then be 498 mA (the reverse of this case is also true). This assumes that your SSB driver's audio bandpass is essentially flat at the test tone frequencies.

A switchable two-tone / single-tone test signal generator which can be set to the proper output levels (with a switch to alternate between the mic and the test generator) would greatly simplify the above test procedure. This allows you to limit your full-power tune up time to just a second or two for verification that your plate current is where you want it to be.

**$N_{p\max}$:** Finally, TANKIT shows $N_{p\max}$, the *theoretical* maximum plate efficiency for a given plate current conduction angle, $\theta_b$. It's theoretical because this number is based on the hypothesis that the negative-going peak of the RF plate voltage is somehow able to swing all the way from $E_b$ down to zero, in which case $e_{p\max}$ would be 2700 V. In theory, this would give the maximum plate efficiency—*if* it was possible. But, since $e_{b\min}$ would then be zero, there would be no instantaneous positive DC plate voltage left to drive current through the plate circuit! If we decide to ignore that pesky bit of reality and work Equation 1 for $P_o$ anyway, we get a result of 1549.8 W PEP output. Dividing this by our input power, $P_{in}$ (the product of $E_b \times I_{b\max}$, or 1998 W), we get a theoretical plate efficiency of 77.6%.

When $e_{b\min}$ is pushed too low the grid (and/or screen) can become more positive than the plate and act like a plate electrode, intercepting the electron stream and potentially dissipating a large amount of power—the grid(s) can easily be damaged or even vaporized (unless they're made of *theoretium*, of course). Therefore, don't attempt this operation at home (by leaving the plate circuit unloaded, for example) unless you really *want* to turn your final tube into a gassy diode. However, by using either $P_{o(plate)} / P_{in}$ or $(e_{p\max 2} / E_b) \times N_{p\max}$ to calculate your actual plate efficiency, you can compare it to the theoretical number and hum thoughtfully while contemplating that cold one waiting for you in the refrigerator.

### Path 2 – Cathode Parameters

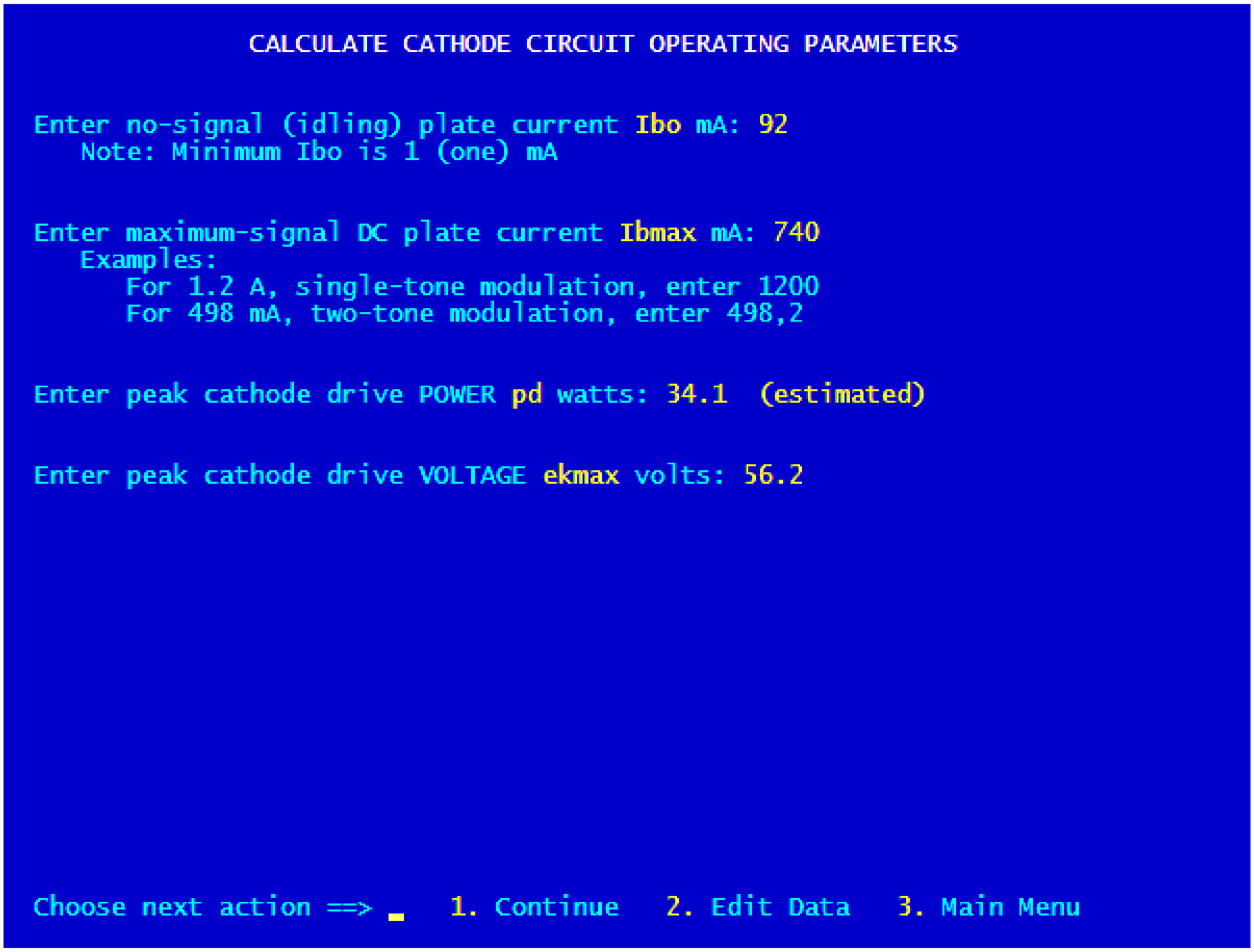


**Figure 4 - A complete Path 2 input screen**

The input screen for Path 2 is similar to Path 1, with the exception of two new input fields: peak cathode drive power, $p_d$, and peak cathode drive voltage, $e_{k\,max}$, which replace some of the plate path queries. TANKIT requires that only *one* of the new fields be known—enter 0 (zero) in the unknown field and it will be (roughly) estimated for you. However, calculation accuracy is likely to be much better if both input fields have known good values. **Figure 4** shows a completed Path 2 input screen with an estimated $p_d$ value that was filled in by TANKIT (the user initially entered **0** in the $p_d$ field; TANKIT overwrote the field with the estimated value after the user entered the $e_{k\,\max}$ value).

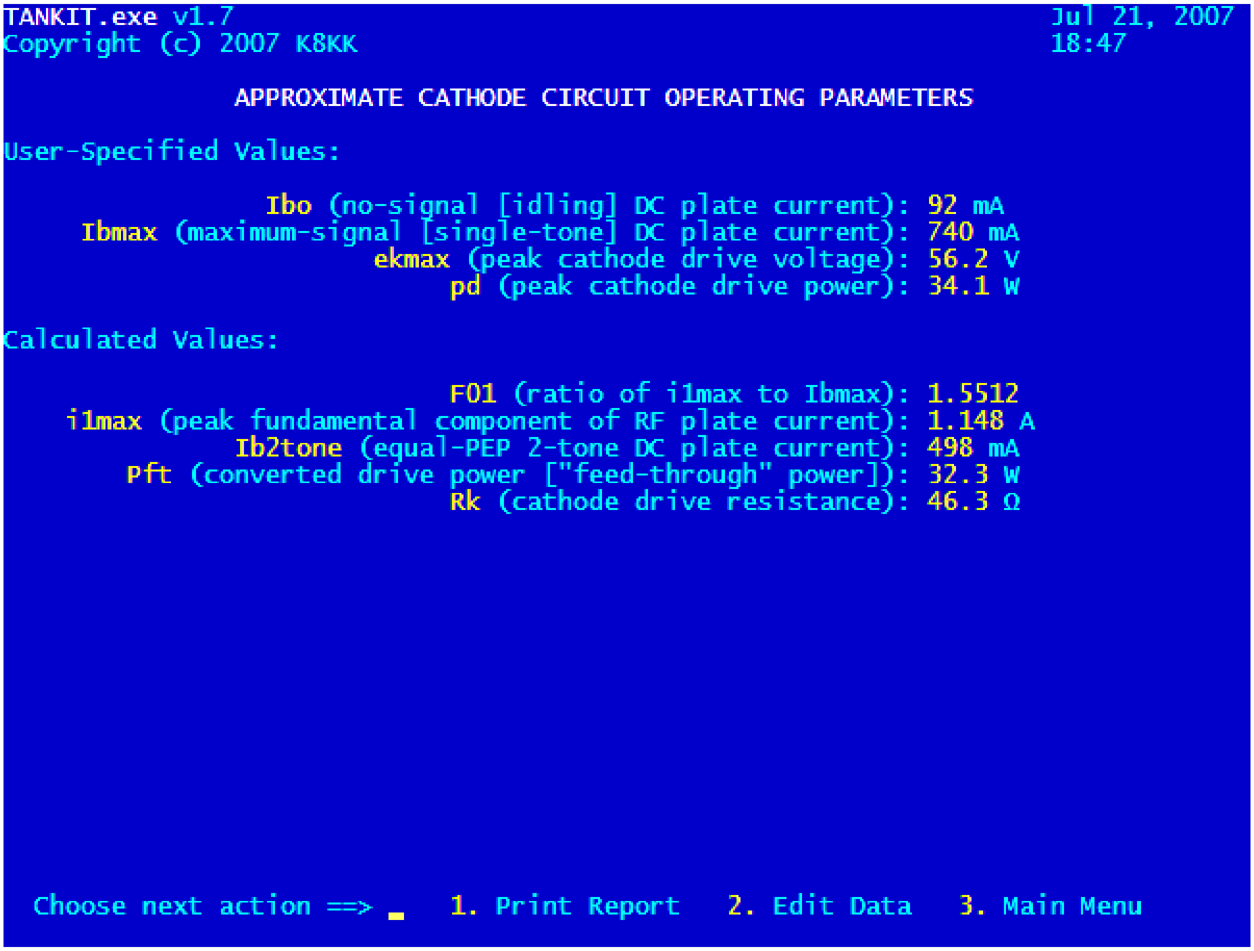


**Figure 5 -- The Path 2 output report screen**

The cathode parameters report screen in **Figure 5** is also similar to the Path 1 report screen. There are two new parameters in the Calculated Values section: $\boldsymbol{P_{ft}}$ **and** $\boldsymbol{R_k}$**:** Here, of course, the focus is on the cathode side of the tube. The new calculated values are the estimated feed-through power, $P_{ft}$, and estimated cathode drive resistance, $R_k$.

The cathode parameters from this path may be somewhat rough in regards to accuracy, due to input data limitations. However, for amateur power amplifier design purposes TANKIT's cathode data can be helpful when no other source of more accurate information is available.

**Path 3 – Tank Design**

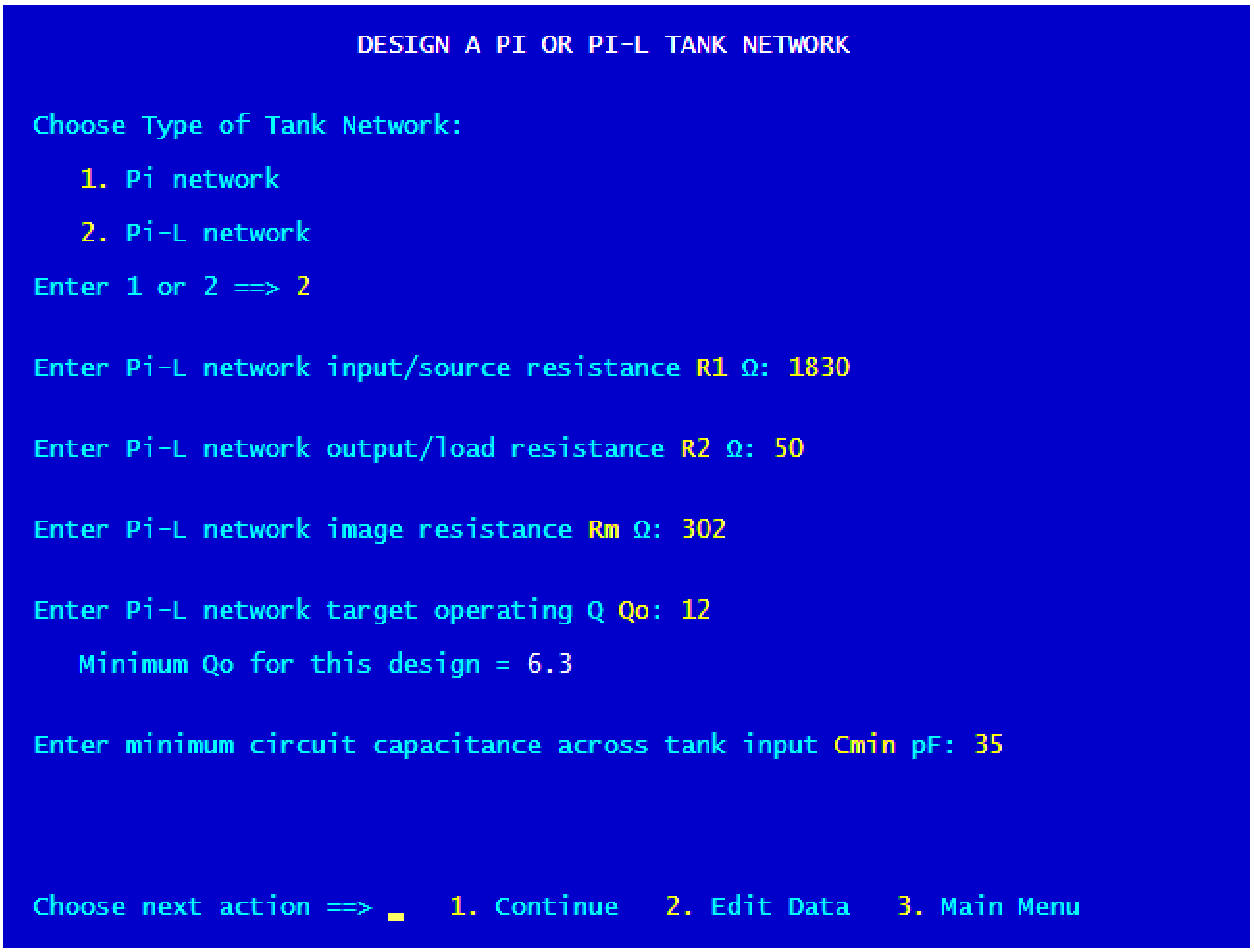


**Figure 6 -- A completed Path 3 input screen for a pi-L plate tank network**

As stated earlier, Path 3 may be entered immediately following Path 1 or Path 2 in order to design an appropriate plate or cathode tank circuit. When this is done, the $R_L$ value from Path 1 or the $R_k$ value from Path 2 is passed automatically to the appropriate Path 3 input field. The tank output resistance for a plate tank and the tank input resistance for a cathode tank defaults to 50 ohms, unless otherwise stated. If you are running Path 3 by itself then you will need to enter the $R_L$ or $R_k$ value. **Figure 6** shows a completed Path 3 input screen for the design of a pi-L plate tank network. The value of $R1$ was passed through from Path 1 where it was known as $R_{L2}$. $R2$ is a default value—just hit enter to get it, or enter a question mark in the blank field to display the default; if you like it, hit enter. Or, you may enter a new value for $R2$.

For a pi-L tank design the image resistance, $R_m$, must be defined. TANKIT calculates a default value that is the *geometric mean* of the network's input and output resistances—just hit enter to get this value. However, you may enter your own value for $R_m$ if you wish.

Next, the desired network operating Q, $Q_o$, must be specified. Note that TANKIT has pre-determined a *minimum* operating Q value, 6.3 in this case. The minimum $Q_o$ value is based on the network's input/output impedance ratio and can be surprisingly high for tank networks to be used with tubes having high plate impedances (i.e., those operating with relatively high plate voltage versus relatively low plate current, such as the old glass tetrodes and pentodes, etc.). If you proceed with a $Q_o$ that is less than the recommended minimum you might end up with a tank that won't tune or load correctly across the entirety of each amateur band. If you don't specify a $Q_o$ value the default is the displayed minimum value, which may be too low for adequate harmonic suppression.

In this example, we entered the commonly-used $Q_o$ value of 12 as our target value. It's called a "target" because, when we restrict our tank design by not allowing input capacitance C1 to drop below a certain minimum value called $C_{\min}$ (35 pF in this case), $Q_o$ is forced to rise as frequency increases. If you set $C_{\min}$ to zero, your target $Q_o$ will indeed appear at all upper band-edge frequencies but this is not realistic for most plate tanks because some calculated C1 values may then become impossibly small **(Note:** TANKIT does not support target $Q_o$ values less than 2.0. This limitation should not impact most practical tank designs).

**Figure 7** shows our pi-L tank's calculated component values for each band. The approximate network $Q_o$ is given for the bottom-edge frequency, mid-band frequency and high-edge frequency of each band. Notice how $Q_o$ rises dramatically in the higher frequency bands on the right side of the report. Since the peak circulating current in the tank is approximately $i_{1\max} \times Q_o$, high $C_{\min}$ values (and 35 pf isn't all that high) can drive up $Q_o$ and the circulating current with consequently greater losses and component heating, etc. Unfortunately, the problem gets worse with higher plate load resistances.

TANKIT's network designs are based on fixed inductance values for L1 and L2, so whenever the target $Q_o$ is 6.0 or more the calculated $Q_o$ must increase slightly at the mid- and low-edge frequencies within each band, whether or not $C_{\min}$ is specified (but if the target $Q_o$ is less than 6.0, the calculated $Q_o$ at the high-edge frequency may be slightly less than the target value, while at the low-edge frequency it may be slightly higher than the target value).

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PI-L NETWORK COMPONENT VALUES

Input Resistance R1 = 1830 Ω Output Resistance R2 = 50 Ω
Image Resistance Rm = 302 Ω Cmin = 35 pF Target Operating Q Qo = 12.0

| BAND | FMHz | C1 | L1 | C2 | L2 | Qo | BAND | FMHz | C1 | L1 | C2 | L2 | Qo |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 160m | 1.800 | 378.9 | 29.59 | 1608 | 9.42 | 13.3 | 17m | 18.068 | 35.4 | 3.07 | 149 | 0.99 | 12.5 |
| | 1.897 | 340.7 | 29.59 | 1449 | 9.42 | 12.6 | | 18.118 | 35.2 | 3.07 | 148 | 0.99 | 12.4 |
| | 2.000 | 306.3 | 29.59 | 1306 | 9.42 | 12.0 | | 18.168 | 35.0 | 3.07 | 147 | 0.99 | 12.4 |
| 80m | 3.500 | 200.5 | 15.00 | 850 | 4.77 | 13.7 | 15m | 21.000 | 36.2 | 2.23 | 146 | 0.84 | 14.6 |
| | 3.742 | 175.2 | 15.00 | 745 | 4.77 | 12.8 | | 21.224 | 35.4 | 2.23 | 143 | 0.84 | 14.4 |
| | 4.000 | 153.1 | 15.00 | 653 | 4.77 | 12.0 | | 21.450 | 35.0 | 2.23 | 138 | 0.84 | 14.3 |
| 40m | 7.000 | 91.3 | 7.85 | 389 | 2.50 | 12.5 | 12m | 24.890 | 35.3 | 1.63 | 132 | 0.72 | 16.3 |
| | 7.148 | 87.5 | 7.85 | 373 | 2.50 | 12.3 | | 24.940 | 35.1 | 1.63 | 132 | 0.72 | 16.3 |
| | 7.300 | 83.9 | 7.85 | 358 | 2.50 | 12.0 | | 24.990 | 35.0 | 1.63 | 131 | 0.72 | 16.3 |
| 30m | 10.100 | 61.0 | 5.54 | 260 | 1.76 | 12.1 | 10m | 28.000 | 39.2 | 1.19 | 141 | 0.62 | 20.1 |
| | 10.125 | 60.7 | 5.54 | 259 | 1.76 | 12.0 | | 28.837 | 36.9 | 1.19 | 133 | 0.62 | 19.5 |
| | 10.150 | 60.4 | 5.54 | 257 | 1.76 | 12.0 | | 29.700 | 35.0 | 1.19 | 124 | 0.62 | 19.0 |
| 20m | 14.000 | 44.9 | 3.96 | 191 | 1.26 | 12.3 | 6m | 50.000 | 40.8 | 0.36 | 126 | 0.34 | 35.4 |
| | 14.174 | 43.8 | 3.96 | 187 | 1.26 | 12.1 | | 51.962 | 37.7 | 0.36 | 117 | 0.34 | 34.0 |
| | 14.350 | 42.7 | 3.96 | 182 | 1.26 | 12.0 | | 54.000 | 35.0 | 0.36 | 108 | 0.34 | 32.8 |

C = pF L = μH

Choose next action ==> 1. Print Report 2. Edit Data 3. Main Menu

**Figure 7 -- The Path 3 output report screen with pi-L tank component and Qo values**

The "hinge" point or reference frequency for the fixed inductor calculations (which applies whenever $Q_o$ is above 6.0) is the *upper* band edge frequency, not the mid-band frequency as may be expected. This is necessary to accommodate support for $C_{\min}$, the absolute minimum capacitance value at the high-edge frequency. However, when $Q_o$ is 6.0 or less, the hinge point moves to mid-band and support for $C_{\min}$ is dropped (it isn't needed when $Q_o$ is that low, anyway).

This enables slightly better fixed-tune characteristics for low-Q cathode pi tank networks (don't use a pi-L design for the cathode tank—it's not practical).

The network component value table makes it possible to determine how much of the tank capacitance for each band actually needs to be variable. Please refer to Figure 7 again. Note that out of the approximately 200 pF maximum value of C1 required for the 80 meter band, there is less than a 50 pF change from the high band-edge frequency to the lower edge. However, this range needs to be expanded by at least ± 10% (use ± 20% for 160 meters) to allow for variations in the output load's resistance and reactance. For example, using the 10% figure, *subtract* 10% from C1's value at the high-edge frequency and *add* 10% at the lower band edge. Now take the difference—the total range of variability needed has expanded to about 75 pF. A 100 pF variable in parallel with, say, a 135 pF fixed capacitance should do the job here. But, don't forget that 35 pF of the total C1 capacitance consists of $C_{\text{min}}$ (the sum of the tube's output capacitance, C1's minimum capacitance, and all other stray circuit capacitances), so in this case the parallel fixed capacitor needs to be only about 100 pF.

The pi network component table is very similar to the pi-L table, except the L2 output inductor column is omitted and $Q_o$ moves over to take its place.

This concludes our "walk" through TANKIT's basic functions.

## Special procedure for graphical analysis users

TANKIT was written as an aid to amateurs who aren't skilled in the traditional graphical analysis techniques which are based on a tube's constant-current characteristic curves. However, if you do have the skill required to analyze tube performance that way, you can still use TANKIT to help with some of the calculations and verify other data obtained graphically. The process as it stands today requires iterating (repeating) Path 1 until certain calculated values come into agreement with your plotted values (i.e., converge with them).

Begin by plotting a trial operating line on your graph of constant-current curves and note the values for $I_{bo}$, $i_{p\max}$ and $e_{p\max}$. Start TANKIT Path 1 and enter your plotted $I_{bo}$ value (if zero, enter one milliampere). Next, enter an *estimate* for $I_{b\max}$—something less than half of your plotted $i_{p\max}$ value should do for starters. $P_o$ may be any arbitrary value at this point, but use the "at the plate" power output specification. Run Path 1 and compare TANKIT's calculated $i_{p\max}$ value to your plotted value—<u>ignore</u> <u>all</u> <u>other</u> <u>parameters</u> in the report. If the two $i_{p\max}$ values don't closely agree, adjust $I_{b\max}$ and run through Path 1 again; repeat this process until TANKIT's $i_{p\max}$ value converges with yours.

Your $I_{bo}$, $I_{b\max}$ and the other plate currents are now set—don't change them during the following step.

Now run Path 1 with $P_o$ set to roughly the plate power output which you expect to get from the tube. This time, compare $e_{p\max 2}$ (the peak swing of RF plate voltage) to your plotted $e_{p\max}$ value. Edit $P_o$ as necessary and rerun Path 1 until $e_{p\max 2}$ converges with your plotted value. All plate operating parameters should now be correct for the plotted operating line (you will need to verify graphically that your grid and screen dissipations are acceptable, etc.). At this point you may move on to Path 2 or Path 3 if you wish.

TANKIT can be iterated this way several times per minute, but yes, it is a guessing game. A new path designed to eliminate the guesswork is being considered for a future update.

### What is the value of this new information?

Perhaps you are still wondering what good all of this new information may be to you. After all, haven't hams been successfully building, modifying and repairing their tube rigs for many decades without this kind of detail?

Yes, many have. But, since you now have a way to quickly know more about the peak voltages and currents in your plate tank circuit, wouldn't you want to use that information so you can be assured that your expensive tank components are correctly sized for the task? And, since you can now calculate your tube's RF plate load resistance more accurately (compared to the usual "shortcut" formulas in the handbooks), why wouldn't you do so? Plus, when it comes time to tune up your new baby for an operating session, wouldn't it be nice to know in advance what your two-tone test plate current should be such that your full PEP output is available when you speak into the mic? There is also a certain satisfaction which comes when you know you've "done your homework" by making an effort to really understand what is going on inside your linear amplifier; that is worth something in itself—it even *feels* more "professional."

Finally, even if you prefer to use the traditional graphical analysis methods for determining a tube's operating conditions, you can still call on TANKIT to speed up the process and get a "second opinion" about your calculations—TANKIT has disclosed several errors in such calculations during spot checks of published material.

## Limitations of TANKIT

Obviously, TANKIT is not a complete "A to Z" amplifier design system—you will still need to depend on your handbooks and technical reference library for design support. Paths 1 and 2 only work for Class AB or B designs. TANKIT doesn't calculate any operating parameters for grid or screen circuits, although sufficient data for them is usually given in the published "typical operating conditions." Since TANKIT is intended only for infrequent use by amateurs it doesn't save any data to disk. However, all input data are summarized at the top of the output reports, so any run may be recreated in a matter of seconds if needed—just be sure to keep your reports along with your other project documentation.

**You should operate your tube(s) according to the operating parameters you enter into TANKIT.** If your design effort is to have any meaningful value, your operating tube currents and output power should really be what you say they will be during your TANKIT design run. Never mind that "heat of the battle" stuff when you're chasing DX—if you expect to reap all the benefits of having a tighter, well-centered design, you may need to check your operating habits more often as well. Be aware that tube manufacturing tolerances and tube aging can, and will, affect the results you are able to achieve.

## Author's acknowledgement

TANKIT is the result of several years of part-time effort researching and experimenting with many mathematical formulas. I never would have started a complex project like this except for the spark of inspiration I received from my old mathematician friend, William T. Ruddock (actually, he's a lot younger than I). Many years ago Bill showed me how a little simple math could solve a tough bandspreading problem I had been grappling with. I was so impressed that I began to explore ways of using math more often to solve electronics problems; TANKIT is my mathematical magnum opus. My *infinite* thanks to you, Bill, and peace!

Keith Kunde, K8KK

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