

Building your own tube type HF amplifier.

By Matt Erickson KK5DR

I have read in many articles, the lamentation over the lack of new hams that are building their own gear, and older hams who don't build anymore. The problem with getting new hams to join the builder ranks is that there are not a great number of books that address this specific area. Most of the books I have read on ham radio, gave little detail on the actual building of the project. Most handbooks cover the basics, but don't give enough detail. Without that level of detail, the newcomer to amp building is likely to fail, or have a less than great outcome, until they gain enough knowledge and experience to do a good job. Such was my first attempts at home brewing, I just didn't know what I was doing, and there was not enough info available in one source to help. It took years to acquire it all. This article is the sum total of my building knowledge as of this point in time. I have written the article to assist the new home-brewer. Bringing all the details together and experience to bear on the project. I have been there, and made most of the mistakes already, so my experience, and knowledge is ready to be passed on to a new generation of hams that wish to continue this great tradition.

For simplicity, this article will discuss only the use and construction of a grounded-grid, triode type HF amplifiers. Since this article is written for the "beginner", the triode tube is the easiest to work with. More complex tubes and amp designs are possible, but that is for a future article (if I care to write one).

So, you wanna "roll your own"? Well, you need to get reading! Read any and all radio handbooks you can, concentrating on the HF amp sections. Read old handbooks, and new ones. If this is your first major amp-building project, you have allot to learn... May I suggest William Orr's "Radio Handbook" circa 1987-1973, ARRL "Radio Handbook" 1945-1965, Essentials of Radio 1948, EIMAC Co. "Care and feeding of power grid tubes.", anything by R.L. Measures AG6K, etc. There are also a number of web sites on the Internet that feature home brew amplifiers, and amp building discussions.

When you read these books, you will have the basics, and are ready to learn the specifics in this article.

Now, you have just read several handbooks, and STILL want to build it. You must decide what type of tube you want to use, how much power output, what bands to cover, what modes, and what features you most desire. The size and overall unit configuration will be dictated by the previous items.

Attention! Caution!

Safety: With nearly all tube type amplifiers, there will be High Voltage. These voltages can be LETHAL! The greatest of care must

be taken when working around HV, better yet, de-energize the circuit, prior to work being done to it. There will be a section on HV safety interlocks later.

Be careful! Never become comfortable around exposed HV! Many hams have died when contacting HV, lets not have anymore un-needed deaths.

\$\$\$? : How much is this going to cost you? That is entirely up to the builder. If you want to spend as little as \$100, or as much as \$10,000, it is your call. If you buy all new parts, the cost will be very high, if you redesign an old amp, the cost might be very low, but hopefully the results will be the same.

Ham-fests and the Internet are great sources for cheap, high quality parts. It would be necessary to design the unit before you start hunting parts, that way you will know what you need. The tube used, and the power level of the output will dictate the parts needed.

Tubes: If you plan to use older type glass enveloped tubes, you better get several of them, because in 10 years or less, there will be no maker of this type tube. If you plan to use a Metal/ceramic tube, be careful not to choose a type that is currently discontinued, or will be in the near future. A good amount of research will help you make a wise choice.

My personal choice is the EIMAC 3CX1500A7/8877, a rugged, powerful triode, it is expected to be in full production for at least the next 15 years, plus there are a large number of these units that are in the used/pulled market at low prices. These "pulls", can have as low as 100 hours of use, or as high as 10,000. There are several companies that buy these medical pulls, and test them, and certify the unit for full output.

Certain tubes can be rebuilt by EIMAC, or a company called "EconCo" (now owned by EIMAC), for about 60% of new price, the rebuilt tube is "as-new", with full warranty.

What bands?: The most simple amp would be a single band unit, very basic, and easy to build. A single band unit may not have some of the common problems of the multi-band units. This is a good type for the "first-timer".

Starting with 160 meters, the difficulty of design and construction goes up, with the frequency. Stability becomes increasingly difficult when the frequency is raised into the 10-meter range. But, a mono-band amp is still the easiest to design and use.

Multi-band HF amps, have a few difficulties that grow more complex as more bands are added to it.

A mono-bander can be "optimized", and will be very efficient, very stable, and easy to use.

Perhaps the builder would like to build a mono-band amp first, to gain experience and confidence, before proceeding to a more complex multi-band design.

Layout: Here, you must decide if you want an "all-in-one, desk top" amp, or a "floor console", or a "two-piece" unit. This is an important decision, and will effect all of the remaining construction. Think about this area for a good amount of time before making the decision.

I have built all three types, and each has its unique problems and benefits.

An "all-in-one" desktop is the easiest type to construct, but must be limited in its size and weight, which will limit the power output, and the size of the tube used. Desktop amps, that are too heavy or large, can be a real problem when it needs to be moved. Your desk might not support it.

A "floor console" will give lots of room for parts inside it, but must be placed next to the operating position, but not in it, like a desktop. Typically, a floor console is heavy, & large, so roller-casters are a must to ease movement.

A "two-piece" unit, is a cross between the previous two units, but has some problems that must be kept in mind. RF filtering must be done to ALL lines that enter or leave both pieces. A multi-conductor cable will be needed for control of the PS from the RF deck, which are usually located in the operating position. Usually, a high voltage cable will be needed too. Connectors for all these cables will be needed for one or both units, which will allow them to be moved or serviced.

As for the RF section, the builder must be reminded that the input side of the tube and the output section must be shielded from each other. It also helps to shield the PS section too. However it is not entirely needed if the PS is located on the input side of the unit. The best possible shield is a solid bulkhead that is RF tight.

Planning: OK, now you have chosen the tube you want to use, the bands you want to cover, and the type of layout you want. Now, you must plan out the design and construction of the unit. Where you start is up to the builder, but starting with the Power Supply section is the simplest area, and will help the builder get a sense of the requirements of the RF section, and will help define the rough configuration of the RF deck.

You can't spend too much time planning the project. Drawings, and mental design of the unit will go a long way to making the project come out the way you want it. Mentally designing and building the unit, envisioning the overall construction, re-designing, re-building, and re-finishing, to do this in you mind, will give the builder a road map for construction.

Documentation: Do yourself a big favor, when designing & planning your amp project, document all your work.

I used my computer to design and print all my schematics, and was able to print out "blow-ups" of individual circuits, that greatly aided in the construction, and helped prevent mistakes. I now have a CD-R that all my projects are stored on, and can be used for reference at any time. I suggest that you at least make drawings. If you plan to keep the unit the rest of your ham career, it is a good idea to keep these documents, because you might forget what you did years ago. A full set of schematics is the least amount of documents you should develop. An operation "Theory" document would be good too. This document describes in detail, the operation of the amplifier, in each area. A parts list, with detailed part descriptions and locations can go a long way to aide in any repair or updates. If you don't plan to keep the unit, and will sell it someday, the paperwork will help you sell it, and help the new owner to understand and operate the unit properly.

"Doing it", just like the big amp manufacturers has its benefits.

Parts is parts: It's time to talk about the parts that are common to all HF amplifiers.

Plate transformer : I suggest "Hypersil®" type, but standard iron core is OK, <As of Dec. 31, 2007, P.W. Dahl Co. is no longer in operation. Harbach electronics has purchased the entire operation and now sells a more limited line of transformers.> These are not cheap, however they are the finest available, and I have never had a problem with them. For example; a transformer capable of 1500 watts RF output continuous, will weigh 35-60 Lbs. A transformer that can sustain 500 watts RF output, may be able to PEP 1000 watts intermittently (50% duty cycle), will weight about 20-30 Lbs. An iron core transformer will weigh about 20% more for the same output as a Hypersil®.

Other transformer makers are;

Universal Transformer in Farmersville, TX. The person to speak with is Chris. Tel. 972-442-2231

Power Magnetics is a large transformer co in Trenton, NJ. 1-800-747-0845, or see: <http://www.powermagneticsinc.com/>

Ham-fest transformers are a great bargain, but many times the specifications are not available, and the condition of the unit might not be good, even if the exterior looks fine, the inner windings might have a large amount of moisture in it, and would shorten the life of the unit drastically. Older transformer design used paper as an insulating media, but was "un-treated" paper which draws in moisture from the air, the process is called "Hydroscopic", when the moisture level reached a certain level, the HV would arc across windings, shorting the transformer internally, once this happens, the unit is junk. Newer transformer designs, use Mylar®, or a plastic media, some use treated paper which is rubberized or impregnated with wax, or plastic. Some designs even use Teflon® insulation, when high heat levels are expected.

A legal limit output amp should use only 240vac primary on the plate transformer.

Next, the formula for B+, HV calculation. The desired plate voltage, i.e. 3500Vdc, requires a transformer RMS secondary output voltage of about 2700Vac. 2700 multiplied by .98 is the voltage output of the full-wave bridge rectifier, equals 2430Vdc, now multiply this by 1.41 to get the peak voltage output of the filter capacitor, equals 3426Vdc, very close to 3500Vdc. It is likely that the output might be slightly higher, dependent on main AC line voltage present.

To find the transformer RMS voltage desired, do the calculation in reverse. Tube required B+ divided by 1.41, divided by .98, equals HV transformer secondary RMS output voltage. This should help the builder design and find the proper transformer for his project.

Filament transformer : Try to match the filament transformer current output closely to the current requirements of the tube you plan to use. A transformer that is rated over the tube requirement will likely run slightly higher voltage than the tube should be run at, so a voltage adjustment resistor should be used on the primary of the transformer, which will negate the need for a step-start on this circuit. 240Vac primary would be good, but not absolutely mandatory. This transformer typically has a very low primary current input, so it could be used with a 120Vac circuit. On a 240Vac two-wire circuit, either one of the lines to ground is 120vac, so it is easy to acquire it in a 240Vac "single-phase" unit.

It is possible to use a regulated DC PS for the filament, but this is only advisable on "indirectly" heated cathode tubes, like the 8877. If you choose to use a DC PS, use one that has an adjustable voltage, and surge/current limiting. Carefully adjust the PS for the proper voltage reading at the tube socket, with a "True RMS" reading meter. A filament PS such as this will provide "in-rush" current limiting, which will lower the stress on the tube filament. There would be no need for step-start or adjustment resistors.

High Voltage rectifiers : Strings of individual diodes may be used, or the "Block" type made by K2AW "Silicon Alley", and a few other makers. The block type should be mounted on a 1/4" thick plate of aluminum or copper, the reason for this is that the block type rectifiers do not dissipate heat very well, and need physical contact with the plate to conduct heat away from the junction. Discrete diodes dissipate heat better, but do it via the air flowing around the body of the diode. Mounting the diodes on a PCB, should be done with a 1/4" space between the board and the diode, this gives the air a route to flow around the diode body and carry heat away.

Why do the diodes need to be cooled? Over-heated diodes effect HV regulation, which affects the linearity of the output RF signal.

Diodes should be "swamped" by resistors, 470-820K ohms @ 2 watts, 1% "flame-proof" type. This swamping resistor equalizes the voltages across each diode in a string. This can't be done to the "block" type diodes. As well as swamping resistors, the diodes should have capacitors across them to suppress "switching transients" which are generated in each diode as it switches from conduction to non-conduction and back again. These transients show up as "white noise" in the side band of the transmitter. The suppressor caps filter this noise. The cap should be .01 μ F @ 1Kv or more, across each diode in the string.

The rectifiers used, should have a PIV (Peak Inverse Voltage) rating of 1.41 above the desired plate voltage. If 3500VDC is used, the diode strings should be of at least 5Kv or more. A legal-limit amp should use rectifiers able to handle 1-3amps of current.

What diodes to use? For an amp using 3500VDC, a full-wave bridge rectifier would need no less than (6) 1Kv 1-3A diodes in each leg or the bridge. I would opt for the 3 amp units, which gives a good safety margin. For "Block," type rectifiers, use 6-12Kv 3A + units in each leg of the bridge, (4) units total.

A full-wave bridge rectifier configuration is the only way to go on a quality amp PS.

Fig.1 shows a typical HV full wave bridge rectifier unit. Each diode in each leg is 1Kv @ 3A. = 1N5408 type.

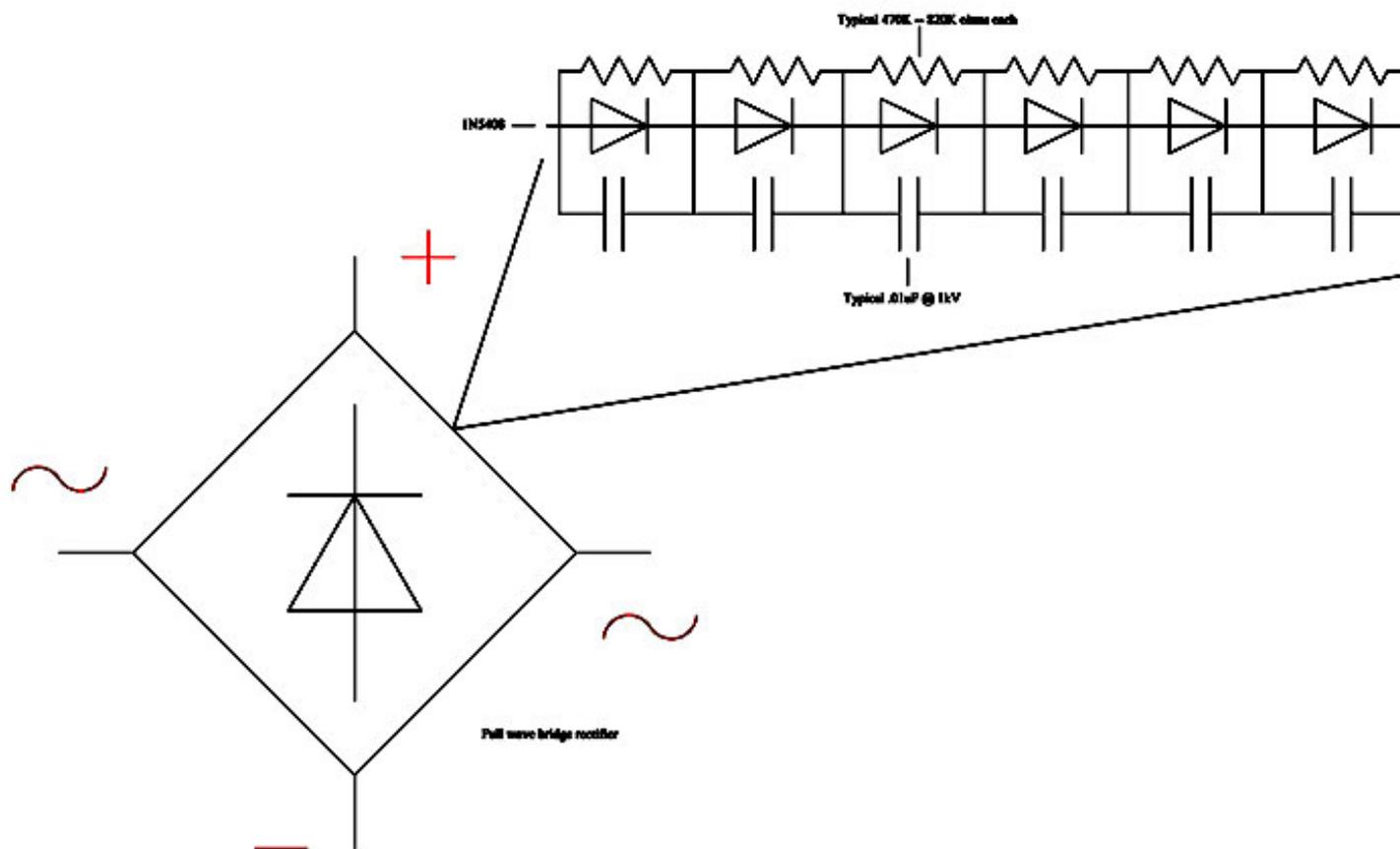


Fig.1

High voltage filter capacitors : The builder can use one capacitor or a large string. The single cap will likely be an "oil-filled" type or an "energy-discharge" type, either one will last a long, long time, but these caps are very large, and have other problems which I'll define later. The "computer-grade" electrolytic type is most commonly used in modern amps, but have a limited life span in comparison to the previous types.

"Computer-grade" capacitors are most commonly radial, screw mount type, meaning that the terminals are on one end, threaded. The case of these units is negative, and a terminal screw on the "plug" end is positive. The highest working voltage rating on these is 450Vdc. A legal limit amp should have a filter capacitance of 25-100 μ F, 50 μ F is the best area to shoot for. An amp that runs 3500Vdc, will need (12) caps rated at about 600 μ F each, to hit the target of 50 μ F, and a total voltage rating of 5400Vdc, well above the peak surge level. Bleeder resistors will be needed across each cap in this string, which will be discussed later in this article. This level of capacitance is a large load when empty or discharged, so a "step-start" system is needed, which will be discussed later. Ambient heat will drastically shorten the life span of these caps, which have an average life span at room temperature of 20-25years. The greater the heat they are exposed to on a long-term basis, the shorter the life span. Failure modes for these caps are two types. Loss of capacitance, or Explosive shorting. Loss of capacitance, is noted by a drop in B+ voltage, and drastic degradation of voltage regulation. Explosive shorting is obvious, and can lead to a chain-reaction failure of the entire string of caps. During normal operation, these caps generate internal heat, which must be carried away, as well as the heat generated by the bleeder resistors. These are the few drawbacks to this type of capacitor.

ESR, (Equivalent Series Resistance), is the reason the computer-grade caps generate heat during operation. Caps with very low ESR tend to generate much lower heat outputs. Energy-discharge caps have much lower ESR than computer-grade electrolytics. Therefore, they generate less heat.

"Oil-filled" or "Energy-discharge" capacitors, are well suited to amplifier PS use, but are usually large & heavy units, and getting hard to find. I have used the energy-discharge type, and they are quite good, slightly smaller than the older oil-filled type. Most of these units are "uni-polar" which means that neither terminal has a polarity, so the builder defines this function with external circuits. A "Step-start" circuit is an absolute must with these caps. A single bleeder is used across this cap, most will be from 100K ohms to 250K ohms. A 100K-ohm bleeder will need to be 200watts, and the 250K-ohm should be 100watts, resistors like this are large, and hard to find. A pair of 100K ohm 50 watt units can be used in series. This is the main drawback of these caps. The desirable point of these caps is that they will last indefinitely, and are little affected by ambient heat.

I tested an energy-discharge cap @ 2.5amps of steady current, with no heating, and no problems. These caps are designed to discharge thousands of amps of current in a few milliseconds, then re-charge in the same amount of time, so operating in an amplifier PS, is actually quite mild for them. They are used in LAZAR, & Nuclear research, so there are a few sources for them.

Maxwell Components of San Diego, Ca. manufacturers some very nice units. Not cheap, but they should last the life of the amp.

Step-start: A PS using high capacitance filter caps will need a "step-start" circuit. This circuit limits the start-up in-rush current to safe levels for a few seconds, then switches to full AC main voltage. Using a time-delay relay to control a larger contactor type relay, the circuit starts with a primary contactor, which can be a DPST (double pole, single throw), with contacts that are equal to, or greater than the maximum current rating of the PS, typically about 20+ amps. The primary contactor closes when the main AC is switched on. At the same time, the time-delay relay begins its cycle, usually anywhere from 0.5-3 seconds long. When the time-delay relay completes its cycle, it closes a secondary AC contactor, which is where the step-starting is done. The secondary contactor must be a DPDT (double pole, double throw) relay the normally closed contacts feed AC to the limiting resistors and then to the transformers. When the time-delay relay closes the secondary contactor, the resistors are shorted out of the circuit, and full AC voltage is fed to the transformers. The resistors used in this circuit can be anywhere from 30 ohms to 100 ohms, 25-50 watts each. See Fig.2 for basic layout of a step-start circuit.

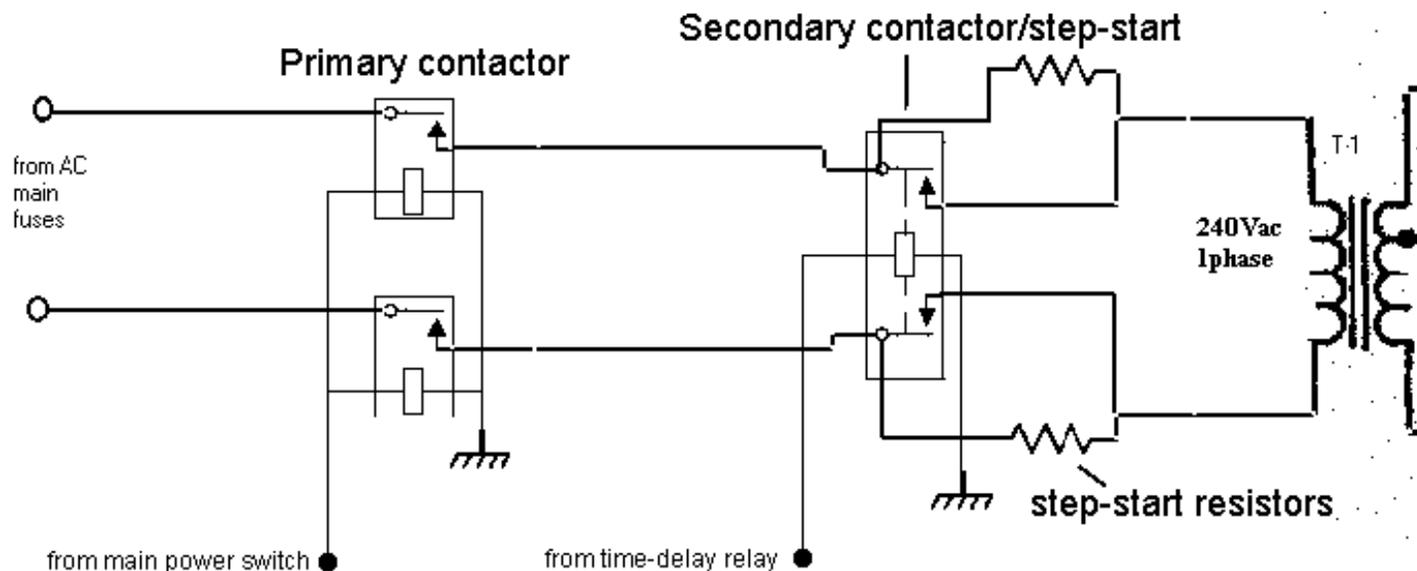


Fig.2

Bleeder resistors: It has been a common practice in the past, for amp builders to use HV bleeder resistors that placed a constant current load on the HV PS, of about 10% of full load rating. For example, an HV PS capable of 1 Amp full load had a bleeder load of 100mA. The reason for this practice was the fact that the power supplies of that day, used filter chokes, which would cause the B+ to rise rapidly when the PS was not fully loaded, so the bleeder would stabilize the B+ when the PS was not fully loaded. The need for this type of loading by bleeder resistors is no longer valid, because filter chokes are not used anymore. I like to use bleeder resistors that place a much smaller load on the PS. An HV PS that used 75K ohm @ 6+ watt bleeders, would now be re-fit with

220K ohm @ 2 watt bleeders. The higher resistance places a much smaller load on the HV PS, and will make the bleed-down time after the PS shut down, much longer.

For a HV PS that uses a single filter cap, the bleeder current should be calculated to select the proper wattage rating of the resistor. For example, A B+ of 3500Vdc will impress a current of 35mA in a 100K ohm resistor, ($I = E/R$). The power/wattage dissipated in the resistor will be 122.5 watts ($P = E \times I$). So, a resistor of at least 150 watt rating should be used, 200 watts would be even better, since 122.5 watts is the constant power dissipation of the resistor as long as the PS is energized. It would be a good idea to place this resistor in an air-flow to remove this level of heat.

Fig.3 shows the typical oil-filled/energy-discharge cap installation with bleeder and HV meter sampling resistors, as well as a current limiting resistor. The current limiting resistor protects the HV rectifiers, and is in the circuit full time, it plays other roles as well, which will be discussed later in this article.

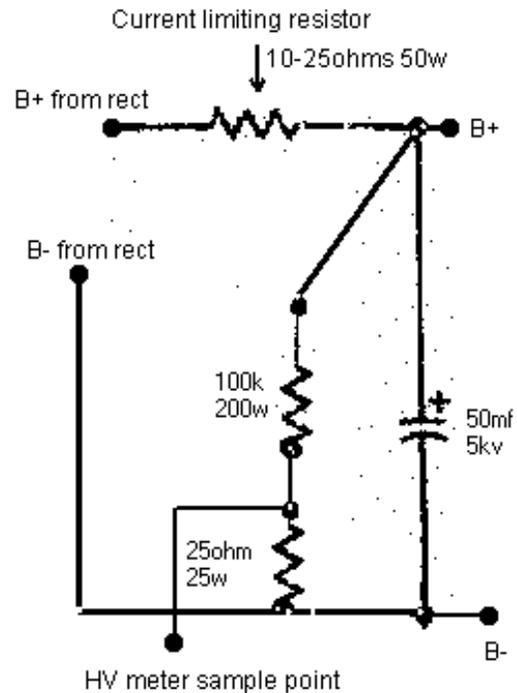


Fig.3

A string of computer-grade caps have less demanding power levels on the bleeders. Each cap will have a resistor across it, which not only bleeds down HV, but equalizes the B+ voltage across each cap. So, a set of (12) caps on a 3500Vdc PS, would have about

291.6Vdc impressed on each cap; (3500Vdc divided by 12). The voltage is still well below the max rating of 450Vdc, however the voltage can and will vary across the entire string. Closely matched bleeder/equalizing resistors are needed to insure proper voltages. A bleeder resistor of 220K ohms with about 292Vdc placed across it will pass 1.3mA, or .39 watts. A 2 watt flame-proof resistor should last a life time in this circuit. It is important to use close tolerance resistors, 1-2% type are best. The total watts dissipated in the string would be about 4.68 watts, (.39 x 12 = 4.68). It takes about 2 minutes for the B+ to bleed-down to a safe level after the PS is shut off. Do NOT attempt to do any repairs or modifications to the HV PS during this bleed-down time.

Starter "latching" relay: Previously I discussed the step-start relays, now I'll tell you about a "latching" starter relay. I like to use these relays to keep high currents from being carried by the main power switch, also, the starter relay will disengage when AC main power fails, and this will prevent damage from a short term power outage.

Fig.4 shows a typical starter "latching" relay configuration.

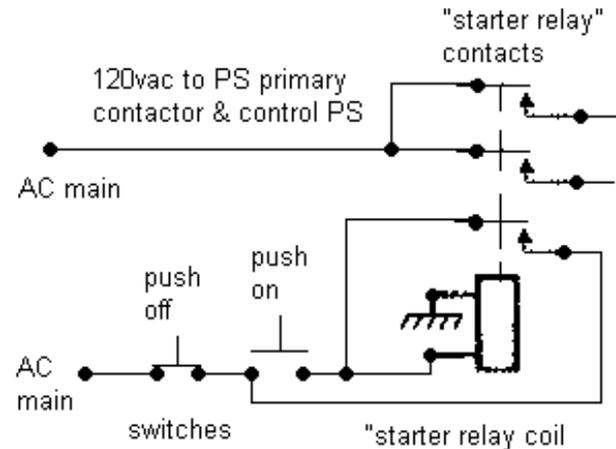


Fig.4

The relay used is a 120vac coil, with at least (3) sets of ST (Single Throw) contacts. The switches are momentary push button type. The power "OFF" button is normally closed the power "ON" button is normally open. When the "ON" button is pushed, the coil of the relay is energized and the contacts are closed, then the switch is released, and the coil stays energized via a set of contacts on the relay. Only the current to energize the relay coil passes through the power switches. The remaining contacts on the starter relay energize the primary contactor, and the control voltage PS, maybe the fans/blowers too. If main AC power drops out while the PS is in use, the starter relay will drop out, and must be re-energized to operate again. This will prevent large scale damage that might happen if the amp is in transmit when the AC main drops out and quickly comes back on. This type of damage has happened before

on amps that were not equipped with this circuit. The other benefit of using this circuit is that the main power switch need not carry the full load current (up to 20Amps on a legal limit amp). To shut down the PS, the user pushes the "OFF" button, AC main power is cut to the starter relay coil, the contacts release, and the unit shuts down. In high current pieces of equipment such as industrial gear, they nearly always have this type of relay. They are easy to build, cheap, and might save you a bunch of money someday.

Surge suppression & EMI filtering: Most HF amplifiers should have some form of AC main filtering to prevent RF from feeding back into the unit via the AC power lines, or from causing interference to other equipment in the AC power system. AC surge suppression is also a concern, since hundreds of minor surges happen every day on the average AC line in a home, and several times per year the home will have a major surge, possibly doing damage to equipment that is not protected from surges. AC line surges happen when large current loads are switched on or off, or when lightening storms are in the area. A storm many miles away can cause large surges in the AC of your home/radio-shack. I have personal experience with a large expensive amp being mortally wounded by a line surge, so I know the importance of this protective device.

The AC line should have fuse or circuit-breaker protection as the primary protective device, then a set of MOV's (Metal Oxide Varsistors) which conduct voltage surges to ground when the voltage on the line reaches the critical level. A 130Vac MOV placed from the AC line to ground will begin conducting at 130Vac, and depending on the model used, will reach full current conduction at about 150Vac. On a 240Vac single-phase service, the normal voltage on each line is about 120Vac, plus or minus a few volts. A 130Vac MOV from each line to ground is the minimum level of protection I would suggest. To go a step farther, place a 275Vac MOV between the two AC main lines. It is very important that these MOV's be soldered in position, NOT crimp connector mounted. The soldered connection will handle much greater current levels. The crimp connector will become very hot under surge conditions & possibly open due to super-heating, which will render the line unprotected, and quite possible that the follow-on current surge will damage the gear.

After the MOV's, an EMI filter (Electro-Magnetic-Interference) should be installed in the AC main lines. This unit will prevent RF from entering or leaving the PS via the AC mains. EMI filters can be bought, but must be rated at the full load current and voltage of the PS, typically 250Vac @ 20Amps per leg. The EMI unit must be well grounded to the chassis.

Wiring harness & connectors: A big part of a well-made amplifier and PS, is the wiring harness. Each circuit should have wire that is large enough to carry the current and withstand the voltage on it. It is better to oversize the wire so it will operate at a cool temperature on a continual basis. Routing of the wire is very important. Be careful not to route wires in areas of high heat levels, or high RF levels. Avoid routing control wires along side B+ lines, or RF coaxial cables. Wires should be "bundled" and routed in areas where they will not interfere with operation, and be safe from chaffing by sharp edges. Use rubber grommets on holes where wires pass through bulkheads. If the builder wishes to take their project to the ultimate end, use "feed-through" caps on wires that pass into or out of the RF areas, however, this practice is not really necessary provided attention is paid to where the wires are routed, and RF by-pass filters are applied at some point on the line. The best possible approach would be to not have any control wires in the RF

deck area at all, but in most cases this will not be possible to do. Some thought should be given to serviceability of certain parts in the unit, should the need arise to remove a part or board for servicing or repair, connectors should be placed on the wires to that component to make removal easy. It takes a little extra effort, but will payoff later should the need come about. The ultimate in unit wiring is the use of Teflon® insulated wire, however this type of wire is not very easy to come by, and is an added expense, but will last the entire life span of the amp/PS. Labeling of the wires is a must, and full documentation, with a wiring key/legend will help greatly to insure that mistakes don't happen. Later servicing/troubleshooting will be aided by this wire guide. Use tie-wraps and cable ties, as well as fixed wire anchors to neatly bundle the wires, and make them secure. A neat appearance as well as a reliable wire harness. Place tie-wraps at 1/2" up to 1" intervals on the wire harness, more if needed. Connectors should be secured with a tie-wrap if the connector does not have a positive locking mechanism. The wiring harness will likely be the most time consuming element of construction, but time well spent here, will make the unit work well, and look great. If possible, test each circuit for proper operation before it is laid down into the wire harness. Temporary test jigs or power supplies might be needed to do the testing, simulated loads, and other test setups might be needed too. All the testing can reveal mistakes or improper operation of the circuit, it is better to find the problem before the circuit is in the harness, or the unit is completely closed up. Again, time well spent in this area, will give a big payoff later when the unit is placed in operation, and it works perfectly, because you did all you testing earlier.

When it comes to the wiring harness, it is not a bad thing to be a little "anal-retentive". Meticulous attention to detail is the key to a great wiring harness, and no problems when the moment of truth comes, when the unit you just spent a huge amount of time building, is powered up, and operates perfectly.

RF filtering: All lines in the amp and PS must have a bare minimum of RF bypassing placed on them. Remember that there is a huge amount of RF field in and around the amp, it can do damage to components and cause harmful interference if not properly bypassed to ground, or blocked. Liberal use of .01 μ F @ 1Kv disk capacitors, which are cheap, will do a good job of removing the small RF currents that become coupled to wires inside the unit. Special attention should be taken to filter the lines coming out of the control voltage PS. Relays should have a cap from the positive coil line to ground. Lights and meters should have a cap placed across the leads and or to ground. Anyplace where DC voltage is used, should have RF bypass caps placed, to prevent RF from coupling to the line and causing problems. I purchase .01 μ F @ 1Kv caps by the hundred pack, that is how much I use them. At about \$.10 each, they are cheap and plentiful. Use lots of these caps, your rule of use of them should be, "Every wire must be filtered at some point." The best places to put the caps are at its beginning, and at its destination points. In this way the line should be clean of any RF that might have coupled to it at any point of its run.

Grounding: This is a very, very important area. The PS MUST have a good ground to the chassis and to the AC main ground, as well as a good independent earth ground. Multiple ground paths will reduce the possibility of RF feedback, and shock hazards. Good mechanical ground connections should be made in any place possible, and as many as possible. Multi ground paths reduce overall

DC/RF resistance. An absolute MUST, is an excellent AC main ground to the chassis of amp & PS, heavy gage wire or strap should be used, as well as heavy ground lugs with tough, tight mechanical connections to the chassis and the AC main ground. A large ground post should be placed in the chassis that a grounding strap can be affixed on the outside of the unit, and routed to a nearby heavy earth ground (ground rod). The logical placement of the exterior ground post is usually near the entry of the AC main power cable, but if this is not a good area on your unit, place it where it is convenient.

Enclosure: A good mechanically strong, RF tight enclosure will help prevent RF feedback or RFI via radiated RF escaping the enclosure. The cabinet you use should have enough room for all the parts and boards you plan to install in it. No parts or components should be placed outside the cabinet with associated wiring this practice is UNACCEPTABLE & UNSAFE. The cabinet must be structurally strong enough to support the full load of components it must carry. Material that is too thin, or is unsupported might buckle or warp. Planning must be done to insure that all parts will fit, and the structure will support them all. Ventilation must be provided via openings in the cabinet. There are several ways to do this. A blower can be placed inside the unit, and air will be drawn in through an opening in the cabinet, and exhausted out another opening. It is important to note that the "intake" must be about twice the area of the blower/fan opening, the exhaust can be the same size or slightly larger than the blower/fan intake. Another important item is the size of the perforations in the openings, too large, and large dust or hair can enter too easy, also RF can escape or enter too. If the perforations are too small, the airflow will be so restricted that cooling will become ineffective. I found that louvers are a good item, but hard to hand build, drilled holes work, but are a lot of work, and sometimes don't look so good. The size of the hole should range from 1/8" up to 1/4" dia., no larger, and no smaller. If you are making air openings from scratch, it might be a good idea to take the pieces to a sheet metal shop and have them install the openings for you.

Aluminum is the best material to use when building your cabinet, but steel or copper can also be used, but has its own problems, and benefits. Whether the builder bolts the cabinet together, or welds most of it together, is up to the builder. The builder must keep in mind serviceability of the unit interior, so access doors or panels must be designed into it. For the beginner to amp building, it might be better to use an old decommissioned amplifier as a basis for the new unit. Most of the cabinetwork is done, and only modifications are needed to adapt it to the new application.

Airflow: While the builder is designing the enclosure, attention should be paid to the flow of cooling air. Making efficient use of the airflow will cool the maximum number of parts, with a minimum of fans/blowers. For example; an entire cabinet can be "pressurized" with a fan/blower, with the only exit for the air being the socket area of the tube(s). This approach works well on the "console" type unit. An RF deck that is separate can use a blower that forces air only into a "plenum" under the tube(s), the side effect of this, is that the air intake draws air into the deck cooling other parts, and a set of exhaust chimneys will be needed to keep the intake and exhaust air flows from mixing into a "feed-back loop". Isolating the intake and exhaust airflows will prevent this.

Fig.5-7 show typical airflows and cabinet configurations.

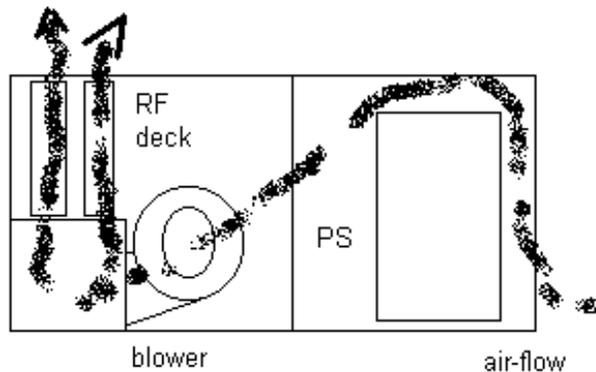
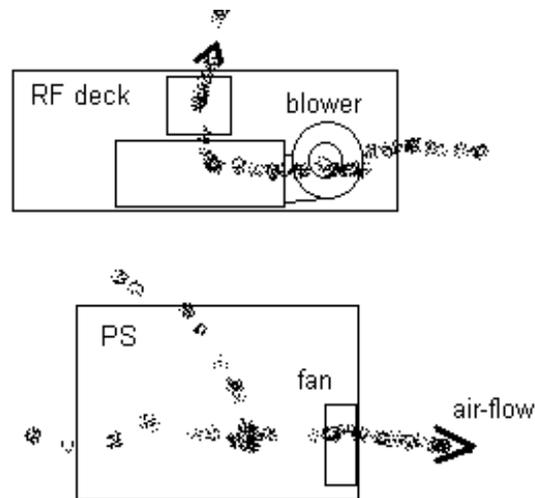
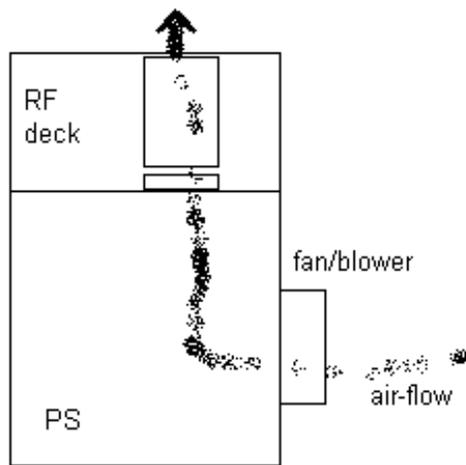


Fig.5

Fig.6

Fig.7

Fig.5 is a "console" type, with pressurized lower PS cabinet; air exits only through the tube/socket and chimney and upper cover.

Fig.6 is a two-piece RF deck and PS, each has a fan/blower and separate airflows. The RF deck has a pressurized plenum below the tube sockets and chimney.

Fig.7 is a desktop "all-in-one" unit, which has a pressurized plenum below the tubes and chimneys. Air is drawn into the unit by the blower, and across all the components in the PS and RF deck before the air enters the blower intake and is forced through the tube sockets and out of the unit.

There can be many variations on these themes. However, efficient air-flow and cooling are the overall goal.

Fit & Finish: An area that is many times overlooked but later becomes a source of irritation is the overall "fit & finish" of the enclosure/cabinet. Here again, good planning, and a great deal of thought will help the builder in this area of the construction. Drawing a good layout on the enclosure parts can help get the finished results you want. All edges should be sanded and smoothed, all holes should be clean and smooth. Joints should fit tight and clean. Pre-fit the cabinet part together, measure internal clearances to insure that the parts inside the unit line up, and do not interfere with the parts mounted on the outside. If you bolt the cabinet together, the screws/bolts should be aligned in straight lines with sharp right angles where the lines intersect. Doing this will make the appearance of the outer cabinet look very professional. Avoid random holes, or patches. In many cases you will have only one chance to do it right, and make it look good. The outer cabinet is as much about aesthetics as it is about structure. Careful planning, and layout are a must in this area. As I have said, "attention to detail" will payoff in the end.

While we are on the topic of metalworking, you will need many tools, and drill bits are no good if they are not sharp, the same for metal cutting tools. A saw blade that is dull will make a big mess out of a thin piece of sheet metal. Do yourself a favor and repair or buy new tools you will need. I can't tell you what tools you will need, that will have to be determined by the builder alone.

Painting: The exterior of the unit will need to be painted, so sanding with fine grit for smooth clean finish will be attained. Prior to painting, the pieces should be rubbed off with solvents to clean oil or grease off, let it dry and its ready for paint. Wear plastic or rubber gloves when handling the pieces during painting, this will prevent oils from your bare hands getting on the surface, and ruining the paint job. Allow the paint to dry well, a few days would not be too much. The interior can be painted too, but should be done first. A fine paint job will make the unit look very good.

Meters: On the typical HF grounded grid amplifier, you will need no less than (2) meter functions, a plate current meter, and grid current meter. If you wish to go first class, add an HV meter. All meters should be dedicated full time reading meters. Each meter should have it's own calibration potentiometer. The style of the meters will look best if all are matching units. If the scales on the meter are not what you need, the scale can be remade to meet your needs. I have done this by taking the scale out of the meter, and scanning it on a flatbed scanner, then used Adobe Photoshop Le® to edit the image to suit my requirements. Then I used my inkjet printer, set on 1200dpi, to print the new scale out. I then cut the image out of the paper, and glued it to the aluminum scale backing, and reinstalled it in the meter. They look excellent.

If there are shunts mounted inside the meters, you should remove them, because it is better to use an out-board precision-resistors for shunts. The meter movements should be protected by two diodes in parallel to each other, reversed polarity to each other across the meter inputs. A .01 μ F @ 1Kv cap should also be place across the meter movement to bypass RF off the meter.

Meter calibration: When you get to the point in construction where the meters and associated shunts and calibration pots are

installed, they are ready for calibration. To do this, you will want to pass a known level of current through the shunt resistor, and calibrate the meter movement to read this known level. DC current passing through the shunt resistor will generate the same voltage in the meter movement, regardless of the voltage that drives the current through the shunt.

Fig.8 below shows the typical plate current calibration setup. Using a good quality digital multi-meter set on the ammeter function, the 12VDC PS provides the current for calibration. The load rheostat controls the level of current flowing through the meter shunt during the procedure, acting as an artificial load. The level of current is set, and the DMM reads the amps, which the meter cal pot. is then set, so that the meter movement reads the same as the DMM. The meter is now calibrated. The grid current is done the same way with lower current level, and attention to polarity.

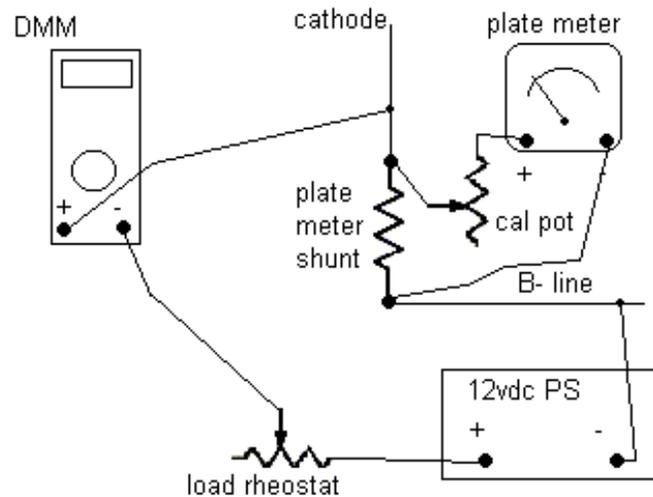


Fig. 8

High voltage meter: There are a couple ways to sample the HV for reading on your HV meter. The first method is to use precision resistors to drop the voltage directly from the B+ line. This method has been used allot in the past, but the demands of the resistors in some cases make it less precise. To get a high level or precision, the resistors used should be no less than 1% tolerance level. Resistors of 1/2% tolerance are available, but harder to get. It will take several Meg-ohms at about 1/2 watt to bring the voltage down to a level that is safe for the meter movement, then a calibration pot will set the reading to a good precise indication. You will need a high voltage probe to read the HV, and make the cal pot read the same on the panel meter.

Fig.10 shows this method.

The second method is to sample the voltage from the B- side of the PS, by breaking the bleeder resistor connection to the B- line side

of the filter cap, a resistor of a low resistance is then placed in the circuit to generate a low level voltage that can be handled by the cal pot of the HV meter movement.

Fig.9 shows this method.

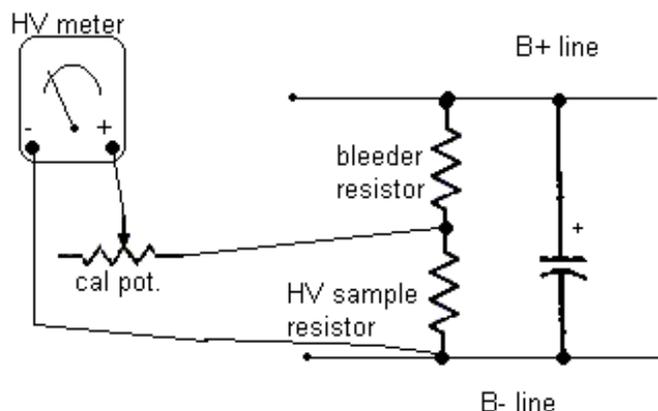


Fig. 9

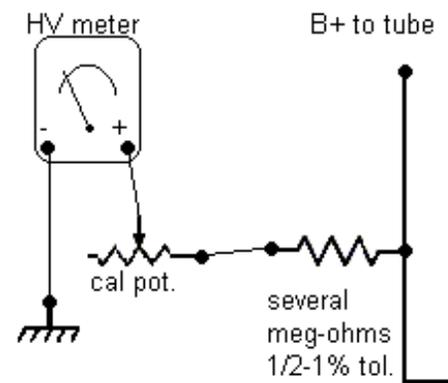


Fig. 10

Interlocks & protections: Tube type amplifiers usually have dangerous voltages present inside during normal operations. The builder should install measures to prevent accidental physical contact with it. The cabinet should have an interlock on it to disable the high voltage (B+) when the unit is opened while in operation. There are a large number of ways to do this. The old method was to use a "shorting bar/rod" that shorts the B+ to ground when the cabinet is opened. This method causes the circuit breaker to trip, or fuses to open. The method is a little bit "destructive". A less drastic, but more complex method is to use a micro-switch to cut power to the PS main AC, shutting down the PS when the cabinet is opened.

Lighting & indicators: Many users like to have the lighting in the radio room set low, so the equipment needs to have adequate lighting for reading of meters and other functions. LED's are very popular now, and can be had in many colors. The current draw of LED's is very low compared to an incandescent light. What type of lights and indicators are entirely up to the builders desires.

Biasing: Speaking of the cathode of the amp tube, there are a few ways to set the operating and "cut-off" bias of the cathode. One way, is to use a high power zener diode to set the operating bias of the tube during transmit function. For example; a 8877 tube will use a zener from 8.2vdc to 12vdc @ about 50 watts. Usually the zener would be mounted on a heat-sink to carry away the heat that could ruin the diode. The zener can also be placed in a circuit that uses a power transistor such as the 2N3055. The diode will control

the transistor, which carries the main amount of current. The diode can then be a much cheaper 1 watt type. Fig.11 shows this kind of circuit.

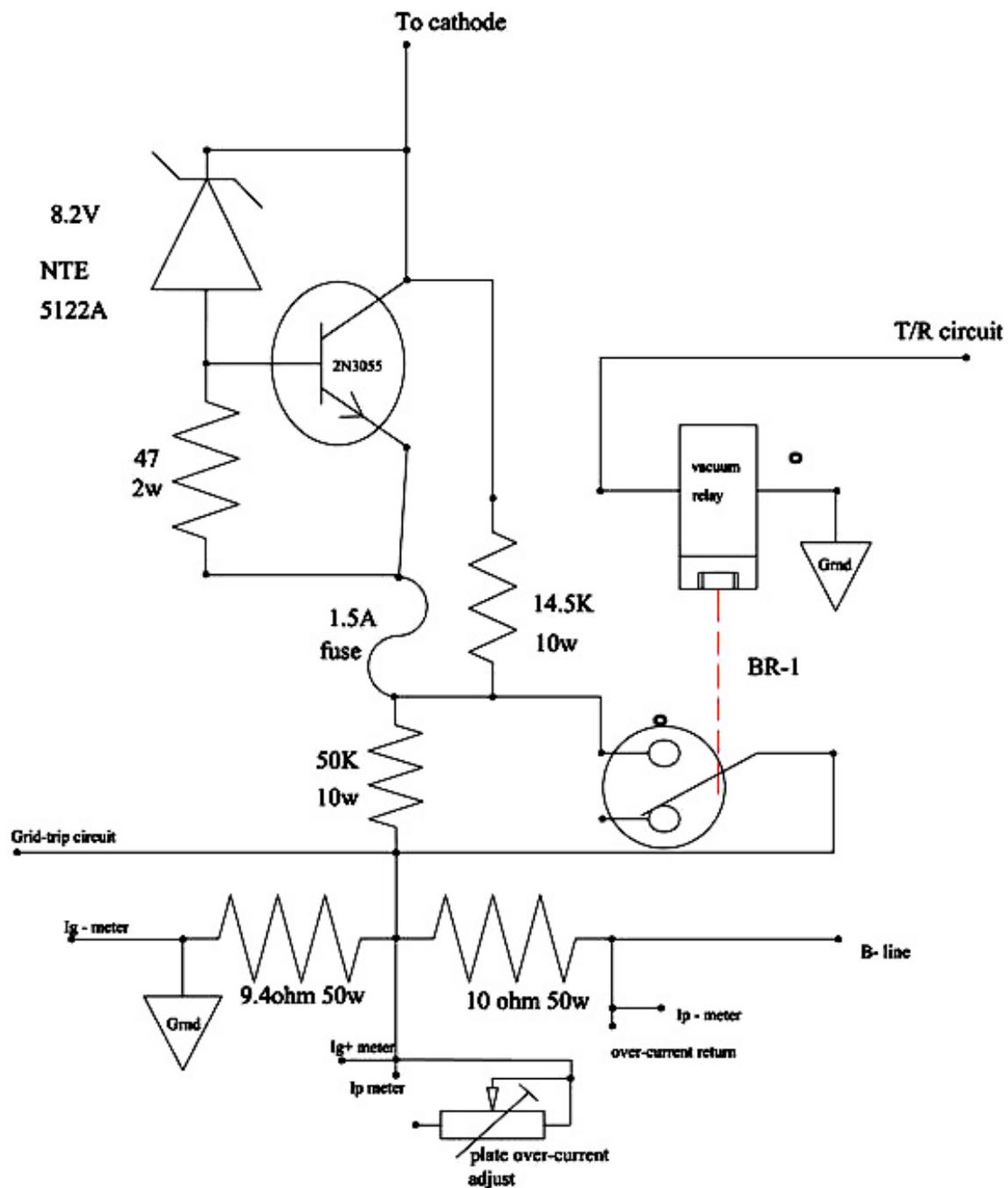


Fig.11

The "overload fuse" would open if too much plate current were drawn, if this happens, the "safety resistor" will bias the cathode to near cut-off until the fuse is replaced. The "cut-off resistor" brings the plate current to full cutoff while the amp is in standby or receive mode. The "cathode relay" switches to short out the cut-off resistor when the amp is in transmit mode. The zener diode can be changed to vary the level of voltage the circuit operates at. This circuit can be adapted and used in a large number of tube configurations of triode tubes. It is easy to build, cheap, and effective circuit.

An optional circuit would be to use a rotary switch on the control zener diode to allow the switching in & out of various values of zener diodes for efficient operation in other class modes. This method can be used on either circuit in Fig. 11 or 12.

An old style of cathode bias circuit can be seen in fig.12.

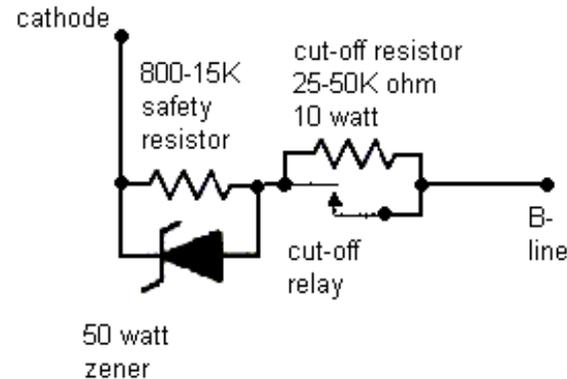


Fig.12

This circuit is very simple, but the 50 watt zeners are becoming very hard to find.

Which bias circuit the builder wishes to use is up to them, each works fine, but has its benefits and drawbacks.

Tetrodes & Pentodes require a much more complex system of cathode, screen and grid biasing, for simplicity I will only address triodes in this article, which are easy for the beginner to work with.

Tuned input & resistive networks: This is one of the essential parts of the cathode area of a triode tube. The builder might ask, "why a tuned input or a resistive input network are needed on a tube that may have a cathode impedance of near 50 ohms?" The reason this circuit is needed is because the input impedance of the cathode is only near 50 ohms for half of the cycle of the input RF signal. During the opposite half of the cycle the input impedance can approach near infinity. This type of load variation will cause the input signal waveform to be distorted enough to cause harmful harmonic distortion to be radiated from the transmitted signal. The tuned input network presents a constant load to the RF drive signal, and also provides a level of harmonic filtering. The circuit has a very low loss, so most of the drive signal arrives at the cathode of the tube. The resistive input network presents the same constant load to the RF drive signal, but absorbs most of the driving signal, so a much smaller RF drive signal arrives at the tube cathode.

Fig.13 shows the typical tuned input network minus any switches or relays used to switch in and out the needed network units.

Fig.14 shows the typical resistive input network, covering all bands without switching, however, since the resistor absorbs nearly all the RF drive signal, the resistor must be rated at about 100 watts, and the value must be selected to match the operational resistance values to acquire a 50 ohm input resistance.

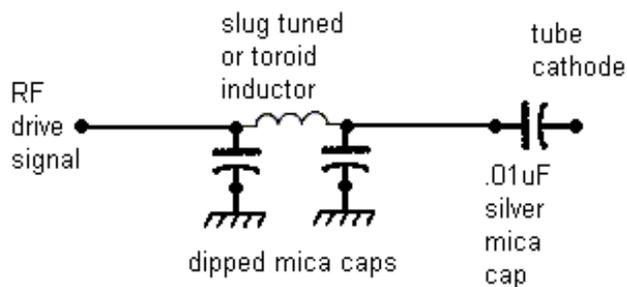


Fig.13

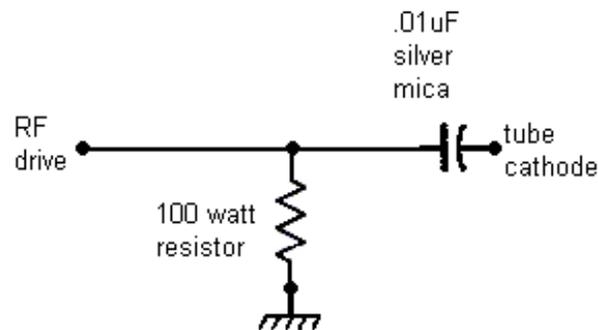


Fig.14

Setting up the tuned input network: First you must find out what the input/cathode "Z" of the tube is. This can be found in the tube manufactures documentation. You will then need the data for a tuned input network for that Z, which can be found in Bill Orr's radio handbook, 23rd edition, page 14-22. Next, you may use the MFJ-259 SWR analyzer and a carbon resistor equal to the tube cathode Z. Next, connect the resistor on the output of your network, then to common ground of the network. Next, place the SWR

analyzer at the input of the network using shielded coax, with the shield to the common ground of the network. Tune the analyzer to the center of the band being tuned in that network. Next, adjust the network for a 1:1 SWR or 50 ohms reading, whichever comes first. A slight re-adjustment or "touch-up" may be needed on some of the networks, most likely on bands above 14MHz, when the amplifier is in operation. Using tunable slug inductors and or tunable capacitors will allow you to adjust the network very easy. Whether you use a "Pi" network, "L", or "T", the same procedure should work. The "Pi" network provides the greatest level of harmonic suppression, but that is not a great concern with today's transceivers, since most have excellent harmonic suppression in their PA sections. The primary concern with a tuned input network, is providing a smooth, constant 50 ohm load to the transmitter. The input network should have a "Q" of at least 2-3, this allows the best load, while offering a broad frequency coverage. Some "older" amplifiers like the Heathkit SB-220 used input networks with a "Q" of only "1", which made the network extremely broad, but the input match was rather poor for late model transceivers. Raising the "Q" to about "2" made the network less broad, but the match was much, much better. The network would still cover all of the ham bands the amp was designed to operate on. It is tempting to use a resistive passive input network because it is quick and easy, but it does have a serious problem. Any amplifier that uses a passive resistive input network can subject the exciter to serious damage should there be a parasitic in the amplifier. This happens because the resistive network has no Q at all, and VHF energy (which parasitic oscillations consist of) passes through this network with little or no attenuation and can damage any components in the circuit path inside the exciter, most of the time it is the exciter PA that is damaged, (during a transmit condition oscillation), the exciter front-end can also be damaged (during a receive condition oscillation), both of these types of damage have been reported on numerous models of amps, both triode (grounded-grid, low input network Q) and tetrode (grounded cathode, resistive input type). Amps which have input networks that have a very low Q of 0-2. This Q does not offer much attenuation for the VHF energy that flows back out the exciter input coax.

There is another option for the builder who wants a high input network Q, but does not want to have to re-tune the network for each segment of the band of operation (high Q circuits are of very narrow bandwidth). LDG offers an auto-tuning input network board, the AT-100AMP (now discontinued, the current model Z-100Plus is a good substitute). This board automatically tunes the input Z of the tube anywhere from 1.8-60MHz and has 4000 memories for ultra-fast re-tunes. It is completely automated, and need only be provided 12Vdc @ a few hundred mA to run. One of nice things about this board is that it is relatively cheap (about \$125 at the time of this writing), and the tuned circuit Q is 5-10, and will attenuate VHF energy very well. The board will usually match to 1.2:1 or less. It monitors input frequency, and reflected power, and any time these change the units runs a tune cycle and memorizes the selects. It is good to 125watts input. I use them extensively. A small LDG ATU may be used outboard of the amplifier, however, the input coax feed line to the amp must be as short as practical, one foot or less in length is preferred.

Cathode choke: Most triode tubes will need a choke in the cathode to block the RF drive signal from traveling down the B- line and into the bias circuit or PS, instead of the tube cathode, where it belongs. The builder does NOT want this choke to resonate at any frequency that the amp will operate on, and have enough inductance to block RF current from getting into the B- line. Fig.15 shows a typical cathode choke placement.

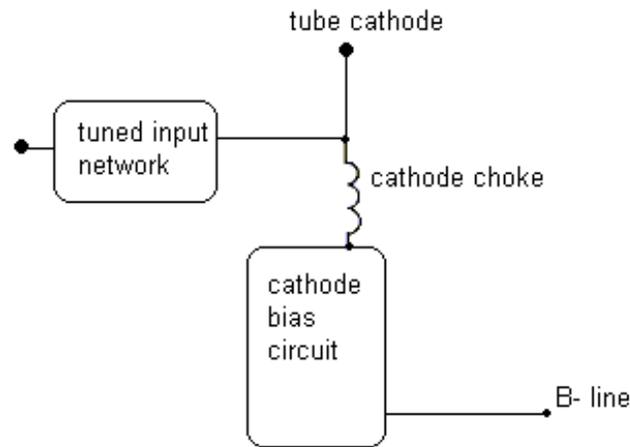


Fig.15

I have found that the cathode choke can be a rod or "solenoid" wound type, or "toroid" type, having an air core, or ferrite. The inductance I like to use is about $160\mu\text{H}$ with a $.01\mu\text{F}$ @ 1Kv cap to ground at the point where the choke joins the bias circuit. A $90\mu\text{H}$ choke would work from 160-10 meters, but a little more inductance works fine, and lowers the possibility that RF can pass through it, or that a resonance would be found on any band in which the amp operates. The cathode side of the tube is a relatively low RF current circuit, so it is not too difficult to design.

Plate choke: High RF current rules this circuit, and makes the design of the plate choke much more difficult. The trends have been to reduce the inductance to the bare minimum required to block RF out of the B+ line. However, this trend in design has serious drawbacks due to the tendency of the plate choke to resonate at certain frequencies within bands that the amp operates on. I have found that increasing the inductance to very high levels by using a ferrite core works well. The tough part of using ferrite in a plate choke is insulation, enough to prevent an RF arc to the core from happening. If enough insulation is installed, a ferrite rod will give a large amount of inductance with a relatively small number of turns. The lower number of turns for a high inductance gives a much lower "distributed capacitance", which is a major factor in choke resonance at high frequencies. My [experiments](#) have proved that for an amp operating 160-10 meters, a plate choke with an inductance of $800\text{-}1200\mu\text{H}$ is entirely stable on all HF ham bands. The problem with a choke with this level of inductance and able to carry the high level of DC current would be very large, and have a high level of distributed capacitance. A hollow core of an insulating coil form can hold a $1/2$ " dia. ferrite rod about 3-4" long. This rod will bring the typical inductance of a $90\mu\text{H}$ choke, up to $1200\mu\text{H}$, with the distributed capacitance of the original $90\mu\text{H}$ choke. However, the higher level of inductance would cause any resonances to be far out of any HF ham bands. Special attention should be given to the insulation of the ferrite rod. I used two layers of heat-shrink tubing, with good results, as long as the coil form is also an insulating material. I have also used a hollow core Teflon® or electrical grade Delrin® rod, which offers excellent insulation, but

lowered the overall inductance to $435\mu\text{H}$ with a number of turns of wire that would normally give about $80\text{-}90\mu\text{H}$ in an air-core inductor. $435\mu\text{H}$ is still more than enough to remove all resonances within the HF spectrum. With a distributed capacitance of the standard $90\mu\text{H}$ choke, the higher inductance forces resonance far below 1.8 MHz . A resonance down in this region will not likely be a problem due to the rapid drop in circuit efficiency. Any resonance currents would quickly dissipate. It's my guess that at $435\mu\text{H}$ the choke would likely self-resonate at around 500 kHz , so low that virtually all the RF energy would be attenuated.

Using this method, allows the builder to fabricate a [plate choke](#) using larger diameter wire and thereby lowering the DC resistance of the choke, which will allow the choke to operate much cooler.

Construction note: To make a Teflon® or Delrin® rod choke, you will need a rod that is 1 inch diameter, by 6 inch long. Using a lathe or drill press, bore a $9/16^{\text{th}}$ inch hole about 5 inch deep into the rod, leaving 1 inch of solid rod for choke mounting. Drill & tap a $1/4\text{-}20$ bolt hole in the part that you left un-bored. This will give you a way to mount the choke in the amplifier. Next, install a $1/2$ inch by 4-5 inch ferrite rod into the bore hole, use hot glue or RTV® to secure the ferrite and seal the open end. Now you're ready to wind the wire on to the rod exterior with a piece of tape or Super-Glue® to hold the wire in place. Use Formvar® or enamel insulated, or Teflon® insulated wire of a sufficient diameter to carry the full load DC plate current. Leave at least $1/2$ inch of exposed form rod without wire wrapped on it, on each end of the rod, this will allow proper clearance for HV insulation from the chassis. Measure the inductance with an LCR meter when you are done, it should be no less than $200\mu\text{H}$, but most will be above $400\mu\text{H}$.

A little history lesson

Many years ago, amp builders used plate chokes rated at 1 to 2.5 mH at about 600 mA DC current rating. As modern amp builders made the units smaller and smaller, and used tubes that required more and more DC current, there was a need to reduce the size of the plate choke, and increase the DC current carrying ability of the choke. Larger wire diameter to carry more DC current, made the chokes much lower in inductance, but amp builders found that they could "get away with" this choke. When more and more bands were added to the amps being built, it was found that these lower inductance chokes would series resonate on certain ham bands. This resonance came because RF current was able to enter the choke, due to the lower inductance now being used. What used to not be a problem, because chokes of the time were very high in inductance, was now a problem.

Now, my theory:

It is my theory that if a plate choke inductance can be raised to the same level used in vintage amps, but still use the heavy wire size to carry the higher currents needed today, the choke will not have the resonance, because NO RF can enter the choke, due to its very high level of inductance. The only way to do this without drastically increasing the physical size of the choke, and therefore the distributed capacitance, is to use a ferrite rod, which artificially raises the inductance. I'm not instructing the beginner amp builder to

use my theory, but suggesting and [exploration](#) of it.

If your not the explorer type, use a standard plate choke of not less than $200\mu\text{H}$, # 24-26 wire should handle legal limit + current draw through it. If you have a resonance (arcing from the choke to ground, or extreme heating of choke windings), change the inductance level, going UP in inductance rather than down. Mount the choke no closer than 1.5" from the tube anode, and no farther than 4" from it.

Fig.16 displays the typical configuration of the plate choke and associated caps, VHF choke, & parasitic chokes.

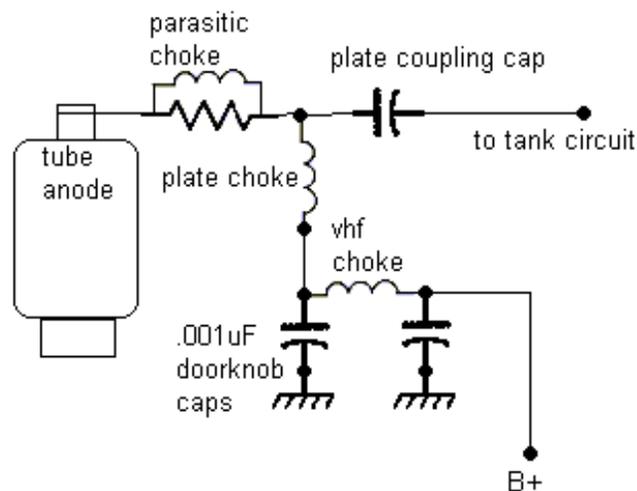


Fig. 16

The VHF choke seen in fig.16 should be made of 14-12ga. solid copper insulated wire. About 10 turns air-core dia. of 1/2", and should be located as close to the base of the plate choke as possible. A 5-10 ohm wire wound resistor can do the same function, rated at 25-50 watts. This resistor would serve two purposes, (1) act as a VHF choke. (2) act as a B+ "glitch" current limiter, should there be a short or HV flash-over. I have used the resistor method and it works well.

Parasitic chokes: In fig.16, you see a parasitic choke. Much has been written about these chokes, much debate, and much conjecture as to what makes an effective choke to suppress parasitic oscillations in an HF amplifier. The basic theory of choke operation is as follows; The HF fundamental energy passes freely through the choke turns, but any VHF energy "sees" a very high impedance in the coil, and must then pass through the resistor which rapidly attenuates the RF to a level that can not sustain an oscillation in the tank circuit. I have experimented in the types of coil material and found that Ni-Chrome® is a little TOO lossy when used on 10 meter band, but it does prevent parasitics. I found that Stainless Steel wire is a good less lossy material to use, and will not "rob" the amp

of 10 meter RF energy.

The "old" practice of using flat copper strap, is a total waste of time, and will not prevent parasitic oscillations at all. Don't use it! Another "old" practice is to wrap the coils around the body of the resistor this is also a poor approach. If you wish to use copper strap, use it as a "U" shaped choke, just wide enough to fix a resistor across the open end of the U, with the length of the U being about 1.5 inch long from the open end to the tip of the curved end. This method is used by several commercial amp builders and I have used it to good effect. If the amp has parasitics with this method, move on to the next method below.

My design of parasitic choke is; About 4 turns of stainless-steel 18ga wire, about 1/4 - 3/8" inside diameter. Silver solder the coil across the a 2-3 watts carbon resistor, 50-150 ohms, or a 100-200 ohm "flame-proof" metal film resistor. The coils should be "along side" the resistor in parallel, not wrapped around the body of the resistor. The reason for this is that I believe the VHF RF "sees" a higher impedance than the old method. I have tested this theory, and it seems to hold up. The wire I used is what is known as "Aviation safety wire", used to secure parts on aircraft. This wire is very flexible and very high in Nickel content. If the coils heat up to much on 10 meter operation, remove one turn from the coil.



My choke design above.

For tough stability problems, a parasitic choke may be placed in the cathode line, between the tuned-input network and the tube socket on the tube side of the cathode-coupling cap. I have tested this practice, and it seems to work well, added insurance against oscillations, or a fix for a problem amp.

Grid grounding from the socket pins to the chassis should be made with heavy copper strap or wire. A grid grounding connection with the least amount of inductance is the goal. Each grid pin on the tube should have its own ground connection to the chassis. The use of RF chokes or caps in this grid circuit is a very old practice that is no longer valid. For amplifiers using large tubes like the 3-500Z or 3CX1200A7, the use of "fuse resistors" in the grid grounding connections can be used for added parasitic limiting insurance. Here is how it's done; Place a 33 ohm, 1/2 watt carbon resistor in each grid pin, to ground connection, the goal being to

get a parallel resistance of about 1-10 ohms total, so, if more pins are used, it might be necessary to connect some of the pins together, or use more resistors, but the target resistance should still be 1-10 ohms with a total wattage rating of about 1-2watts. These resistors, placed in the grid circuit like this will "float" the grid above ground slightly, and present enough resistance to generate a small amount of heat in the resistors during normal amp operation, but should a parasitic or HV flashover happen, the large amount of grid current during such an event would "super-heat" the resistor causing them to "explode", opening the circuit, which will bias the grid forcing the cut-off of all plate & grid current, limiting the damage to the amp & PS. Only carbon resistors should be used, since these actually "open", vaporizing, and effectively blocking the circuit, even with HV present, and super high currents flowing at the time. Keep several replacement resistors around to repair the amp and place it back in service, but not before you find the cause of the problem.

Plate coupling capacitors: In fig.16 you can see a "plate coupling" cap, sometimes called a DC "blocking" cap, or tank coupling cap, any of these are accurate descriptions. The purpose of the cap, is to couple the RF energy from the tube anode, into the tuned tank-circuit, while blocking the DC plate voltage from entering the tank. These caps must have an ultra-low inductance, and be capable of carrying very high RF currents over the range of operation of the amplifier. I have found that for 160-10 meter use a capacitance of anywhere from .001 μ F up to .004 μ F will work, a good amount to use is .002 μ F. The voltage rating of the cap is usually given in "DC" rating, for "RF" use de-rate the voltage by 60% of the DC rating. So, a cap rated at 30Kv DC will handle at least 18Kv RF, with a good safety margin. Another rule to keep in mind is that the RF voltage rating should be at least 4 times the DC plate supply rating. A B+ rating of 3Kv requires a plate coupling cap voltage rating of 12Kv but since the caps are de-rated for RF service the cap should be rated at least 20Kv DC. This rating will give a good safety margin. RF current is another story. Most "door-knob" type caps are rated at a few amps RF @ 1Mhz, but are rated at about 10amps RF @ 30Mhz. The use of "disk" type caps as plate couplers is not advised for a legal limit type amplifier. Disk caps will handle the RF current, but are unreliable in the presence of high DC voltage and RF current as well. I advise the use of door-knob type only for this area. My experience has been that two or more door-knob caps mounted in parallel will carry legal limit + RF levels very reliably. I would not use less than two in parallel for any legal limit amp. The mounting of the plate coupler caps is also an area of concern. A heavy copper or aluminum strap or plate is an excellent low inductance method of mounting the caps. Most door-knob caps will have screw sockets or studs for mounting, this is best for mounting directly to the strap. Do NOT use small wire to attach these caps, too inductive. Keep the distance from the plate choke to the tank circuit as close as possible, this will make a low inductance connection. The shorter the path for RF to tank, the lower the possibility that a parasitic circuit will be present. Remember, the RF current in this area will be very high, do all you can to give it a low resistance path, with low inductance.

NOTE; RF current typically follows this theory; at 1.8 MHz the RF voltage is very high and RF current is very low for a given RF amplifier output. As the frequency of operation is raised, the RF current increases and the RF voltage goes down for the same output as that of the lower frequency operation. At 30 MHz the RF current will be very high when compared to the current of 1.8 MHz, but the voltage will be very low. This is why the tank circuit "heats up" on the higher bands, because of the high RF current circulating

in it. With this in mind, the builder will have to design a tank circuit that can handle both extremely high RF voltage, and RF current, when the amp is to be used from 1.8 - 30 MHz. Hence, the challenge...

Tank circuit: The modern HF amplifier should use a Pi-L tank circuit, it has the lowest harmonic distortion levels, and will load the best. For a legal limit HF amplifier, the tank coil should be no less than 3" diameter, made of 3/16th or 1/4" copper tubing. This tubing can be found at hardware stores known as refrigeration tube, used to route water to ice makers. The tubing will be used in the "L-1 or Pi coil" which usually operates 10-80 meters. If space is at a premium in your RF cabinet, using tubing all the way to 160 meters, your going to run out of room before you can get there. The alternate method is to use toroid cores to gain the inductance needed for 80 & 160 meters in both the Pi and the L coils. The cores required are T-200-2 red mix, wrapped in 3MTM glass tape, stacked two or three high. Number 12-10ga. wire will be needed to wind them, the wire should be Teflon[®] insulated, or FormVar[®] with Teflon[®] tubing slipped over it. Once the toroid is made, it must be mounted on insulated stand-offs to prevent arcing to the chassis. Use an accurate LCR meter to find the tap points on the core. Tables in the handbooks will tell you how much inductance and capacitance will be needed in your tank.

OK, how do you "tap" your tank coils. I have learned a trick to do this very accurately and you don't need to energize the unit to do it. You will need an MFJ-259 SWR analyzer or some equivalent unit. Next, you need to know the "plate impedance" of your tank circuit, or the desired target impedance. Once you have chosen the tube you will use and the plate voltage and current you want, you need to use this equation to find the target plate impedance; $1.8 \times \text{Max. plate current}$, divided by the Max. plate voltage. Example; 3500Vdc @ 1A. will be $1.8 \times 1 = 1.8$ which then is 3500 divided by 1.8 = 1944.44 ohms or rounded off to 2000, since this is a common tank Table value. Now, you know the impedance of your tank circuit. Next place the tube in the socket connected to the tank circuit as if you were ready to operate it. You need a non-inductive resistor equal to your plate impedance, for this example, 2000 ohms, wattage is not important, because you will not be running any amount of power through it for this procedure. Place the resistor from the anode of the tube, to the chassis ground. Connect the SWR analyzer to the amp output coax connector. Now, place the T/R relay in the TX mode, either by energizing the relay coil with a battery, or using a piece of metal to short the contacts. The output T/R relay need be the only relay energized, the input circuit is not in use for this procedure. Place the main band-switch on the 10 meter position or the highest band the amp will operate on. Tune the SWR analyzer to the middle of the band the band-switch has been set for. Place the tune and load caps of the tank circuit in the pre-determined positions found in the Tables of the handbooks. Use your LCR meter to set the caps to the correct capacitance, the caps will need to be disconnected for this set-up. Once the caps are set, re-connect them into the circuit. Now, using a short piece of wire that is about the same length as the connection wires needed to go from the coil taps to the band-switch connections, clip this wire to the coil, moving it around the coil until a "dip" is noted on the analyzer. A small amount of adjustment on the caps can be done, this compensates for the stray inductance and capacitance in the tank network. Continue moving the tap until a maximum "dip" is achieved on the analyzer meters. The dip should be very near 50-ohms. Now that you have "found" the optimal tap point on the coil, solder a heavy wire or copper strap from this point to the band-switch connector for that band. Repeat this process for each band. Tapping 10 meters is the most difficult, they get

progressively easier as the frequency goes down. A construction note: if you use heavy wire for your tap connections, you can drill a small hole in the coil tube at the tap point, and push the wire in until it "bottoms", then solder it in place. If you use heavy copper strap for your connections, wrap the strap around the tubing at the tap point and solder it on. Either method works equally as well. Whether you use insulated wire or strap does not make enough difference on HF to mean one method is better than the other. The needs of the installation will determine which method should be used.

NOTE: If the tap point appears to be incorrect when the amp is placed in operation, likely means that the 259 was "fooled". Due to tight coupling, sometimes can cause the driving oscillator to be "sucked out" into the tank circuit, causing erroneous readings on the unit. If this problem is found, place a small value cap across the output T/R relay, leaving the relay on the "RX" position for this procedure. The cap would be in the area of 3-100pF, voltage rating is not critical. This method will give a loose coupling and a greater accuracy in tapping, but the dip will be very small, and the tap point will be very precise/critical. Another method of doing this type of tapping of a tank coil is to use a spectrum analyzer and a tracking generator, but there are very few of these in the ham shacks of today.

A comment I can make on plating of your tank circuit; on frequencies below 30Mhz plating is NOT a critical item. For example, at 30MHz, silver-plating of the tank coil increases the overall efficiency by 0.3 %. It looks pretty, but contributes little to the operation. For the home brewer, it is much easier to polish the copper coils to a high shine, and then coat them with clear acrylic or epoxy to keep them that way. For amplifiers operating far above 30Mhz plating becomes very critical, and in the UHF spectrum Gold-plating is necessary.

Tank tuning capacitors: Once the builder knows the tank circuit impedance and therefore the inductance and capacitance, you can select your tuning capacitors. If you plan to operate from 160-10 meters the caps you choose will need to meet some very difficult parameters. The maximum capacitance is easy to get to, but usually "air" caps of this size have a very high minimum capacitance value. A couple of methods can be used to get around this problem. An extra bank on the band-switch can be used to switch a door-knob cap in series with the tuning caps when the amp is used on 10 meters. Another method, using a smaller tune cap value, and switch in to parallel a door-knob cap to use on lower frequency bands like 40-160 meters. In figure 17 below, there is an example of two methods of switched capacitors in a tank circuit.

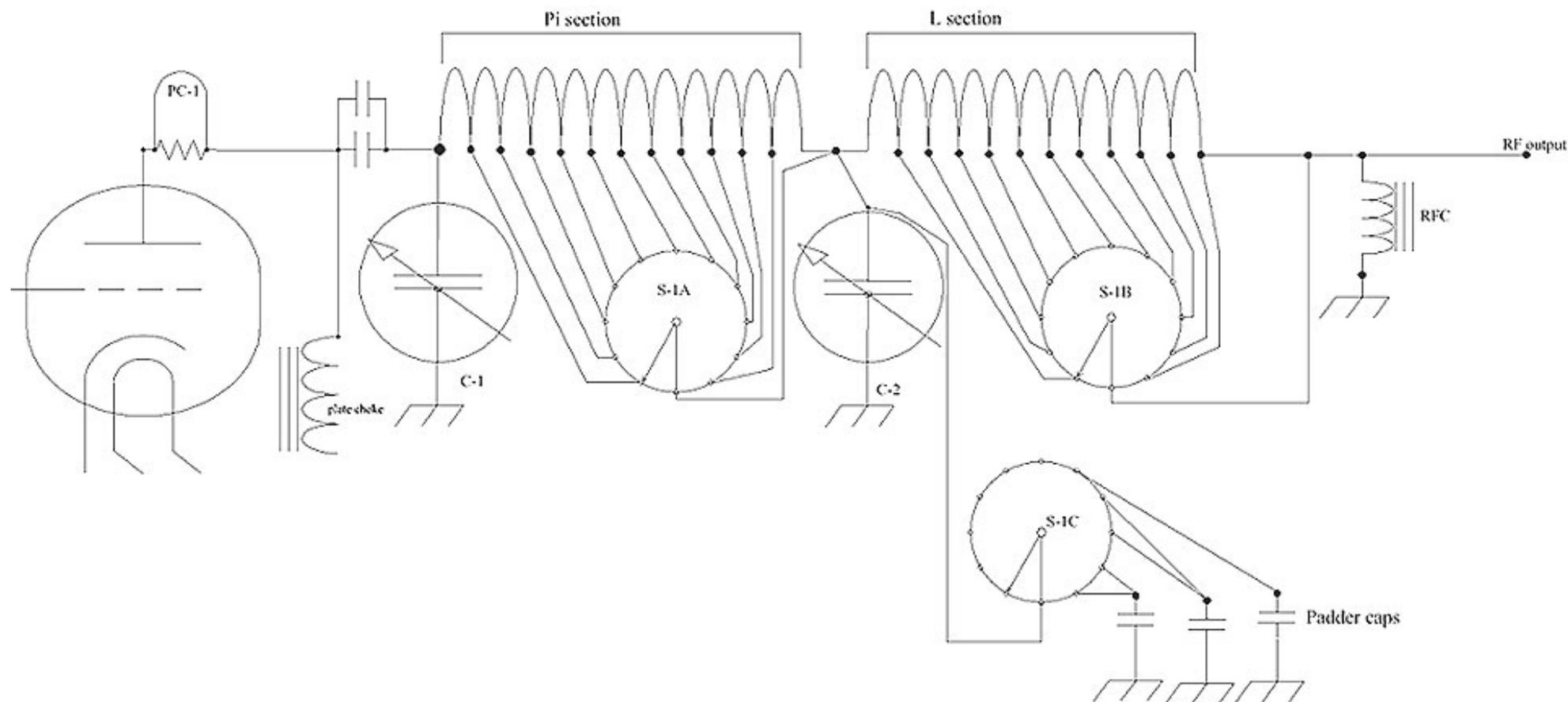


Fig 17.

A "split-stator" tuning cap can be used in the "plate-tune" cap, this cap will allow optimal tuning on 10 meters while maintaining a good level of plate spacing in the cap.

Air vs. Vacuum variable capacitors: Air variable caps are easier to get, & cheaper, but have the problems mentioned above. Vacuum variable tuning caps are expensive, hard to find, but usually will have the desired range required for a given tank circuit, without switching in fixed caps into the circuit. Another benefit of vacuum caps, they have very high voltage ratings, don't change with humidity or air pressure, and can pass massive amounts of RF current. I have never heard of anyone ever arcing a vacuum cap. The average vacuum cap in an HF amp can pass many, many times the RF current that the amp is capable of generating. Most vacuum caps are "screw drive" requiring multi-turns to run them from min to max capacitance levels. The drive requires the builder to install "turns-counters" to be able to re-set the cap to the setting for a given band. End-stops are also needed to prevent the cap from damage by an "over-shoot" end run. Mounting can be a problem with these caps too, but many come with mounts, but can

easily be fabricated. Any number of ways for installation can be used, the cap can be mounted horizontal, vertical, or hung down from a bulkhead.

For a truly "high power" HF amplifier, the vacuum caps are the best choice, ultimately reliable, can't be arced, and can handle massive levels of RF power. True, they are very expensive, but if you want to build the best possible, spend a little more money.

One point, the higher the plate voltage used, the harder it will be to find air caps that can handle the B+ and the high RF current without arcing, or very difficult range problems. At 3Kv B+ levels & below, air caps can be used with little difficulty, but as you get above 4Kv the difficulty goes up exponentially.

A note about buying vacuum caps: if the cap does not have clean shiny copper "pleats" inside, it's likely to have lost vacuum. If there is NO resistance when the screw drive is being "drawn" out, expanding the "pleats", it is probably bad. There must be a significant amount of resistance to expansion, and the copper "pleats" must be shiny, like new polished copper. If not, pass it by.

Band-switch: Do not go cheap on this part. Buy the best you can get, if you don't, you could be sorry. Radio Switch Corp. (now called [Multi-tech Industries.](#)) makes very nice units. Their model 86 is good, the model 88 is the best, top of the line band-switch. The biggest, is the Model 90, a true giant, over 7" in diameter, and 12" long, very few builders will try to use these. The Model 88 is rated at 13Kv and 30 Amps. Even a 5Kw amplifier could not arc this switch. For a Pi-L output network you will need at least two banks of contacts on the switch, three would be better. A set of contacts will be needed for each band you intend to use. A special coupler must be made to attach the end of the shaft of the band-switch to the shaft that switches the tuned input network if that is used. If a resistive network is used the shaft will not be needed. Another method is to use a much smaller switch to operate the tuned input network, but it should be electronically interlocked with the main band-switch to prevent improper input and output alignments. Pictures and other specs can be found at Surplus Sales of Nebraska, and you can buy them there too, as well as turn-counters if you can't find them anywhere else since they are a bit "pricey" there.

Figure 17 has a switch configuration that will help the builder understand the requirements for a 160-10 meter tank circuit.

Hunt ham-fests and the Internet for bargains on used or surplus switches of these types.

Filament chokes: A choke in the filament line is an absolute must on a "directly heated" cathode, but on an "indirectly heated" cathode such as an 8877, it is not always needed. The directly heated type, are found in most all of the glass enveloped power tubes, using Thoriated-Tungsten as the filament element. High current, and high RF voltages are present, and must be blocked from the filament PS, so a very heavy-duty choke is installed. The choke is usually a large "bifilar" type, meaning that two wires are wrapped side-by-side on a ferrite rod to choke off any RF current from the PS, by-pass caps are usually placed on the PS end of the choke, to ground. This type of choke has very high inductance levels, but can carry lots of PS current. I have also used a Toroid for a filament

choke, which works well and makes a very small package.

An "indirectly" heated cathode tube, is where the cathode is usually "oxide" coated, and wrapped around a heater element which heats this "sleeve" to produce the electron emission. These filaments draw much less current than the direct heated, and are less subject to high RF voltages due to the inherent shielding effect of the "sleeve". However, a filament choke should be used, but is not absolutely necessary, to reduce the possibility of RF current coupling to the PS through this line. The type of choke used here does not have to be nearly as large, because it is carrying much less current, and need not have as much inductance, because there is much less RF present on it. A small bifilar type, wrapped with rubber or Teflon® insulated wire of the proper gage size to carry the current, a small ferrite rod or toroid will do. Some where between 30 to 300 μ H of inductance will work well from 160-10 meters. Bypass caps should be placed from the two lines to ground on the PS end of the choke. Place caps across the choke at the tube socket, and to the cathode. RF coupling to the cathode will allow the RF voltage to be the same on both. This will keep the RF from "flashing over", like it could if not coupled.

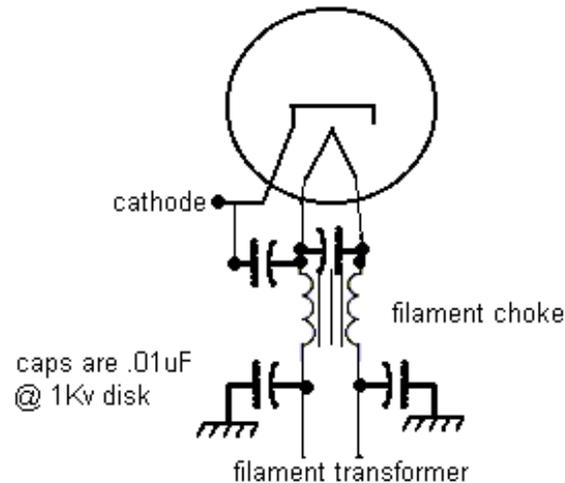


Fig. 18

Above, in figure 18, is a typical indirectly heated cathode tube with typical filament choke installed.

ALC: This circuit is a must. The only exception would be if you use a tube that can be driven with the full power RF output of the exciter you will be using. An example would be the 3CX1200A7, which can be driven with up to 120watts of RF. However, if you are using a tube like the 8877 or the 3CX800A7, 120 watts of drive would instantaneously damage the grids. An ALC circuit will help prevent this from happening, but if you "like" changing tubes far sooner than you should, don't put one in. The best point to sample the exciter's input RF to the amplifier is between the input T/R relay and the tuned input unit.

The ALC circuit in the amplifier rectifies a small portion of the exciter's input RF signal. This rectified DC signal is negative that can range from -1 to -12 Vdc. The "negative-going" signal is fed back to the exciter, which biases the PA amp in the exciter, which reduces the RF output from the exciter and keeps from over-driving the final amplifier.

The procedure for setting the ALC "threshold" is as follows:

- (1) Tune the amplifier to normal full output level.
- (2) Adjust the ALC pot control until a slight reduction in RF output power is noted.
- (3) You're done.

With the ALC set in this way, the RF drive level on the exciter can be raised or lowered, but the maximum output of the amplifier will not exceed the level of the ALC limited setting.

Placement of the adjustment pot can be on the back panel or the front control panel, but should be clearly marked. A lockable control would be a good idea, this would prevent accidental changes in the control. Once set this control is rarely changed.

Figure 19 shows a typical ALC unit, simple and effective.

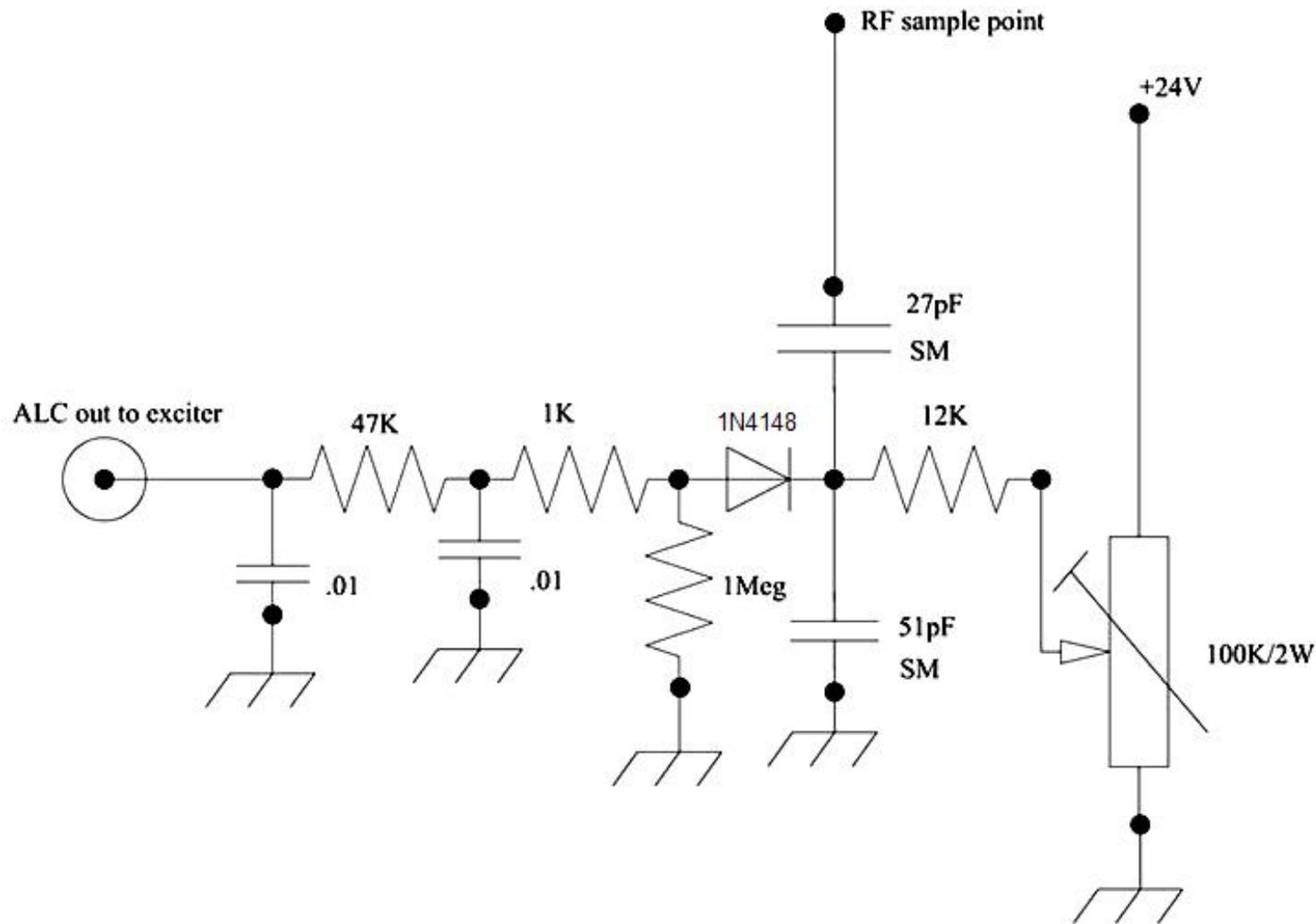


Fig 19

Controls: The most visible part of the amp is the control panel it is also the most complex. There are a huge number of ways to design and control the unit. How fancy, or simple you design it, is up to the builder doing the design and construction. There are "ready built" PCBs, that can be bought and installed in an amp, but that is a little off the point of building the amp, if the beginner is not comfortable designing his own, it might be the route to take. Remember, "more complex" means harder to fix or repair. Simple and reliable is the way to design it. If the designer wants to build a "Fully automatic" amp, and feels he can handle the task, please, have at it. The difficulty will be huge, and problems WILL happen. For the beginner, I suggest the most simple, and reliable, "bare-bones" type of design. The next unit you design/build can be more complex/fancy.

Look at it this way, "YOU are the engineer, YOU decide what you want it to do, how it does it, and how much work it will take to get it there."

Final words: In this day, where it is easy to buy and use the ham gear we want, it is easy to forget about the satisfaction that building your own piece of equipment can give you. Those who buy it, and play it, will never know this feeling. But, for those of you who still want to learn, and use your own minds & hands to design and construct an HF amplifier like "they" did it years ago. Words cannot describe the feeling of accomplishment, satisfaction, and fulfillment you will get from the experience. Best of all, you might accidentally learn something in the process...

73 de Matt Erickson KK5DR

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