The 2X-813 Linear Amplifier

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Introduction

The 2X-813 homebrew linear amplifier shown in Figure 1 was constructed to complement my Octal Tri-Bander Transceiver described elsewhere on the kg7tr.com website. It is the same physical size and features identical styling. Electrically, the amplifier is very similar to the HB-600 linear (detailed at kg7tr.com) and covers 80, 40 and 20 meters. It is intended for SSB operation only. Whereas the HB-600 uses a pair of 572Bs, this amplifier uses a pair of 813s. As in the HB-600, the grounded grid (GG) configuration is used. For 813s, that means grounding the screen grid and beam forming plates (called suppressor grids in RCA's tube data) as well as the control grid. When connected this way, it is surprising how closely the characteristics of the 813 match those of the 572B.

When the HB-600 was constructed I procured a pair of Chinese 572Bs for it. At that time (2012 time frame) these tubes were in production, were relatively easy to find, and went for about $90 to $100 for a matched pair. Currently new Chinese tubes have limited availability, and are going for somewhat higher prices if you can find them.

Meanwhile, after completing the HB-600 I developed a desire to build another linear using 813s. I've always liked the solid look and feel of an 813, and they have a great legacy – RCA introduced this tube just prior to WWII. If there is ever such a thing as a beauty contest for vacuum tubes, surely the 813 would have to be a finalist. Of course beauty is in the eye of the beholder.

So I started looking around for 813s at hamfests and on eBay. Eventually I acquired several tubes of mixed brands, as well as some genuine E.F. Johnson sockets and Millen plate caps. On eBay I was able to find two pairs of new old stock (NOS) tubes with matching date codes. One pair was made by Ken-Rad and the other bears Westinghouse labels. I suppose it's possible that all of these tubes were made in the same factory and individually branded for a variety of manufacturers. Prices for the hamfest tubes were quite reasonable. The NOS pairs found on eBay were close to the current price for a pair of new Chinese 572Bs. In my opinion the 813 is a more rugged tube, at least the ones made through the 1970s. My experience so far indicates they are very conservatively rated, and for the most part are bulletproof in GG service.

I still check hamfests, classified ham ads and eBay, and 813s show up all the time. There were lots of them made that apparently got snatched up by hams over the years. Whether due to an SK passing or just cleaning house, they are not too hard to find today. I think 813s offer a reasonably priced and classic way to homebrew a linear amplifier in the 600 watt PEP class.

A Little History and Some References

Research for this project consisted of what I could find on the internet and going through my back issues of Electric Radio magazine dating to February, 1991. As far as I was able to determine, grounded grid operation of a pair of 813s first appeared in the mid-1950s in the B&W L-1000-A amplifier. In the manual for this amplifier, B&W states in the amplifier circuit description that they conducted extensive testing of the 813 and other tubes in grounded cathode and grounded grid configurations. They go on to cite a variety of reasons why a pair of 813s in GG is ideal for SSB transmitters available in the day. In 1959, an exact clone of this commercial amplifier was presented as a construction article in GE Ham News. Later issues of GE Ham News included errata, recommendations for alternate parts, and operating information on 813s in grounded grid service.

ER's online directory was searched for the keyword "813" in all their back issues. Several articles described grid driven, plate modulated 813 amplifiers, which were not really relevant to a GG design. In the April, 1998 issue, WA5UEK presented a very interesting story about his restoration of an L-1000-A. The June, 2005 issue contained an article by W3BYM about his construction of an 813 GG amplifier on a Heathkit SB-220 foundation. Of particular interest here was the author's development of the tuned input circuits, which used techniques similar to mine. Finally, there was WA6VVL's 813 GG linear described in the December, 2010 and January, 2011 issues. This project was essentially a single tube clone of the original B&W amplifier.

All of this data was used as background for the design of the 2X-813 amplifier described here. For readers interested in more details, the B&W manual and GE Ham News articles are available for download from the kg7tr.com website at the bottom of the 813 Linear page. Also available there is an RCA data sheet for the 813 from 1955. Worthy of note is that GG operation is not mentioned anywhere in the RCA data sheet. Later data sheets may cover GG, but I was not able to find any. The WA6VVL article in ER does show an RCA advertisement from CQ magazine, where they tout use of their 813s in the new B&W L-1000-A.

Also available on the internet were a few blogs about using 813s in homebrew amplifiers. Some comments were positive and some negative. Of course the 813 was never designed for GG SSB service, and it can't be expected to outperform, in every category, tubes like the 572B, 3-400z, 3-500Z and other triodes that were. But despite the age of its design, it provides reasonable performance. The 813 certainly deserves a measure of respect even today.

Tuned input circuits were not commonly used in the early GG designs, and the B&W amplifier does not have one. The GE Ham News version shows a pi-net input circuit as an option. A tuned input circuit like that used in the 2X-813 does provide definite improvements in distortion and efficiency, and makes the amplifier easier to drive. In addition, the bias circuit used in those mid-20th century amplifiers seems a bit overpowered. I believe the 2X-813 circuit design is a more sensible way to do it.

Mechanical Layout

Top and rear views of the 2X-813 amplifier (with the cabinet removed) are shown in Figures 2 and 3 respectively. Figure 4 shows the rear view with the cabinet installed. The amplifier is built on a 13 x 17 x 3 inch chassis mated to a 10.5 x 19 rack panel. The arrangement of the RF components topside results in reasonably short leads. Braided, tinned copper wire was used for the RF wiring. This might seem somewhat unusual, but the various components can move around relative to each other during handling. I didn't want to risk breaking the RF choke, tubes, variable capacitors, bandswitch or anything else by using heavy, solid wire.

The PA coil is a modified Illumitronic Pi-dux 2808D4 mounted on ceramic standoffs. The PA tuning capacitor is mounted on top of the PA loading capacitor and is a dual section transmitting variable, 100 pf per section. The rear section is used on all bands, and the front section is connected by the bandswitch on 80 meters to provide additional tank capacitance. The loading capacitor underneath is a single section 1,500 pf transmitting unit. A side view of this arrangement is shown in Figure 5.

A heavy duty, single pole, three position switch made by Radio Switch serves as the main bandswitch to select taps on the PA coil, as well as the front section of the PA tuning variable. As in my previous designs, a servo wheel from the RC modeling hobby is attached to the rear of the Radio Switch shaft. This wheel is connected to another one below chassis by control rods. The wheel under the chassis is mounted to the shaft of another rotary switch that selects the proper input circuit for the band in use.

The tube sockets are mounted to a plate that is recessed about 1.5 inches below the chassis. This allows a little more clearance between the plate caps and the top of the cabinet. A box fan mounted in the rear of the cabinet blows directly on the tubes.

The power supply components are on the right side of the chassis. Notable here is the use of an Antek toroid transformer for the high voltage supply that will be discussed later. In front of the transformer is the high voltage doubler and filter board, mounted horizontally on threaded spacers.

Three NOS Triplett meters with custom designed scales are used to monitor plate current, grid current and plate voltage. This eliminates the need for a meter switch, and allows monitoring of everything simultaneously. This is especially useful for tune-up, where it is important to monitor grid current and plate current together for proper loading.

The underside of the chassis is shown in Figure 6. The recessed mounting of the tube sockets can be seen here. The filaments of the 813s require 10 volts at 10 amps total. In the early planning for this project I procured a pair of 5 volt/10 amp control transformers (Stancor P-6135) that were on sale at MPJA, with the idea that I could connect them in series to get the required voltage. MPJA no longer has stock on these. These transformers can still be procured from regular distributors, but the current street price of a pair will likely exceed the cost of a new 10 volt/10 amp transformer that might be available from other sources (e.g., Hammond). Still another way might be to modify the Antek toroid as discussed later.

At any rate, I did end up using the two transformers in series and mounted them to the side of the chassis. The filament choke runs from a terminal strip between the transformers over to the center of the tube sockets. The filament choke itself is made from an inexpensive Amidon kit (P/N FLC-10). The part number suggests it is a 10 amp choke, and it is wound with 14 gauge enameled wire covered with heat shrink tubing. I was a little concerned about heat dissipation since the 813s would draw exactly 10 amps. But measurements of the voltage drop across each leg of the bifilar wound choke, with the parallel tube filaments as the load, indicate a total heat dissipation of about 3 watts. This barely warms the choke.

The input network is in front of the tube sockets. The switch linkage from topside can be seen near the front of the chassis. The LC circuit values were determined by experiment to arrive at the lowest SWR between the exciter and the linear. The three coils ended up being identical to the ones used in the HB-600. The capacitors are slightly different. All of this again suggests the 813s look a lot like 572Bs in GG service.

To beef things up, a section of 1.0 inch by 1/8 inch thick aluminum angle stock runs sideways across the chassis and is secured every few inches with 6-32 screws and nuts. This angle also provides a mounting surface for the vertical plate used to mount the input bandswitch and coils. It was also necessary to provide a stiff foundation for the toroid transformer, which weighs 16 pounds and mounts with only a single bolt through its center. As seen in Figure 6, a box structure beneath the transformer provides the necessary strength. To make the box, a right angle section was cut from an old TU-5 Tuning Unit chassis and firmly mounted to the chassis bottom and each side. A square plate of tempered .063 aluminum sheet was also mounted directly under the toroid and secured in each corner by 6-32 screws and nuts. The toroid was mounted using the steel disk, two rubber pads and mounting bolt supplied with it. The reinforcements ensure the heavy toroid stays put and does not rock from side to side. A 6 x 6 x 2 inch chassis mounted in the corner of the amplifier chassis could probably accomplish the same thing.

Power control relay K1 is located inside the box against the side of the chassis. Soft start relay K2 is a plug-in unit mounted to the side of the box. T/R relay K3 is located to the rear of the tube sockets between the RF input and output jacks.

Construction of the cabinet is identical to the Octal Tri-Bander Transceiver and will not be discussed here.

The Antek Toroid Plate Transformer

My original intent for this project was to procure the same NOS plate transformer I used in the HB-600. But somebody beat me to the last one that Surplus Sales had in stock. So that led me to the line of toroid transformers offered by Antek (antekinc.com). These are reasonably priced and conservatively rated. The unit I ended up using is their P/N AN-8T800. This is an 800 volt-ampere (VA) unit with dual 120 VAC primaries, and dual 800 VAC at .5 amp and 6.3 VAC at 4 amp secondaries. This transformer currently sells for $105 and can be shipped in a standard USPS mailer. With the exception of a hamfest bargain with no tax or shipping, it would be hard to find a cheaper way to get your hands on a plate transformer like this.

Antek states their primary to secondary insulation is tested at 3,500 volts, but not specified is the insulation between secondary windings. In theory, the two 800 volt windings could be connected in series and worked into a full wave bridge (FWB) rectifier with a capacitor input filter. This would yield about 2,250 volts DC under no load conditions. But it seemed to me that this could also put some pretty high peak to peak voltages between the two 800 volt windings, depending on phasing and how they are physically wound. Maybe it would work fine, but I was not up to risking a disaster. Accordingly, I decided to connect the two windings in parallel and go with a full wave voltage doubler as used in the HB-600 and a bunch of commercial linears in this power class. The filter configuration would have been identical with either configuration, so that was not a consideration. A FWB would require maybe a few more diodes, but that would be about it.

In the end, the doubler circuit I used produces the same 2,250 volts no load. This drops to about 1,800 or so under a 500 ma steady plate current, but some of this is due to line voltage dropping on the 15 amp household circuit I am using. Given the size of the filter capacitors used, I do not believe a FWB would offer any additional voltage under load. The 813s will deliver about 500 watts of single tone output (for a brief tune-up period) with 1800 volts on the plates and 500 ma of plate current.

The transformer also has dual 6.3 volt windings. These are connected in series and FWB rectified and filtered to provide -17 volts for the relay coils and PA transmit bias circuit. This is obviously a total underutilization of these windings, but they were there and I needed this voltage so I used them.

In looking at the transformer, the low voltage windings are visible on the outer part of the core. There are only about nine turns of wire spread around the core to get 6.3 volts. It seems perfectly feasible that one could wind about 14 or 15 turns of wire around this core and get 10 volts for the 813 filaments. There is plenty of steady state reserve power available in the transformer, so the additional 100 VA for the filaments should not be a problem. And the 50 VA available in the 6.3 volt windings is not even used. The wire could probably be 8 or 10 gauge, residential grade solid wire from the local home improvement store. Alternately, two side by side windings with smaller wire connected in parallel could be used. Of course all of this would need to be determined experimentally ahead of time.

Circuit Description

Refer to the Figure 7 schematic for this discussion. A parts list is also provided at the end of this article. When the linear is not keyed, RF input from the exciter at J1 is routed through K3 contacts back out through J2. When the amplifier is keyed by grounding the coil of K3 at J3, RF from the exciter is coupled to the filaments of V1 and V2 through a pi-network matching circuit selected for each band by S5. The filaments are isolated from RF by RFC1. In transmit, grid bias from the wiper of R8 is applied to the tubes through a one ohm meter shunt and RFC3. The screen and suppressor grids on pins 5 and 3 respectively are grounded directly at the tube socket. Each signal grid on pin 4 is grounded for RF by a .001 µF disc ceramic capacitor. The 51 pf ceramic capacitor also connected to ground is there because it was used in the circuits described in the references. It was probably used to tame an oscillation on 10 meters. I don't if deleting would have any effect on 20 meters and below.

The plate circuit is shunt fed nominal 2,250 volts DC through RFC2. RF at the plates is coupled through C9 and C10 to the pi-network output circuit. The input is tuned by C11 and the output by C12. S4 shorts out sections of L4 on 40 and 20 meters, and adds the additional section C11B to the plate tuning capacitance on 80 meters. C12 is a 1,500 pf transmitting variable and somewhat overkill in this application. A multi-section BC type variable would also work. RF output is routed from C12 through K3 to J1. RFC4 is the standard safety choke to keep DC from appearing on the output.

The amplifier does not exhibit any instability, which could be a result of limiting it to 20 meters and below. Standard parasitic suppressors are used at the tube plates, but the amplifiers described in the references do not have them. They might not be needed in this application either.

The power supply is a voltage doubler similar to the SB-200, 30L-1 and other popular amplifiers in this power class. Transformer T1 was described previously. The effective capacitance across the plate voltage is 45 µf, so during SSB voice transmission the PEP is easily maintained at 600 watts. No automatic level control (ALC) was incorporated into this amplifier.

The metering circuits are straightforward. "Glitch" diodes are connected across all meters and R9 to protect things in case a tube or other component shorts out. The 15 ohm resistor in series with RFC2 is also intended to provide some protection in a short circuit. In addition, this is a wirewound resistor so it acts like a choke. Bypassing it on both sides with 2200 pf capacitors provides additional filtering to keep RF out of the power supply. 10.5 meg precision resistors were used for the plate voltage meter because I had a bunch of them in the junk box. 10 meg resistors could be used with proper selection of the 4.7k resistor across the meter to provide 3,000 volts full scale.

Note that in this design, operation on 240 VAC is feasible by series connecting T1's dual primaries and series connecting the primaries of T2 and T3. The soft start circuit would need modifications, and K1 and the fan would need to be changed to 240 VAC units.

The coil of T/R relay K3 is energized for transmit by grounding the ANT RELAY line at J3 just like most other linears. Because of the bias arrangement, -17 volts DC is present on this line in standby. The current is only 100 ma when the line is grounded, so any exciter that uses a relay to key an external linear will work fine. The secondaries of T1 are also used to power the 12.6 VAC winding of T4. Its 120 volt winding is half wave rectified, filtered and voltage divided to provide about -58 volts cutoff bias to the tubes in standby. In transmit this bias line is connected by K3 contacts to the wiper of R8, and can be varied from 0 to about -5 volts. This allows setting the idle plate current to 40 ma, as recommended for SSB linear amplification in the references. Because of the resistances involved, the -58 volts from the standby bias circuit has negligible effect on the voltage at the wiper of R8 in transmit.

On the power input side of things, a 16 gauge power cord feeds a 10 amp circuit breaker for the plate transformer and a 3 amp breaker for all other circuits. The 10 amp breaker used for the HV supply is adequate given that a soft start circuit is used for initial turn on.

S1 energizes K1, which puts AC from the 3 amp breaker on the primaries of T2, T3, and the box fan identified as "B" on the schematic. When S1 is in the on position, green LED D2 illuminates. The 620 ohm resistor in series with the fan slows it down for quieter operation. This resistor has to be selected for the particular fan in use. For operation under adverse conditions such as extended tune-ups, testing or hot ambient temperatures, the fan can be run at full speed by closing S3.

K1 also makes AC available from the 10 amp breaker to the slow start circuit at S2 and K2. If AC is present and S2 is turned on, AC is applied to T1 primary through the 10 ohm, 20 watt resistor to slowly charge up the high voltage filter capacitor string. AC is also applied through a diode and 1.0 k, 20 watt resistor to the coil of K2, which is shunted by a 4,700 µf capacitor. It takes about three seconds for this capacitor to charge to a voltage high enough to pull in the armature of K2. When this happens the 10 ohm resistor is shorted out by K2 contacts and full AC is applied to T2's primary, just as the high voltage has reached about 2,000 volts.

Another set of contacts on K2 illuminates red LED D1 and makes -17 volts available to T/R relay K3 and the bias circuits. This arrangement prevents keying the amplifier and applying grid drive until full high voltage is available. This implementation provides two important protection functions. First, if drive was applied and plate current drawn before K2 closes, the 10 ohm 20 watt resistor in the soft start circuit could burn out due to the extra load. Second, inhibiting grid drive when plate voltage is not present helps prevent exceeding grid dissipation, since without an active plate circuit the grids can draw more current. This feature was not in my HB-600 design, but a retrofit is on the to-do list.

The steady state DC voltage on the coil of K2 is about 21 volts with S2 on. When S1 or S2 is turned off the coil and capacitor are discharged through a 15 ohm resistor to provide fast turn off. (**NOTE**: The S1 discharge loop was added in February, 2018. When S1 was turned off but S2 was left on, it was taking several seconds for the circuit to discharge and de-energize K2. If S1 was turned back on before this happened, full line voltage was applied to T1. This could trip CB1 or the service protection breaker, and weld the contacts on K1.) The control circuits are designed so that if S1 is off or either circuit breaker is open no high voltage can be generated. S2 can be left on at all times and the soft start feature will still work.

The Final Tank Coil

CAUTION!!

The next three sections include discussion of some generic testing and adjustment methods. Since any vacuum tube linear amplifier uses lethal voltages, use extreme caution if you find yourself working inside one.

For this radio I used an Illumitronic Pi-dux 2808D4 donated from K2RP's stash of parts (Thanks again, Ron). Pruning this coil down to the final configuration was a two-step process. Before starting, I gathered up some small clips of the type used for tapping large air-core coils. These had to be filed down and insulated with paper strips in order to fit between the close windings of the 80 meter part of the coil. Flexible wire was attached to the clips and the process was started.

First the cold tuning method was used to get rough placement of the coil taps for the three bands. With all power off, ten 250 ohm/3 watt non-inductive resistors were connected in series and connected from the plate caps to ground. The resulting 2,500 ohms is pretty close to the operating plate load impedance for the 813s. All components were in place in the plate, grid and filament circuits, including tubes. A small amount of RF from my Drake TR-5 solid state radio was fed through a cross needle SWR bridge into the RF output of the linear. The tank capacitors and coil taps were then adjusted for minimum SWR. The method works because the pi network is bidirectional and power can travel in either direction. 50 ohms at the output is transformed to about 2,500 ohms at the plates when the pi-network is resonated with the right component values. During the testing, if a decent match could not be obtained the tap was moved on the coil. Because each coil section affected the other two, it was necessary to go back and forth. This is where a solid state radio like the TR-5 is handy, because you don't have to retune it for each band. Of course you don't want to use any more power than necessary to get a usable reading. After this step one or two extra turns were left at each end of the coil.

Next, the amplifier was powered up into a dummy load and the optimum coil tap locations refined by trial and error. Of course extreme caution was used here to make sure nothing was hot when making adjustments. The tap locations can vary as full loading and output is approached, so it was necessary to make the final placements at full power. Once this was done the excess windings were cut off and the final connections made.

There are many other coils and variable capacitors that could be used in the output pi-network, including those identified in the references. The B&W 85x series of bandswitched pi-networks are attractive candidates, but decent ones are very hard to find. The cut and try methods outlined above might still be needed if working with just a coil.

The Input Circuits

The input pi-network circuit is essentially the same as the HB-600. I used the same methods to finalize the design, i.e., feeding RF from my TR-5 into the amplifier through an SWR bridge and adjusting the input coils and capacitors for minimum reflected power. A dummy load was connected to the amplifier output, and the output tank circuits resonated for maximum power. Drive was applied only long enough to make quick adjustments. For this testing the amplifier was turned completely upside down. Certain tubes like the 813, 811A and 572B cannot be operated on their side unless the internal elements lie in a certain plane. Otherwise internal heat can cause elements to droop from gravity and short to each other. There is no problem when they are inverted.

To make testing easier, I temporarily soldered a large mica padding capacitor across each side of the coil under test to ground. After finding the right settings, the padding capacitors were removed, measured, and fixed capacitors of equal value permanently installed in their place. Another thing I did was remove and discard the spring clips used inside the National coil forms to put drag on the slug threads. This allowed me to turn the slugs quickly with my fingers. When the right inductance was found, the slug was simply locked into place with a 6-32 nut tightened down on its threads.

Tuning and Operating the Amplifier

Tune-up and operation of the amplifier are basic. With no drive applied and the linear keyed, R8 is adjusted for 40 ma idling current. Enough RF drive is then applied from a properly tuned exciter to get about 150 ma of plate current. PA TUNE and PA LOAD are alternately adjusted for maximum power output, which should occur very close to the plate current dip. Then drive is increased and the amplifier tuned and loaded to 450 to 500 ma of plate current. At this point the grid current should be about 80 to 100 ma and output should be about 500 watts. If grid current is too high, loading is probably too light.

In SSB operation the plate and grid current will kick up to about a third of their steady state tune-up readings on voice peaks. Since there is no ALC care must be exercised to prevent overdriving. Most newer solid state transceivers have very effective power limiting that can be used. For older radios the output should be monitored for peak flattening. A less desirable method is to turn down the exciter mic gain if you get complaints.

The references contain information about using this type of amplifier for CW or AM. For CW the grid bias must be increased for zero plate current and the steady state plate current reduced. It may be necessary to modify the bias circuit used in the 2X-813 to achieve zero plate current. For AM the bias is the same as SSB but the operating plate current must be reduced. If CW or AM operation is desired the reader should investigate the references.

Figure 1: The 2X-813 Linear Amplifier

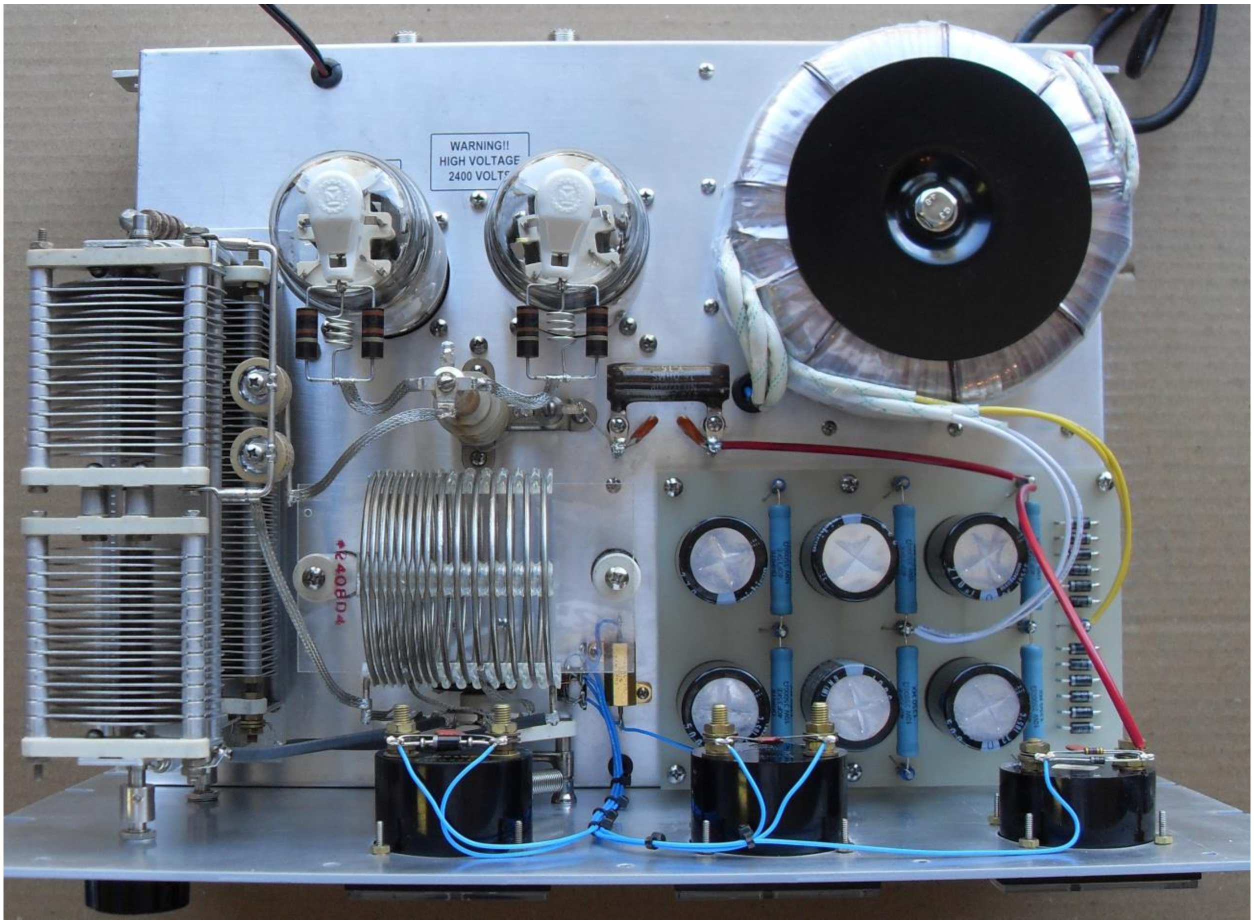

Figure 2: Top View

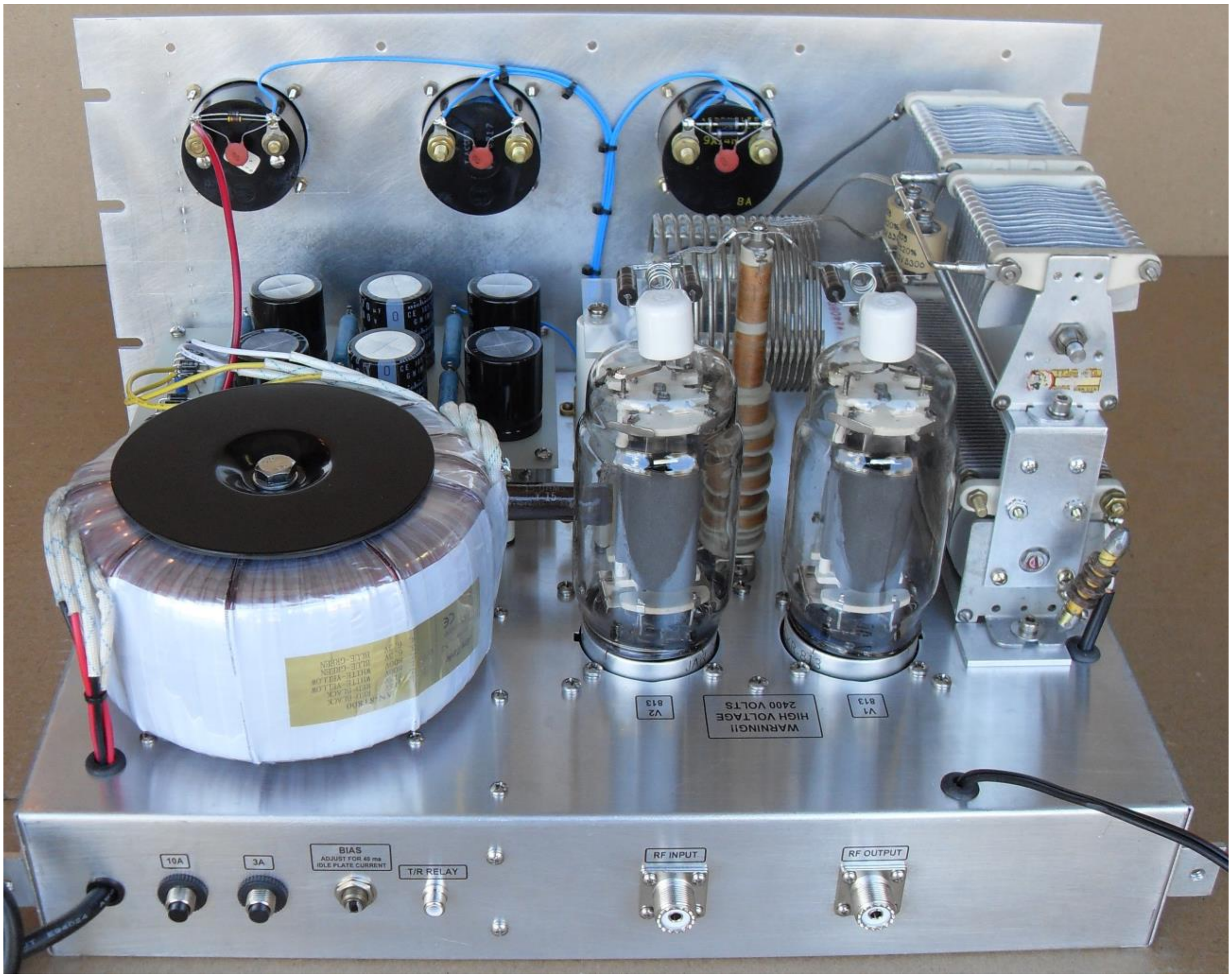

Figure 3: Rear View

Figure 4: Rear View with Cabinet Installed

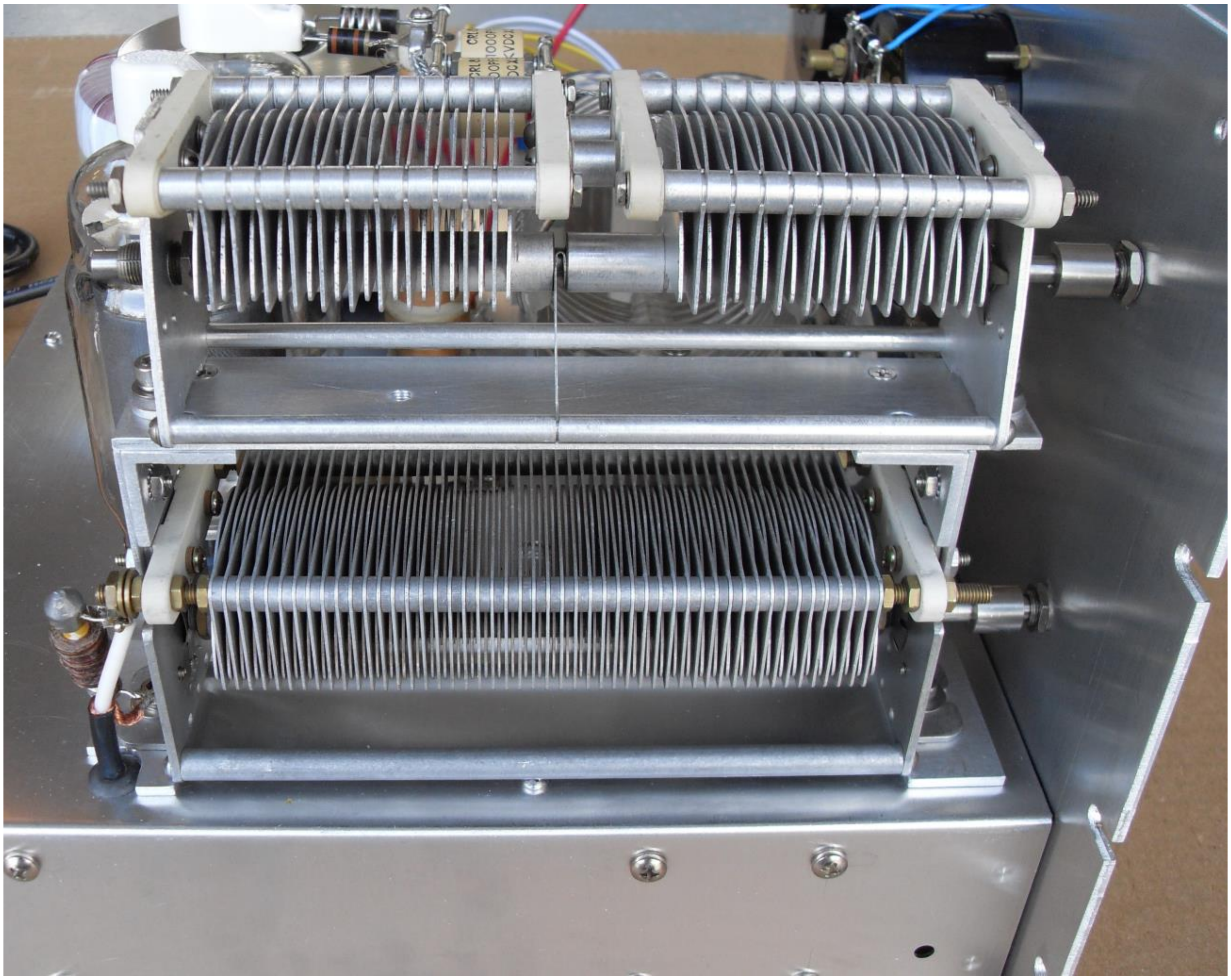

Figure 5: Side View Showing C11 and C12 Mounting

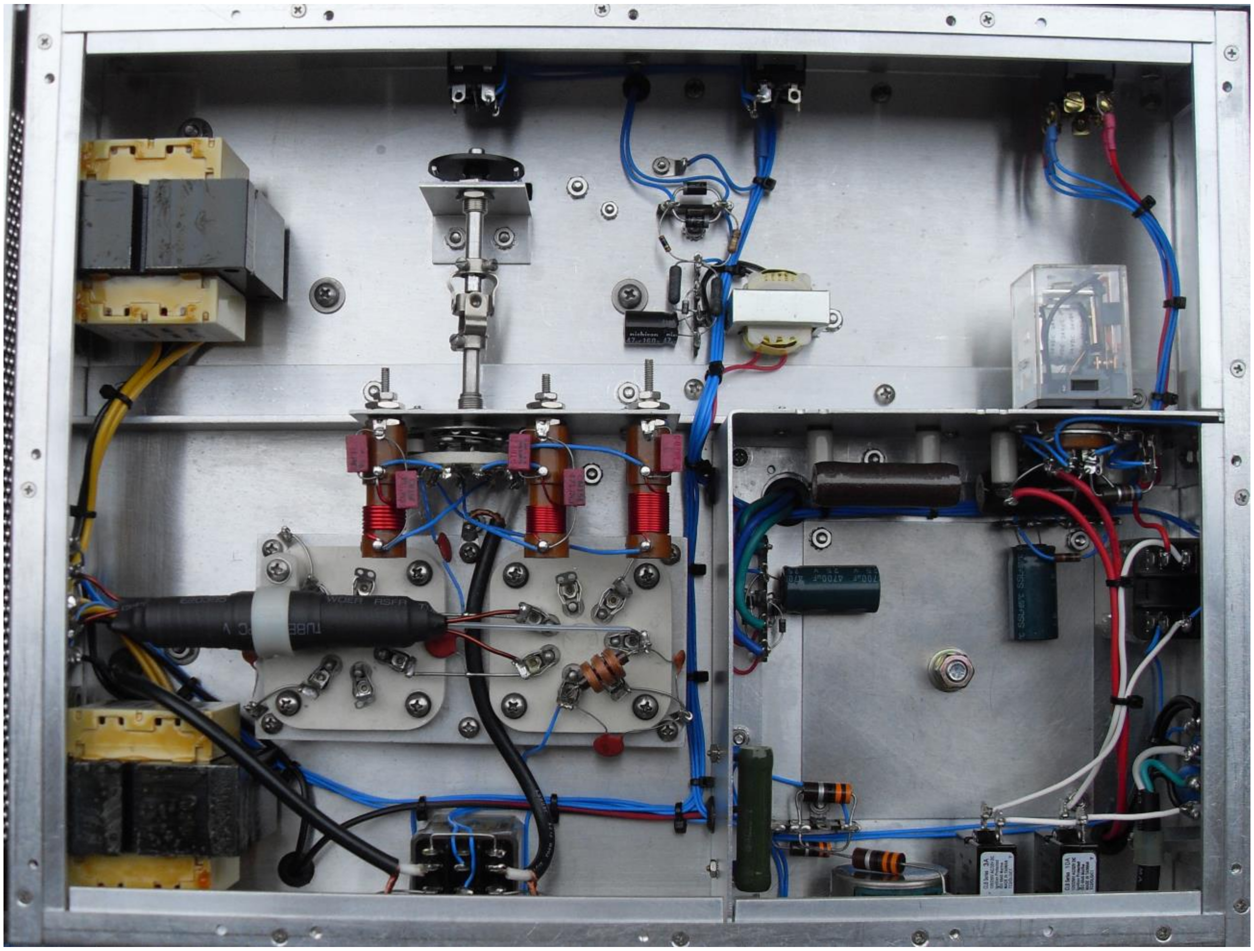

Figure 6: Bottom View

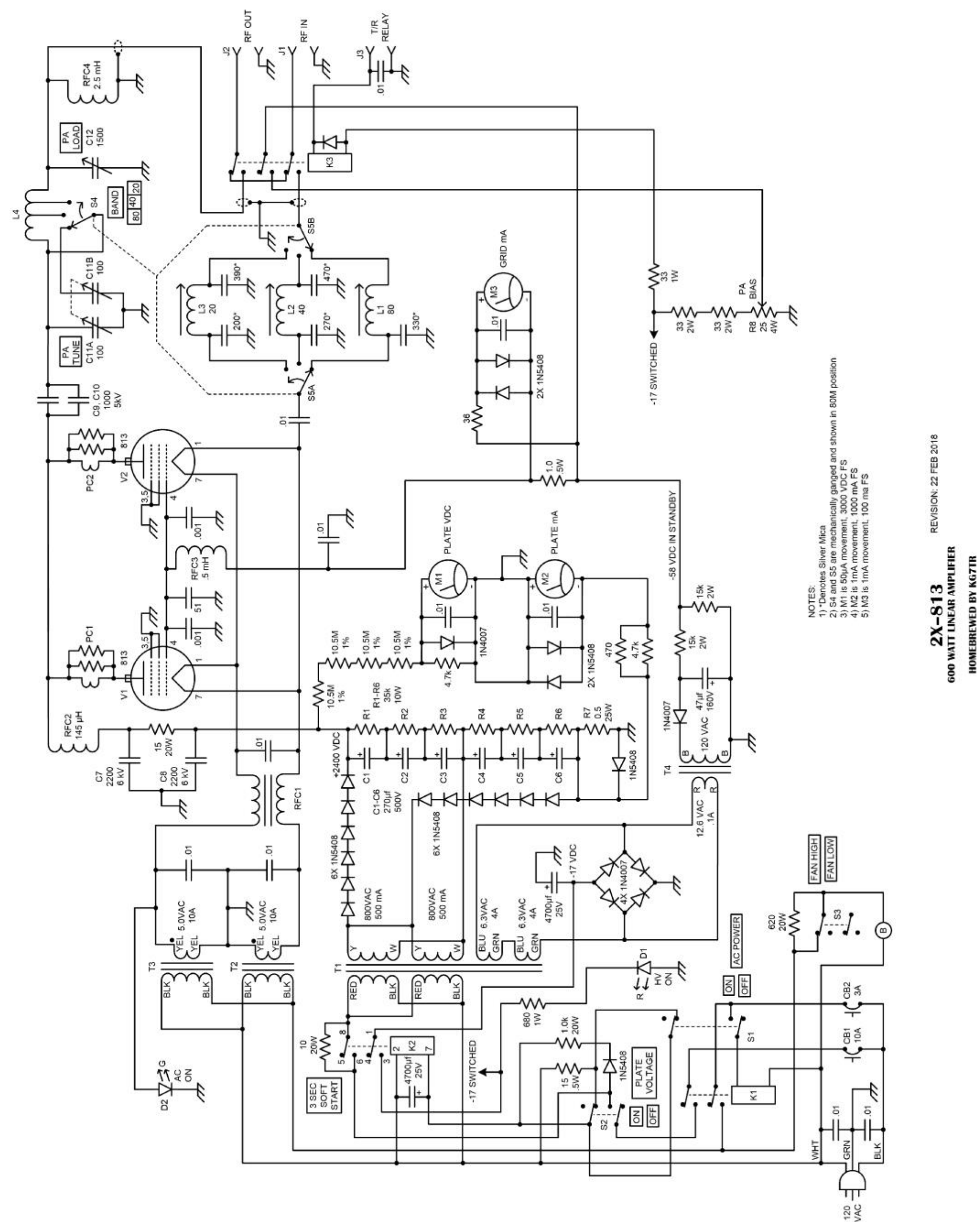

Figure 7: 2X-813 Schematic Diagram

Parts List for the 2x-813 Linear Amplifier

(Parts in parentheses were used in the actual unit)

B	4.68 inch muffin fan, 120 VAC
C1 thru C6	270 µf at 500 VDC, snap in electrolytic (Nichicon LGN2H271MELC40, available from Mouser)
C7, C8	2200 pf at 6 kV disc ceramic (Vishay 564R60GAD22, available from Mouser)
C9, C10	1000 pf at 5 kV minimum doorknob capacitor. (Centralab 858S-1000)
C11	Transmitting variable, dual section, .075 inch minimum spacing, 100 pf per section
C12	Transmitting variable, 1500 pf. Multi-section receiving type variable also suitable.
CB1	10 amp circuit breaker (Carling CLB-103-11B3ABA, available from Mouser)
CB2	3 amp circuit breaker (Carling CLB-033-11B3ABA, available from Mouser)
D1	Red LED
D2	Green LED
J1, J2	SO-239 UHF Jack
J3	RCA phono jack
K1	DPDT, contacts 15A at 120 VAC, 120 VAC coil
K2	DPDT, contacts 10A at 120 VAC, 24 VDC coil, 475 ohm
K3	3PDT, contacts 10A at 120 VAC, coil 12 VDC, 120 ohm
L1	16 turns #20 close wound on .5 inch diameter slug tuned form, National XR-50
L2	11 turns #20 close wound on .5 diameter inch slug tuned form, National XR-50
L3	7 turns #16 close wound on .5 diameter inch slug tuned form, National XR-50
L4	(Illumitronic vari-pitch pi-dux P/N 2408D4, see photos)
M1	50 µa panel meter, calibrated to 3000 VDC full scale
M2	1 ma panel meter, calibrated to 1000 ma full scale
M3	1 ma panel meter, calibrated to 100 ma full scale
PC1, PC2	4 turns #18, .3 inch diameter, .5 inch long, paralleled by two 100 ohm, 2 watt carbon comp resistors
R1 thru R6	35 kohm, 10 watt, wirewound (Ohmite 40F35KE, available from Mouser)
R7	0.5 ohm, wirewound, 25 watt, 1% preferred, chassis mount
R8	Panel mount potentiomer, wirewound
RFC1	Filament choke, #14 enamel bifilar wound on four inch ferrite rod type R61-050-400 (Amidon FLC-10 kit)
RFC2	Plate choke, 145 µH (National type R-175A)

RFC3	Pi-wound choke, .5 mH
RFC4	Pi-wound choke, 2.5 mH
S1	DPDT toggle, contacts 5A at 120 VAC
S2	DPDT toggle, contacts 10A at 120 VAC
S3	SPST toggle, contacts 5A at 120 VAC
S4	Single pole, 3 position rotary switch, heavy duty (Radio Switch Corp)
S5	Double pole, 3 position rotary switch, mechanically linked to S4
T1	Plate/filament transformer, toroid, 800 VA, dual 800 VAC at .5 amps, dual 6.3 VAC at 4 amps, dual 120 VAC primaries. (Antek P/N AN-8T800, available from antekinc.com)
T2, T3	Control transformer, 120 VAC primary, secondary 5.0 VAC at 10A (Stancor P-6135). See text for alternates.
T4	Filament transformer, primary 120 VAC, secondary 12.6 VAC CT at .1A (Xicon 41FG100 available from Mouser)

General Notes for Linear Parts:

1. Fixed capacitors: Capacitors marked with an asterisk are silver mica, 500 volt minimum rating. Capacitors with a plus sign are electrolytic. Unless otherwise noted, all other fixed capacitors are disc ceramic, 500 volt rating minimum.
2. Fixed resistors: Unless otherwise noted, resistors are 0.25 watt, 5 percent tolerance, carbon composition or carbon film. 0.5 and 1.0 watt are also 5 percent tolerance, carbon composition or carbon film. 20 watt are wire wound.
3. 10.5 meg resistors used in plate voltage meter circuit may be 10 meg, 5%, .25 watt. Select value of 4.7 k across meter to give correct reading.
4. Diodes: With the exception of the HV doubler circuit, lower PRV diodes can be used in other locations. However, since 1N5408 and 1N4007 diodes are only pennies apiece in quantities of 100, no alternates are specified.