Rapid Class C Plate Tank Design

By Keith A. Kunde, K8KK

Several years ago I developed a free computer program called TANKIT to assist in the design of plate and cathode tank circuits for Class AB or B grounded-grid linear amplifiers. One part of that program is independent of the class of operation and produces the actual pi or pi-L tank component values needed to match an RF plate load resistance to the output load.[1,2] Here is how to use that section of the program to rapidly design a plate tank for your Class C final.

Before we get into the details, let's try out the program with a generic example. Download TANKIT.exe from my website, www.radiok8kk.com (it is not necessary to download any of the documentation at this time). The program is self-contained and about 112 kB in size.

Start the program and select Path 3 from the main menu. This path is the only part of the program usable for Class C design work.

```
                    DESIGN A PI OR PI-L TANK NETWORK

Choose Type of Tank Network:
   1. Pi network
   2. Pi-L network
Enter 1 or 2 ==> 2

Enter Pi-L network input/source resistance R1 Ω: 5100

Enter Pi-L network output/load resistance R2 Ω: 50

Enter Pi-L network image resistance Rm Ω: 505

Enter Pi-L network target operating Q Qo: 12
   Minimum Qo for this design = 10.1

Enter minimum circuit capacitance across tank input Cmin pF: 35



Choose next action ==> _   1. Continue   2. Edit Data   3. Main Menu
```

Figure 1 - Completed Path 3 input screen

Figure 1 shows a completed Path 3 input screen with representative values entered for all prompts. You can either use these values or enter some of your own choosing (the values for R2 and Rm are defaults—just hit enter to see them, or enter your own). If you make an entry error keep going until the “next action” menu appears at the bottom of the screen, then go back and edit your data. While editing, just hit enter to keep the existing data in any field. When you come to a prompt you wish to change, simply type your new data ***in its entirety*** over any old data in the field (ignore any old data which may still be visible in the entry field—the program only looks at your newly entered data).

Note that the second line of the prompt for the desired operating Q, Q_o, specifies a minimum allowable value—the program won’t accept a Q_o lower than this in order to insure that the resulting network design will perform satisfactorily.

When you are satisfied with your input data, hit the enter key. The network component values for all HF bands are displayed as shown in Figure 2.

TANKIT.exe v2.0 Mar 04, 2009
Copyright (c) 2007 - 2008 K8KK 10:44

PI-L NETWORK COMPONENT VALUES

Input Resistance R1 = 5100 Ω Output Resistance R2 = 50 Ω
Image Resistance Rm = 505 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	135.0	76.93	971	12.65	13.3	17m	18.068	35.3	2.89	165	1.32	29.9
	1.897	121.4	76.93	875	12.65	12.6		18.118	35.1	2.89	164	1.32	29.8
	2.000	109.2	76.93	788	12.65	12.0		18.168	35.0	2.89	162	1.32	29.7
80m	3.500	71.5	39.01	513	6.42	13.7	15m	21.000	36.5	2.09	162	1.13	35.3
	3.742	62.5	39.01	450	6.42	12.8		21.224	35.7	2.09	158	1.13	35.0
	4.000	54.6	39.01	394	6.42	12.0		21.450	35.0	2.09	155	1.13	34.6
40m	7.000	37.6	18.07	258	3.36	14.2	12m	24.890	35.2	1.53	150	0.96	40.0
	7.148	36.1	18.07	248	3.36	13.9		24.940	35.1	1.53	150	0.96	39.9
	7.300	35.0	18.07	234	3.36	13.6		24.990	35.0	1.53	149	0.96	39.8
30m	10.100	35.3	9.22	203	2.37	17.9	10m	28.000	39.4	1.11	161	0.83	49.6
	10.125	35.2	9.22	202	2.37	17.9		28.837	37.1	1.11	152	0.83	48.2
	10.150	35.0	9.22	201	2.37	17.9		29.700	35.0	1.11	143	0.83	46.8
20m	14.000	36.7	4.67	185	1.69	24.7	6m	50.000	40.8	0.34	150	0.46	89.2
	14.174	35.8	4.67	181	1.69	24.4		51.962	37.8	0.34	139	0.46	85.9
	14.350	35.0	4.67	176	1.69	24.1		54.000	35.0	0.34	129	0.46	82.6

C = pF L = µH

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

Figure 2 - Network component values

At this point the network component value table can be printed on any *Windows* printer by hitting the enter key. Line printers (e.g., LPT1) are not supported.

That is basically how the TANKIT program works. Now, let’s make it work for your design.

The key figure needed, of course, is the RF plate load resistance, R_L, required for your final tube’s operating conditions; this is designated $R1$ in the program’s input prompt. The “formal” way of calculating R_L is to divide the peak value of RF plate voltage swing by the peak fundamental component of RF plate current (whee!). You may already know a simpler way to determine the R_L value for your tube’s operating conditions, but if not the following method gives a close approximation:

1. Choose a Class C *operating angle* (i.e., plate current conduction angle) from the following table (all Class C amplifiers operate with plate current conduction angles of less than 180 degrees). If you aren't sure what this means, a good compromise angle for either 'phone or CW is around 140 or 150 degrees although 'phone angles as short as 120° were once the norm (much more harmonic content, however, and harder on the final tube). The operating grid bias governs the conduction angle (this angle is difficult to measure; see note 8 below).

Operating Angle	**Factor F01**
180°	1.571
170°	1.611
160°	1.651
150°	1.689
140°	1.725
130°	1.760
120°	1.794
110°	1.825
100°	1.854
90°	1.881

2. Insert factor F01 from the table into the following formula:

$$R_L \approx \frac{.9 \times V_b}{(F01 \times I_b)}$$

In this formula, V_b is your plate supply voltage (B+). The .9 multiplier represents a typical 90% swing of RF plate voltage which occurs at the peak of the RF plate current pulse, although it might have to be a bit less than this for the older screen grid or beam type tubes. I_b is the normal DC plate current you will be running, in **amperes**. It is multiplied by a factor called F01, which is (hang on to your hats) the ratio of the peak fundamental component of RF plate current to the average DC plate current. The net of this formula is that it comes pretty close to the “formal” method of calculating R_L mentioned earlier. Here’s an example of how it works:

From your tube’s operating data you determine that your plate supply will be 2200 volts and your plate current will be 225 mA, giving a plate input of about 500 watts. With a 140° plate current conduction angle, the maximum *theoretical* plate efficiency is:

$$N_{p\max} = \frac{F01}{2} \times 100\% = \frac{1.725}{2} \times 100\% = 86.3\%$$

To realize this theoretical efficiency the plate voltage would have to swing all the way down to zero at the peak of the plate current pulse, which, of course, it just can’t do. Since we’re using a 90% swing factor in the numerator of our R_L formula, we should multiply the theoretical number by .9 to get 77.67% efficiency at the plate. However, since we are usually more interested in our efficiency at the output load, we need to deduct another 5 or 10% (or possibly even more above 20 MHz) due to various losses in the output tank circuit. Multiplying the 77.7% number by .9 represents a 10% tank circuit power loss and gives us an output efficiency at the load of a bit less than 70%.

With 500 W plate input, your usable carrier output power will be about 350 W and your output on modulation peaks (assuming plate modulation) will be roughly four times this, or 1400 W PEP. Finally, plugging the nums into the formula for R_L (don’t forget the parentheses if you’re using a calculator!):

$$R_L \approx \frac{.9 \times 2200\,\text{V}}{(1.725 \times .225\,\text{A})} \approx 5100\,\Omega$$

At this point you can run TANKIT's Path 3 and design your own pi or pi-L plate tank circuit—should take you just a minute or two.

Notes:

1. The total inductance needed for your tank design is the value listed for the lowest frequency band you intend to use. The higher frequency bands are tapped off this total value at the inductance listed for each band, as measured from the input end of the tank coil. The total inductance may be split among two or three separate coils which together add up to the total.

2. The variable portion of the total capacitance for C1 or C2 required for each band may be determined by subtracting the smaller figure in the report from the larger. Add at least 25% to this value; that is all that must be variable—the rest may be a fixed capacitance. This might save space and expense on 160 and even 80 meters if you can figure out how to handle the band switching.

3. The minimum capacitance C_{min} (i.e., plate output capacitance + C1's minimum capacitance + stray capacitance) across the tank's input will usually force the operating Q to rise substantially at the higher frequencies. If Q_o exceeds 25 or so, be prepared for significant tank component heating on those bands if you plan to run higher power. Heavy tubing coils and even a little forced air directed at the tank components may be required. In the above example, the peak fundamental current is $1.725 \times .225\,\text{A} = .388\,\text{A}$, times the Q_o for the 10 meter band of about 48, gives a peak circulating current of approximately

18.6 amperes, or a little over 13 amperes RMS; for 6 meters it is over 23 A RMS!

4. Most transmitting tubes have plate modulated Class C ‘phone plate dissipation ratings that are only two-thirds the “normal” plate dissipation rating. For example, a 4-400A has a 400 W “normal” plate dissipation rating, but only 270 W in AM phone service. Your fixed bias (a.k.a., “safety bias”) should keep the plate dissipation at or below this number when no grid excitation is present.

5. Consult the older handbooks for help in designing your final’s grid tank circuits and biasing arrangements.

6. The LC meter kit offered by Almost All Digital Electronics[3] is an excellent tool for tank design work and the price is reasonable. Check their web site for specifications.

7. The L/C/F/coil winding slide rule offered by the ARRL[4] is indispensable for designing coils and resonant circuits. The only clinker with this thing is the outrageous shipping cost!

8. The plate current conduction angle can be roughly estimated by dividing your measured output power at resonance by your DC input power, multiplying by 100%, then comparing the result to your efficiency at the load for the desired conduction angle, calculated using the method discussed earlier. Adjust the final’s bias until the two efficiency figures match reasonably well; this should put you close enough to the ballpark to at least smell the crowd.

References

[1] Elmer A. Wingfield, W5FD, “New and Improved Formulas for the Design of Pi and Pi-L Networks,” *QST*, August, 1983, pp. 23-29

[2] "Pi-Network Equations at C_{min}," *The ARRL Handbook 2000*, p. 13.6
[3] *LC Meter II-B*, Almost All Digital Electronics, 1412 Elm St. S.E., Auburn, WA, 98092, 253-351-9316, www.aade.com
[4] *L/C/F and Single-Layer Coil Winding Calculator*, order number 9123, ARRL, 225 Main St., Newington, CT 06111, order phone (US) 1-888-277-5289, (Foreign) 860-594-0355