Heathkit SB-220/221 restoration and optimization

Acknowledgements: The author would like to that the following contributors to this guide. W8IJ, W7RY, W7BBI, W1QJ and many others for their input and web information that went in to the research and development of this guide. This is an 'Copy Left' open source document intended to be shared freely to any interested party for any purpose and may not be sold or resold.

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Happiness is 2 pairs of matched pairs of 3-500ZG tubes!

DISCLAIMER: This is a general guide to aid in understanding Heathkit linear amplifiers. Use at your own risk, you agree by reading and using this document to release the Author, Contributors, and Manufactures from any damages or claims including but not limited to: loss of life, loss of property, equipment damage, any injuries, technical errors or omissions.

By modifying your amplifier, you accept full responsibility for meeting all FCC and other requirements for this class of device, further you accept that you are creating an experimental amplifier by making any changes and are responsible directly for the amps safety, proper compliance and operation.

SAFETY WARNINGS:

- **Without question any tube linear amp with its covers off can kill you instantly.**
- **Voltages are over 3000 volts with over 1 amp which will be fatal if you make a mistake touching something with power on or have not properly discharged the filter caps before touching the amplifier.**
- **With all legal limit amplifiers regardless of technology there exists strong RF fields and voltages on the antenna or dummy load at the legal limit may exceed 500V.**
- **RF burns may occur if the top covers of the amplifier are open during testing.**
- **If you are not sure what to do, stop and find a ham who is familiar with the amp. It's not worth your life.**
- **Refer to the 2018 ARRL Handbook for proper safety procedures with working with RF amplifiers and HV voltage.**
- **This author and all the other contributors are not responsible for your death, injury or damage to your amp or facilities. (See DISCLAIMER)**
- **And you must insure amp has proper load and grounding before powering up or both you and the amp may be damaged.**
- **You have been advised.**

Overview

The Heathkit SB-220/221 is one of the most successful linear amplifiers ever built. A legal limit amp, with a well-done design that has served the ham community for over 40 years. Like all amps they all have their quirks, and this guide addresses the optimizations to achieve a reliable and stable amplifier.

This document details a well, tested and designed set of modifications the result of multiple hams, K7BIT, W7RY, W8IJ, W7BBi and others work to both restore and optimize SB-220/221 amps.

We welcome comments and suggestions for improvements and correction of defects.

Common Questions

What is the difference between the 220 and the 221

- 220 has 80,40,20,15 and 10 meters, the 221 does not have 10 meters unless the heathkit option kit available only to licensed hams has been installed.
- In the SB-221 there is a 11 meters filter in series with input cap to pair of 3-500Z triodes and the bandswitch all three wafers are missing the 10 meters position.
- In SB-221 you will find a molex connector on the HV power transformer, this is so you can easily remove transformer for shipping.
- SB-220 has several variations on LOAD capacitor, from large capacitor without trimmers to smaller capacitor with pair of integrated trimmers, each has different signal routing and smaller cap uses two holes and ¼" brass strip to connect to tank circuit below RF deck.
- SB-221 uses the larger single capacitor with single hole to tank circuit.

What does it take to add 10 meters

1. You need to find a 10m input coil
2. Locate a set of bandswitch wafers that have the additional 10 meter band position. (Lou W1QJ, gudguy@aol.com does 6 meter single band conversions and will sell those to you at a reasonable price. Lou is an expert on linear amps if you need help.)
3. Add the coil and two silver mica caps per Heathkit SB-220 manual
4. Replace original bandswitch wafers and save the old 80-15 M ones, they are worth $50 to someone who broke one and does not want 10M.
5. Assuming rest of amp is already running, connect your exciter and check your SWR from radio to amp. If your tuner will not get SWR below 1:1.25, the slug in the input inductor needs to be adjusted. (See tuning input network later in document.)

How much power will the amp put out

Let's start with the stock power transformer, 871/1171 VAC @750ma IACS (intermittent Amateur Commercial Service) the CW voltage is 2505VDC and SSB voltage is 3176VDC with 238VAC input voltage. ~2380 Watts DC, at least as Heathkit at the time of the design rated DC input power.

Power output is highly dependent on specific tube manufacture, how much drive your using, how they are biased, idle current, class of operation, how much power your PS can supply and band your using. Generally lower bands have more power, with power decreasing above 20 meters. Typically this amplifier produces 1300 watts PEP 80-40-20 and 800-1000 watts PEP 15 and 10 meters, assumes a dummy load as antenna and its related tuner, etc will change depending on match, and we assume maximum of 100 watts PEP drive, past that point 3-500Z/ZG are fully driven.

Hammond Manufacturing builds Peter Dalh transformers and there are stock replacement with 750ma, 1A and 1.3A, CCS Continuous Commercial Service rated options. Note some mechanical work on larger transformers is needed.

What is SB-22X class of operation

Heathkit designed this amp as a grounded grid Class B amplifier. Heathkit also added grid RFC and capacitors in the original design which they consider is still grounded grid. There has been a lot written and debated on removing the RFC's and caps, and directly grounding the grids. While researching this guide both options were tested. Result was mixed. In some SB-22X this made amp oscillate at idle whereas with original components reinstalled, it would not oscillate. In others amp was completely stable with directly grounded grids. So keep your original parts, try GG direct and see how your amp behaves. Self oscillation is a very complex discussion.

What is the effective vs input power

There are a lot of variables however rule of thumb for SB-22X Class B grounded grid, literature suggest 52-63% or 2380 watts input, with 100 W PEP drive will result in 1200-1350 W PEP into 50 ohm non-inductive load at recommended SSB mode (3176VDC), and plate/grid current settings. (Note: 100W drive is added to base output power). Note also that Heathkit is very conservative on its plate current and grid current recommendations and recommend no more than 100W PEP drive. Transformer can provide short bursts of 750MA plate current and 200ma grid current, the 3-500Z/ZG can handle 400ma (max) plate current each and grid 100ma (max) each. W7BBi has experimentally driven SB-22X with 200 W PEP AM and produced over 2000W output under ideal test conditions. However, it is strongly recommended to follow Heathkit guidelines in fact running in low power mode increases life span of the components in the amp.

Design and restoration goals

Over a three year period, a reviewed a large number of alternative modifications, best practices and forum sources. All of them were built and evaluated for fitness, cost, reliability and complexity. And significant research was done on what components failed, their root causes. And most importantly mods that can be achieved by the Ham that owns the amplifier. Goal is DYI.

The goal for the restoration and optimization are as follows:

1. Design for longest life span and availability
2. Fix arcing issues
3. Clean up or replace band switches if damaged
4. Evaluate true grounded grid operation, convert if applicable
5. Add QSK with both active high and active low T/R relay inputs that are 12VDC 10 MA replacing the old original open frame relay that suffers from hot switch and race conditions.
6. Add reed relay for input RF and vacuum relay for RF output, solving race and hot switching issues and significantly reducing arcing while tuning.
7. Add Step Start to reduce current spike on power up to maximum of 11 Amps.
8. Add both cathode and anode glitch resistors to save PS, and output components if tuning or shorting tube fails.
9. Add B- protection circuit.
10. Adding 250MA fast blow 250VAC fuse to 90 VAC secondary winding to protect transformer from arc and other faults.
11. Replacing parasitic resistors with 47 ohm 5W non-inductive MOF resistors in parallel but on outside of 3.5 turn parasitic coils.
12. Replacing door knob capacitors with 20KV and using 10KV caps RF deck areas.
13. Replace original PS/RM with Harbach kits
14. Modifying Harbach kit to add B- protection
15. Adding 10K pull down resistor in active high QSK T/R relay input to keep signal low unless pulled.
16. Adding standby switch and integrating to QSK board. (optional)
17. Add new matched pair of PentaLabs 3-500ZG tubes.
18. Drafting updated AS Built schematics of unit once work is completed.

Parts

We use the following sources:

- Mouser for everything except the following
- PentaLabs matched pair of 3-500ZG triodes
- Max Gain Systems for VHC-1 vacuum relay
- W7RY for QSK, reed relay and Step Start boards (available on eBay)
- Lou W1QJ gudguy@aol.com for bandswitch parts
- Harbach for PS/RM-220 kits
- Hammond Industries for Peter Dalh designed transformers (Optional)
- DeOxIt for cleaning switch contacts
- CRC circuit board cleaner
- Acetone for metal clean up

Tools

Tools are critical for both safety and getting the job done successfully.

- B&K or similar DMM high voltage probe 40KV 1000:1
- True RMS 1% or better DMM

- ATLAS 55 and 45 semiconductor and RLC meters
- 60/40 leaded solder
- Teflon wire 24 or 26GA.
- 50W soldering iron
- Usual set of hand tools
- Dummy load MFJ cantenna is $80 and good for 2500W intermittent
- Radio to use as exciter 100W with adjustable output

Analysis of candidate for restore and optimization

We are all passionate about our Heathkits in the same way we love our classic Chevy's, Dodges and Fords. Here are some things to consider when acquiring a vintage linear amp.

- *Do not buy amps over the internet, otherwise you cannot verify their condition without completely surveying them, shipping amps is the number 1 cause of basket case amps so LOCAL PICKUP and DEMO is the only good way obtain an amp. (Every amp we have ever seen had some form of damage only 2 of 25 actually still worked correctly when we inspected and bought them)*
- ***Do not power up before you have done inspection unless ham who is selling has amp already running. There is fire risk, shock and RF burn risk if amplifier has problems.***
- Take lots of pictures
- Unplug the amp from AC power, wait 10 minutes and short plate cap to chassis with insulated screw driver.
- Insist on opening up the amp and doing a through visual inspection and ohm out transformer before powering up.
- Look for burned or missing parts, open or shorted transformer, burned bandswitch contacts, hacks, leaking caps, dirt.
- Pull tubes look for date codes for example 7944 is 1979 44th week of manufacture.
- Old 3-500Z's are either good but end of life, gassy and arc or are completely failed. Ones that have sat unused for year, will have gas problems. This is why an actively used SB-22X with good tubes is what your looking for. Its important to know the history. 3-500Z run for years if used daily, and frequently fail if not used. So they are a crap shoot. And 50% of the value of the amp.
- Once you have verified all the parts are consistent with manual, pull tubes and ohm filament should be near zero ohms, then filament to grid and plate then grid to plate. Those should be open.
- Take your ohmmeter and connect on the RF Input connector center pin and other end to RF Output center pin you should see zero ohms if old relay is still functional. Then measure center to chassis, that should be open.
- At this point you have verified no burned or missing parts, transformer and tubes are OK.
- Make sure you have amplifier wired for correct input voltage per Heathkit Manual.
- Warning amplifiers that have been sitting and/or are 20+ years old will have capacitors that are past their useful life span and may short, smoke, or leak on initial power up, transformers filament in particular may have pin holes between 90VAC and primary winding, symptoms range from funny smell to outright melt down on initial power up. Plan accordingly.

Now for safety information. Without question any tube linear amp with its covers off can kill you instantly. And you must insure amp has proper load and grounding before powering up or both you and the amp may be damaged. If you are not sure what to do, stop and find a ham who is familiar with the amp. It's not worth your life.

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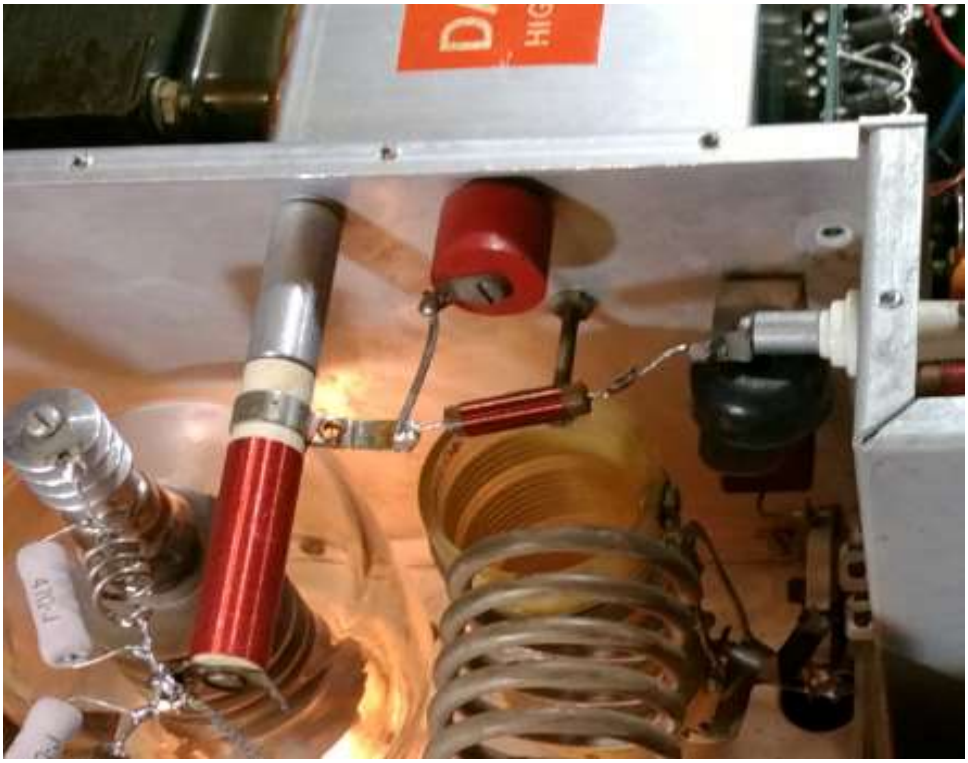
Initial Power up of candidate linear amplifier

With SB-22X linear amps there is a HV safety shorting spring in the chassis when you remove the inner top cover it shorts out your HV, you must put rubber stopper between shorting spring and B+ bar otherwise your HV will be damaged. Failure to do this correctly may cost over $500 in transformer, and diodes to repair. (see rubber stopper under B+ post and HV shorting strap below)



With shell and internal top cover removed. WARNING WARNING WARNING

Great care must be used to insure you are not electrocuted. Follow 2018 ARRL Handbook procedures for working with RF and HV.

Always make sure the power supply capacitors are discharged before getting your hands inside the amplifier. Observe Right Meter with it set to HV, verify zero volts, then using insulated screw driver short plate cap to chassis, several times until meter is zero and no sparks occur.

- Again double check your work prior to applying power to the amp.
- Make sure your amp is correctly wired for your 120 or 240 VAC power.
- All tube linear amps require a proper 50 ohm load either dummy load or antenna system capable of handling legal limit (1500W PEP and 600 volts RF) power. The transceiver (exciter), connected to input of the amp (RF Input), the output of the amp connected to dummy load or tuner with antenna connected to output of the tuner and your grounds are connected.
- Make sure your tuner, transmission lines, antenna, baluns and grounding is working correctly before hooking up amp. You can do this with amp off, just hit your autotune button on your transceiver and let it match the antenna or dummy load through the amp to verify system is good.

- Now that we have verified the dummy load or antenna matches through the un powered linear amplifier, our grounds are good, slide a plastic mat under the amp to further help insulate from your bench.
- To protect your radio a temporary isolation relay is advised.

  Wire up an isolation 12V relay between your exciter and the T/R relay RCA connector on the back of the linear amplifier. This short term protects your transceiver from SB-22X 120VDC relay circuit that will blow up your radio. This will be removed once QSK mod is completed.

TEST #1 HV, Filament and Fan, Amp in not keyed state

- For this first test disconnect the T/R Relay RCA cable from the jack so amp cannot be keyed up.
- Set Plate at 40M, set Load at 2, set Band Switch 40M, CW/SSB switch in CW position, Multimeter switch in HV position.
- Plug in power, turn on power with front panel switch.
- The HV should be about 2500 VDC, tubes should light up, fan must be running, spend next 5 minutes switching between HV and Plate and Grid positions on the meter switch.
- There should be zero Grid or Plate current, with HV 2500 VDC unkeyed.
- Keep smelling for burning smells. Turn power off immediately if burning occurs, plates look red, or popping noises.
- After 5 minutes of observing, turn power off, disconnect the power plug, put meter in HV position and watch the voltage go to zero, then short using insulated screw driver between plate cap and chassis to insure capacitors are discharged. Short several times until no spark occurs. HV should be zero, now it's safe to visually inspect again for unhappy parts. If you get filaments lighting up and HV at 2500 volts the most expensive things in the amp is OK the transformers.
- If the tubes did not turn orange and plate or grid current did not show on the meter, the amp is generally OK. This test may result in bad tube arcing or melting down so observe and turn off power if tubes look like they are glowing with amp un keyed.

Test #2 40 Meter basic amplification

- Next thing is 40M test of amp for power. Of course make sure amp and load is correctly connected, use the isolation relay so your transceiver can safely key the 120VDC T/R relay signal through your isolation relay. Plug in the isolation RCA jack into T/R relay jack.
- Install 50ohm 2500 W dummy load on amp RF output with power/SWR meter in series so you can monitor output power.
- Set transceiver to 7.200 Mhz mid band phone side. Set radio mode to CW, install your hand key so you can send some brief bursts.
- Very important set your transceiver drive to less than 25W or 25% this keeps drive low while your investigating if the amp is working.
- To test you hit your radios transmit button, you should see plate current meter (left) rise to 100-120ma which represents its plate idle current with the amp on but no modulation (handkey is not down) if it is zero or higher amp's bias/idle circuit is damaged and needs repair or replacement prior to moving past this point. If within correct range proceed to next step.
- Put the Multimeter switch in Grid current position.
- Make sure your radio is set for 25W output in CW mode.
- You will be monitoring grid and plate current as you depress your hand-key for length of a dash (<500ms) then releasing. Following the Heathkit manual for this next series of steps.
- Tip if grid or plate current looks to high, lower input drive and continue attempting to tune. Grid current should be below 100ma with 25W drive, plate current below 400ma.
- If either grid or plate current is above 100 and 400ma stop reduce drive to 15W and see attempt to re-peak the Plate, Load tuning. (If it is not working as expected you may have one or two bad tubes.)
- Once you have a feel for grid and plate current dipping and peaking at 25W drive we know the basic amp is generally working. There will not be much output power but we have proven the amp can be tuned, and has working bias and idle circuits.
- Now we increase on your radio the output power to 60W PEP.
- While observing the grid and plate currents, following the Heathkit procedure for CW tuning, in CW mode into 50ohm dummy load with grid at 200ma and plate at 400ma you will see 600+ watts into the dummy load, again limit key down time to 500ms. That keeps tubes cool.
- Now repeat process for each band Following instructions per the Heathkit SB-22X manual to preset the controls to the proper starting position for the band selected.

For each band follow the manuals setting instructions, and note the output power on your tuner or SWR or power meter. Keep drive below 60W or 50% while you learn to tune the amp correctly expect 400-600W on 80-40-20, 15 and 10 will be less. You only want to hold key down just long enough to see Tune and Load peaked for frequency your transceiver is on. Your looking to keep grid current in particular below its maximum level. Tubes will start to glow dull red to orange as you apply more drive. Do not exceed 65W.

At this point the amp survey is complete. This should be done before purchasing any used amp and with any new amp.

We know all the basic circuits are working, tubes even if soft are still putting out power and not arcing. Therefore you will either have an amp the works and is ready for upgrades and optimization or a parts amp.

Determining Amplifier Value

If the amplifier passed all the tests, is clean, is not hacked and does not have modifications is a functional original amp. Current pricing is $475-600 for amplifier in this condition with original parts and no mods.

- Any amp with damaged chassis, missing parts, bad or broken tubes is a basket case worth $50-75 AS IS.
- Bad meter, scratched or missing meters subtract $90 ea cost of replacement meter and these are hard to find for SB-22X.
- No HV or filaments or 120VAC bias voltage transformer is bad subtract $325 or $225 as it's a basket case. If both are bad subtract $550 as that is replacement cost shipping included. Whats left is worth $25. These are referred to as Donor amps.
- Blown parasitic resistors these can be caused by multiple problems. Symptom is low or no power output. If HV, Filaments are good, check bandswitch for burns, relay for burned contacts, and one or both tubes may be bad. Generally another type of basket case, amp is worth $50-100 if transformer and bandswitch are OK. Bandswitch replacement is $200 or more and hard to find.
- Hacked (CB mods) sloppy wiring, ohm out transformer and check bandswitch. These can be lotta work, so offer $50.
- Any cosmetic damage: subtract $100 as that's what rescreening or painting costs.

Now there exist a few hams that have done exceptional restore and optimization work and these amps are worth a lot more than original amp unmodified if it has the follow and is documented.

- New pair of matched PentaLabs/Matchlett tubes $383
- with Harbach PS/RM-220 kits $110+$38
- QSK, reed/vacuum relay mods ~$180
- Glitch and protection circuits added ~$20
- Input network tuned, $50 labor
- New doorknobs $72
- Step Start installed $45
- Demonstrated in to dummy load and antenna on all bands, CW and SSB modes, 1/2hr shop time
- Peter Dalh transformers $325+225 for pair

Average labor cost for completing this list varies, author flat rates at $150 for clean complete amps, up to $350 for basket cases and/or smoking amps. Generally shop rates in 2018 are $75/hr plus shipping and insurance both ways paid by customer. Parts and their shipping is additional and varies per amp.

These amps are worth up to $1200-1850 as upgrading a $400 amp costs $600-1200 for parts alone. This assumes a neat job, and clean mechanicals.

These mods are implemented into this guide.

What to plan for

Amplifier restoration and optimization takes time.

- Parts take 2-6 weeks from point of order to arrive
- Takes time to locate electronic copies of manuals.
- Its normal to spend more than the amp for parts to fully optimize the amp
- Think twice on sub standard parts, blowing up your amp can be very expensive
- If you must ship the amp remove the tube and transformers, ship in separate boxes.
- Total restore time first time through is typically 10-40 hours depending on your experience.
- Shop rates for restores varies generally $75/hr, look for flat rate deals.

OK BIG GLUP WERE DIY

If you have not done this before reach out to those that have, most hams that can build a kit can successfully restore and optimize a SB-220. 100's of hams built these from kits and Heathkit has always provided the best manuals in the business. So yes, you can do this.

We assume you can read schematics, can solder have basic tools and follow basic circuit theory.

This however is not a beginner's project, you are working with high voltage and a lot of power.

Safety is critical to your survival. Take your time, verify every step, find a friend to help.

Never rush or work when distracted or tired. ARRL 2018 Handbook has excellent procedures for working with RF, HV and assembly technique.

Our build

This build includes the following:

- Add pair of matched PentaLabs 3-500ZG
- Add W7RY Step Start
- Add W7RY QSK
- Add W7RY reed relay board
- Add VHC-1 vacuum relay
- Add anode, cathode and B- protection
- Replace doorknob, input and 500pf HV caps with 20KV door knobs and 10KV input and 500pf caps
- Replace parasitic resistors with 5W non inductive MOF 47ohm
- Optionally remove Heathkit grid network and direct ground grids
- Replace Heathkit power and meter boards with Harbach PS and RM – 220 kit (includes parts)

NOTES:

1. Harbach includes all parts for their kit.
2. W7RY when your order will send you a set of instructions, parts list with links to each part most from Mouser, for QSK, reed board and Step Start pcbs.
3. Vacuum relays Max Gain Systems $79 plus shipping for VHC-1
4. You will need to buy or build mounting bracket for relays

Our candidate amp, using the procedure in this document was surveyed and found to have good transformers, one broken 3-500Z date code 7950 and one working 3-500Z date code 7944 non-gassy with 70% rated output, burned input bandswitch, bent right side chassis panel, partially working Heathkit PS and meter board, but burned components causing meters to not read correctly, meters OK, multi switch OK, wiring lots of bad solder joints, bad RG58 input coax, input cap and 500pf leaking.

While this amp is technically a basket case, we were able to get new panel made a local shop, and locate full set of parts. Amp was purchased as scrap for $50 in unknown condition.

In addition to list above we replace band switch and T2 which ran for two days then melted down due to pin hole between 90VAC and primary windings. ($225 with shipping)

Build

In this build we do things in stages

Inspect new tubes

- Check shipping boxes for damage file claim immediately and connect seller to insure you have notified them as damages, then as how to handle insurance claim
- Glass high vacuum tubes are very sensitive to breakage and mechanical damage therefore handle gently.
- Before ever putting any tube in an amplifier check the following
    - Take DMM and ohm across filament should be near zero ohms
    - Measure between filament pin and all three grid pins should be open
    - Measure from filament pin to plate should be open
    - Measure from each grid pin to plate should be open.
- Set them aside until all mods are completed and amp is ready for final tests.

Replace damaged bandswitch

- Unplug power cable, discharge capacitors per previous notes.
- Remove case, top cover, loose set screws on knobs on front panel and remove them.
- Remove tubes and put in safe area where they will not be damaged.
- Remove the nuts on caps, pots and switch on front panel
- Remove 4 front panel screws and nuts
- First we put band switch in 80 meters position, mark top of each wafer so we get indexed correctly on reassembly. We also mark top of the shaft. Then take pictures.
- Carefully easy the front panel off taking particular care not to bend the band switch area. I usually cut all the wires to parts on front panel so I have plenty of area to work in.
- Using the Heathkit assembly manual for reference remove the old band switch wafers.
- You will be unsoldering both front (input) and read (output) wafers, this is a difficult task take your time, follow Heathkit manual reversing the assembly process. Prioritize on saving the wiring as the switch wafer s are bad already. Take videos as you do this so you can refer to them during reassembly. Bandswitch wafers are ceramic and very sensitive to mechanical damages to not flex or stress them.
- If you bend bandswitch mechanicals they are very hard to find replacements and expect to pay $200-250 for used parts. Gentle touch is required.
- Make sure new wafers are mounted exactly per manual with indexes correct prior to soldering back wires.
- Reassemble front panel following Heathkit manual procedures.

Replace side panel

Follow the Heathkit assembly instruction from the manual. Make sure everything lines up correctly.

Installing Harbach PS-220 and RM-220

- Using the Heathkit manual for reference remove metering board
- Remove 4 nuts holding the capacitor holders under the chassis
- Remove the capacitor (metal) holder and the 8 plastic cap spacers
- Remove Capacitors and Heathkit cap board
- Build the Harbach RM-220 kit per instructions
- Build Harbach PS-220 lot per instructions

Replacing door knobs and 500Pf capacitors in RF section

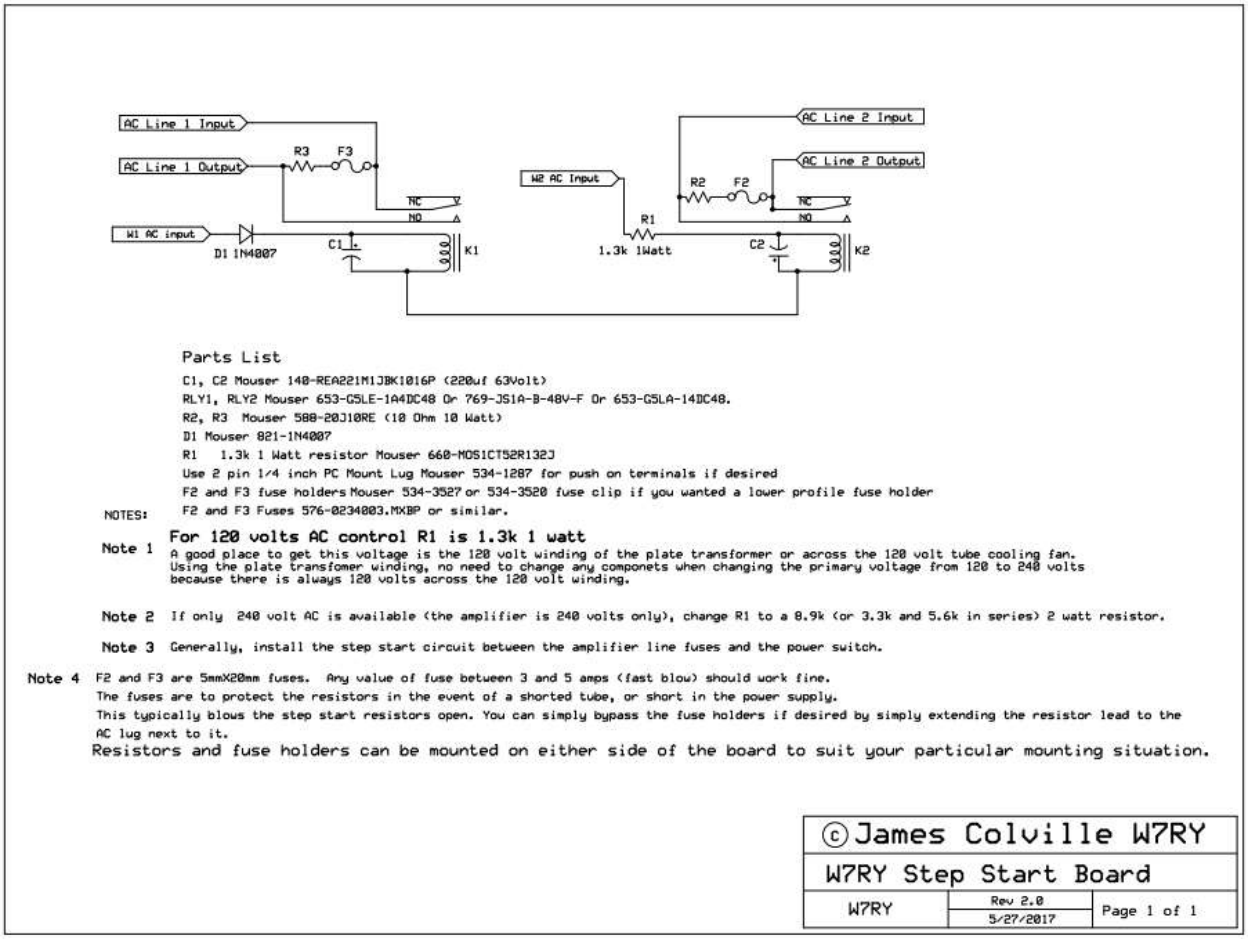
W7BBI had a great suggestion on how to check Heathkit door knobs, first run ESR tester on them, then squeeze them if the are not firm and depress they are shot.

Use ceramic commercial 1000pf 20KV doorknobs as replacements you will have to use larger mounting screws but they will just fit.

The square 500pf cap next to B+ and rfc should be replaced with 500pf 10KV part as should the input capacitor under the RF deck with 0.02uf 10KV part.

Building W7RY Step Start

Follow the W7RY instructions, be sure you order 20 ohm 10W resistors if your using 240VAC for your power. R1 on the Step Start should be 1300 ohms. 10 ohm 10W resistors if 120VAC.



Parts List

C1, C2 Mouser 140-REA221M1JBK1016P (220uf 63Volt)
RLY1, RLY2 Mouser 653-G5LE-1A4DC48 Or 769-JS1A-B-48V-F Or 653-G5LA-14DC48.
R2, R3 Mouser 588-20J10RE (10 Ohm 10 Watt)
D1 Mouser 821-1N4007
R1 1.3k 1 Watt resistor Mouser 660-MOS1CT52R132J
Use 2 pin 1/4 inch PC Mount Lug Mouser 534-1287 for push on terminals if desired
F2 and F3 fuse holders Mouser 534-3527 or 534-3520 fuse clip if you wanted a lower profile fuse holder
F2 and F3 Fuses 576-0234003.MXBP or similar.

NOTES:

Note 1 **For 120 volts AC control R1 is 1.3k 1 watt**
A good place to get this voltage is the 120 volt winding of the plate transformer or across the 120 volt tube cooling fan.
Using the plate transfomer winding, no need to change any componets when changing the primary voltage from 120 to 240 volts because there is always 120 volts across the 120 volt winding.

Note 2 If only 240 volt AC is available (the amplifier is 240 volts only), change R1 to a 8.9k (or 3.3k and 5.6k in series) 2 watt resistor.

Note 3 Generally, install the step start circuit between the amplifier line fuses and the power switch.

Note 4 F2 and F3 are 5mmX20mm fuses. Any value of fuse between 3 and 5 amps (fast blow) should work fine.
The fuses are to protect the resistors in the event of a shorted tube, or short in the power supply.
This typically blows the step start resistors open. You can simply bypass the fuse holders if desired by simply extending the resistor lead to the AC lug next to it.
Resistors and fuse holders can be mounted on either side of the board to suit your particular mounting situation.

W7RY Step Start Board

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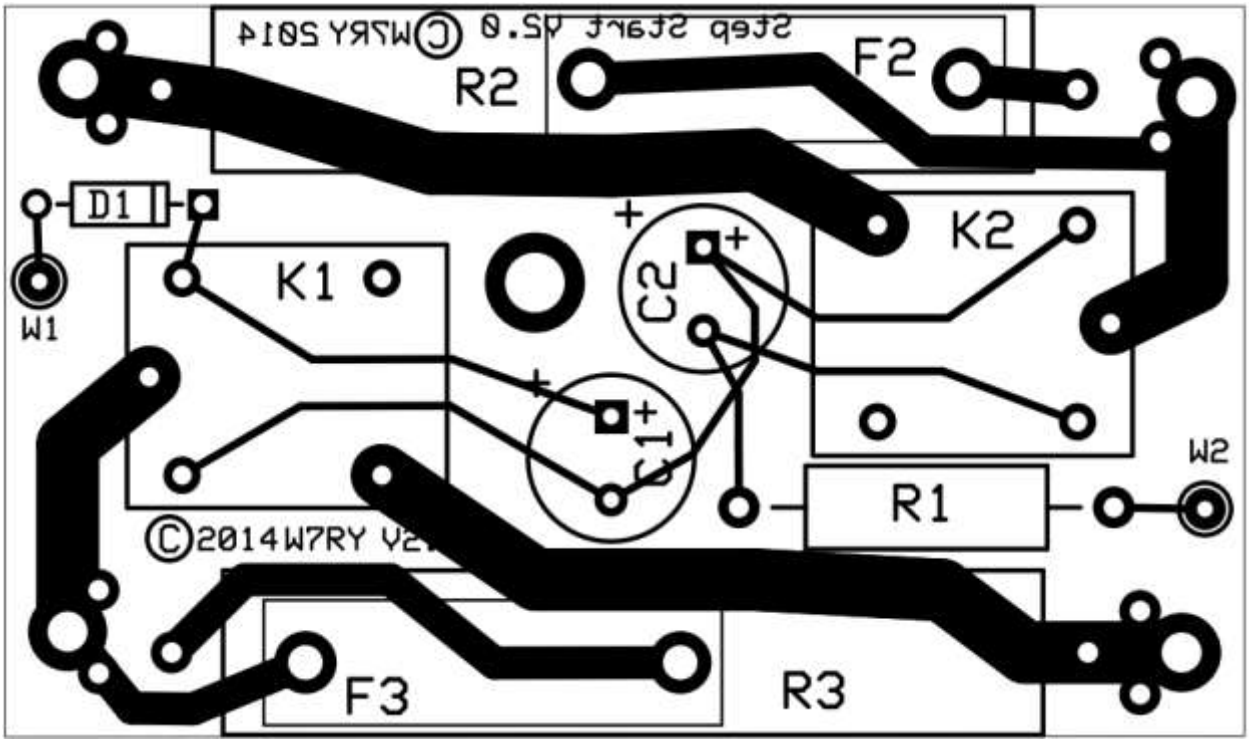


Step start before power is applied has 2 20ohm resistors in series with transformer, the capacitors, charge up to the pull in voltage of around 80VDC then the 2 48VDC relays which takes 2 seconds to close bypassing the dropping resistors and suppling full power to transformer. You can see the action with meter switch in HV position it will pause at 1800-2000VDC then jump to 2500VDC in CW(lower power).

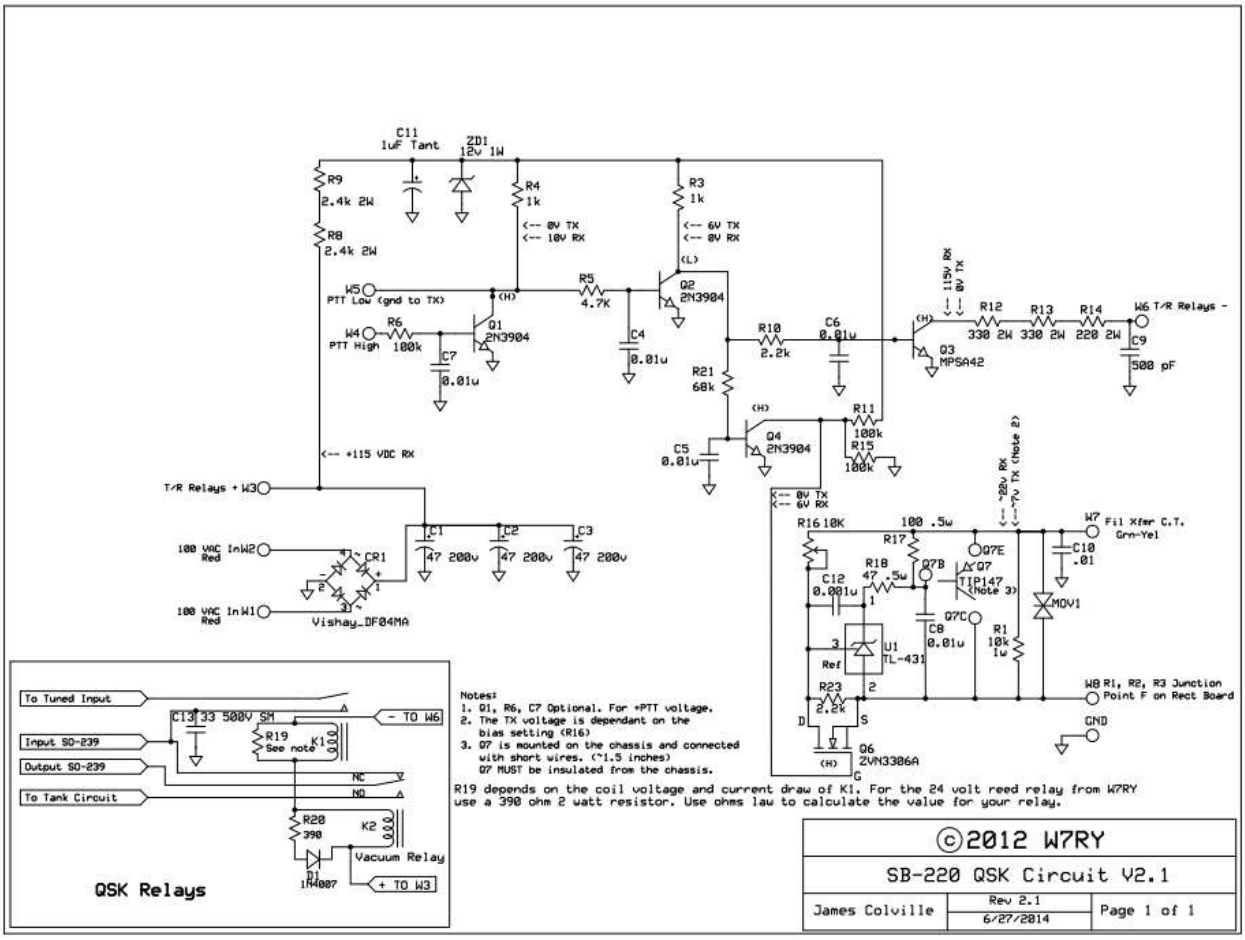
SB-22X have room for both QSK mod and Step Start. You can use standoffs or glue down plastic insulation for the Step Start board. Be sure to use 3A fuses on these.

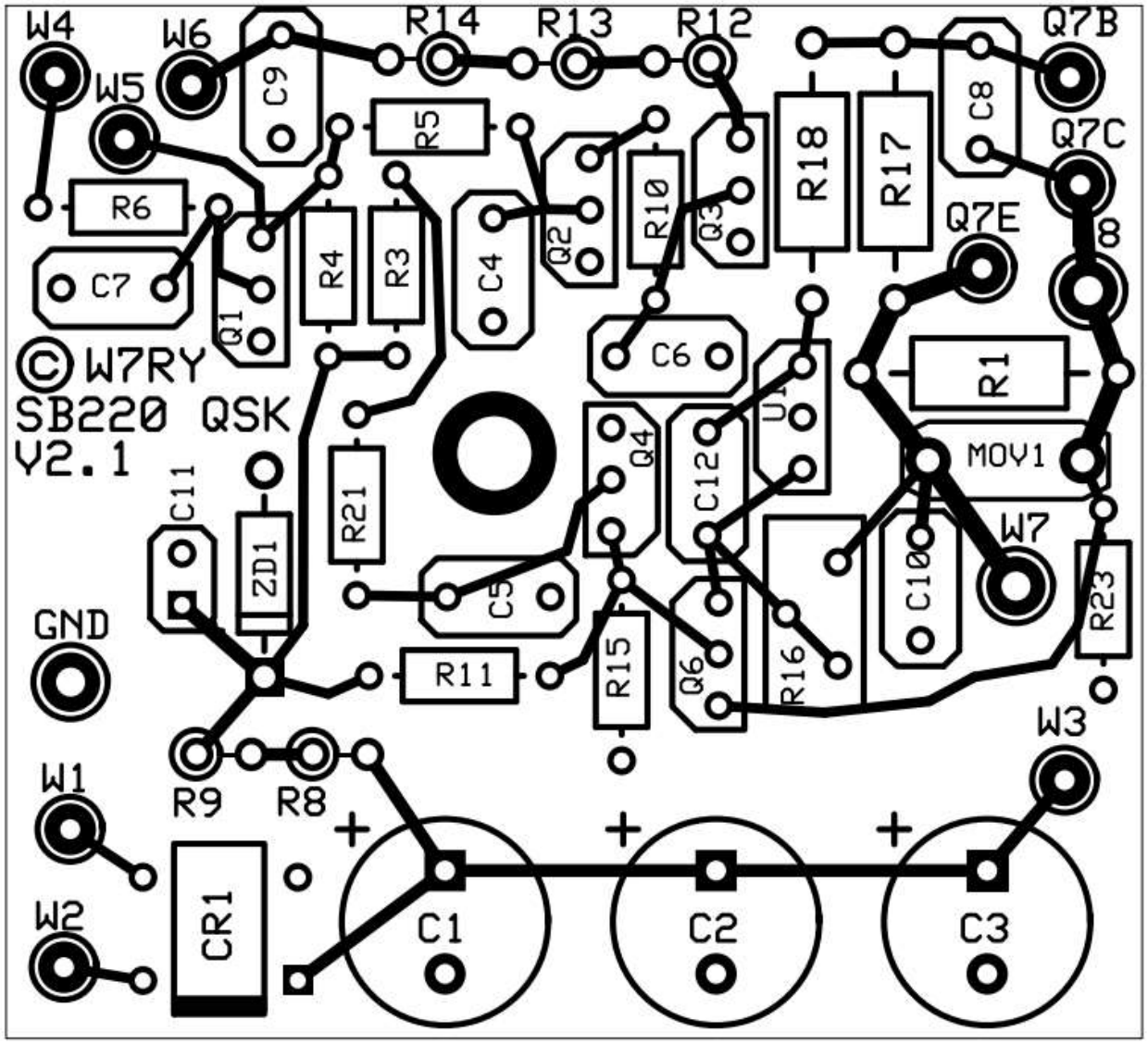
W7RY Step Start in SB-220

Installation and construction of W7RY QSK board

The W7RY QSK board is a generic QSK board that leverages solid state switching, high precision plate idle adjustable setting, and integration with high speed reed relay and vacuum relay to optimize T/R sequencing, timing and switching for the linear amplifier.

The board features both active HIGH and LOW input for very low current T/R switching compatible with solid state transceivers. Note: Yaesu FTDX-1200 use active HIGH T/R switching. Be sure to check your radio for correct polarity before connecting to your modified amp.





The QSK board W4 or W5 connect to exciters PTT output to change state of the amp between Receive and Transmit using appropriate logic consistent with exciter. W4 for active high logic, inverts via Q1 and drives Q2 which in turn conducts if W4 or !W5 is low, to turn on Q6 and Q3 chains.

Q6 and Q7 switch between ~25VDC+ and 5-7VDC+ switching between 3-500ZG cutoff and transmit idle current based on setting of R16 at 120MA spec for 3-500ZG plate idle current. Note Q7 requires a heatsink and must be isolated from the chassis.

Q7 switches via W7 the green/yellow center tape of the Heathkit filament transformer providing bias and idle voltage/current to the 3-500ZG.

W8 connects to F on both original Heathkit meter/rectifier or Harbach board. *Note the E connection is no longer required, and the original relay and its associated red and blue coil wires are removed*. The blue wire from the Heathkit SSB-220/221 T/R Relay port is connected to W4 for Yaesu or W5 for active low exciters.

Q3 on the QSK board is used to drive the reed and vacuum relay that have replaced the original Heathkit open frame relay. The QSK board and companion reed relay board See figure 8, are connected as shown in figure 2.

Note reed relay board only uses NO and C connections, NC is not utilized. The vacuum switch NO is connected to the SSB-221 TANK, the C is connected to heavy coax to the PL-239 connector on the SSB-220/221 amp RF output connector.

In transmit mode, Q7 provides idle current to 3-500ZG tubes, TANK is connected to AMP OUTPUT, and reed relay connects exciter IN to TUNED-INPUT so exciter is now driving the amp. In receive mode 0V is on the relay's which are in series, and Q7 has biased 3-500ZG into cutoff with ~25VDC.

Note the reed relay is polarized note +/- connections. The Vacuum relay is non-polar so it makes no difference how its coils are connected.

Q3 completes the connection on the minus side of the reed relay via W6 – T/R relay signal. W3 provides positive 110VDC to the chain of relays. R12, R13 and R14 all 2W resistors, creating 880 ohms in series and there is a 390 ohm 2W across reed relay, in series with 390 ohm 2W in series with diode 1N4007 to the positive 110VDC provided by W3.

The VHC-1 vacuum relay has coil voltage of 26.5vdc and coil resistance of 335 ohms. The reed relay is similar. The 110VDC is dropped to 53VDC across the relays in series during transmit. The effective resistance of this network is 1.240K resulting in 88 MA of current flow when transmitting.

If your using different relays, with different voltages you need to chance the resistors to provide the correct 80-90MA current through them.

- Start by downloading and printing out your QSK board instructions so you have them available
- Build the QSK board per documentation
- Build the Reed relay board with correct 390 ohm resistor (for relays specified)
- Disconnect both small red wires from 90VAC winding of filament transformer
- Add 250ma 250VAC Fast Blow inline fuse on one of the small red leads
- Remove the open frame relay, its 47K resistor.
- At this point you need to manufacture a mounting plate for the vacuum relay, with a place for the reed relay board on a standoff close to vacuum relay switch pins. I use old heat sinks, drill hole large enough for vacuum relay, mount on short stand off the reed relay board on same side.

- You need to read the QSK 220 schematic carefully to insure you wire correctly.
- Before installing the pot, use DMM and set it so its centered at 5000 ohms mid range of the pot this will help when setting plate idle current in later steps.
- Mount the QSK board on standoff, then remove so you can wire easily

- W1 connect to the other end of the 250ma 250V Fast Blow fuse, this insures 90VAC 100ma winding is protected from damage if faults occur.
- Wire W2 to other red lead. This removes the red wire that was on the ground lug of the original 90VDC, if you fail to remove the ground you will burn out the filament transformer to the tune of $190. This picture is original barrier post with one red lead on ground lug the one that must be removed.

Modified barrier strip ALC now powered off QSK W3 +

Both T2 Filament transformer 90VAC lines now wired direct to QSK

- Remove the old diode and capacitor on the original 90VDC barrier strip it is no longer needed
- Optionally after diode and cap are removed you can run a wire from W3 to ALC to provide +90VDC if you desire to keep the ALC. Generally most folks remove the ALC.
- W7 is wired to the center tap of the 5VAC winding the yellow/green wire this connection provides the bias/idle electronic switch to the 3-500ZG tubes.

- W8 is connected to point F on the Harbach board, as its Zener diodes are no longer used. Same if you kept original Heathkit meter board. The TIP147 provides this now from the QSK board. Point E on Harbach or Heathkit are no longer used.
- Mount the TIP 147 transistor on its special insulated pad to side of heat sink used for vacuum relay or chassis with pins up for easy soldering. It must be insulated from the chassis, check with ohm meter each pin to chassis, should be open. Good idea to label from manufactures spec sheet E,B and C. Then wire up three less than 2" wires, heat shrink them, and the other end connects Q7E to E, Q7B to B and Q7C to C.
- Solder a short wire to the QSK GND pad, then to a star lug on the chassis to provide good chassis ground for QSK.
- The Reed Relay board has label incorrect on the schematic. There are three ground holes on right side of the picture. Two on top, one just above NO. We will wire those later.

  - W23 Reed Relay board connect to W3 on QSK provides positive relay voltage
  - W24 Reed Relay board is wired to vacuum relay coil either pin.
  - W22 Reed Relay board is wired to vacuum relay coil remaining pin.
  - W21 Reed Relay board is wired to W6 on QSK provide ground to reed and vacuum relay
- Locate input coax from input SO-239 RF IN on rear panel and wire center conductor to Reed Relay board pad labeled NO. Leave shied off for now.
- Locate Tuned Input coax from bandswitch, wire center conductor to C pad on Reed Relay board, leave shield off for now.
- Add 18GA short wire from NO Pad on Reed Relay board to NC lug of VHC-1 vacuum relay (they are label in blue on side of vacuum relay)
- Wire Tank Circuit to NO lug of VCH-1 vacuum relay
- Locate output coax from SO-239 RF OUTPUT, wire free end to C lug of VHC-1 vacuum relay. You can use short 18GA wire solder in relay then solder to heavy output coax to complete the connection. Note: RG400 can be used and RG142 for input if desired.
- Now we need to connect the shields, solder 18GA wire in the three ground holes on the Reed Relay board and wire them to shield on RF IN coax, RF Out coax, Tuned Input shield, On the

Output coax wrap lug around coax per original where it provides chassis ground. The Goal is good RF grounding.

- The clean up your routing of cables and tie wrap under chassis.
- Now connect DMM and measure from center conductor of RF IN SO-239 to center conductor SO-239, you should see zero ohms. If not your wired wrong recheck your steps and schematic. This is the most critical step, incorrectly wired dumps your amps output in to your radios output. You can also connect radio to RF IN and antenna to RF OUT if you here normal signals you are wired correctly. If you miss wire Reed Relay swapping + and – the reed will not work.
- Finally wire W5 or W4 to the T/R Rly RCA jack's center pin. Wire a 10k .25W resistor from W4 to ground to insure PTT is not falsely triggered. You need to check your radio to determine polarity of your PTT.

YAESU specific linear interface

On Yaesu FTDX-1200 and similar radios the default QSK timing is 25ms, it is adjustable however default is shortest timing. See Yaesu manual for correct settings. You use the pin 2 TX GND to center pin of RCA male plug that connects the amp to exciter. Pin 3 is connected to the shied providing the ground return. Remember Yaesu on this radio uses active high signal, open collector where the 1K pull up in the QSK T/R input is held low on W4 input, until amp is keyed. The high on Q1 is inverted on Q2 driving the transmit sequence.

Therefore: QSK fast relays running at 1-3ms, add to the exciter internal timing. Stock Heathkit and Kenwood relays are open frame, and much slower, further they switch bias and input/output signals in parallel creating race conditions. The QSK, reed relay and vacuum relay improve speed, separate bias from other switching, improving sequencing and stress on output tubes.

Icom specific linear interface

IC-7300 are the opposite polarity and use W5, wire a 10K pull up to 13.8VDC pin on accy jack, wire other end to Send pin and center conductor of cable with RCA plug on the other end. Wire accy gnd to shield on RCA jack.

At this point the most complex part of the restoration and optimization is complete.

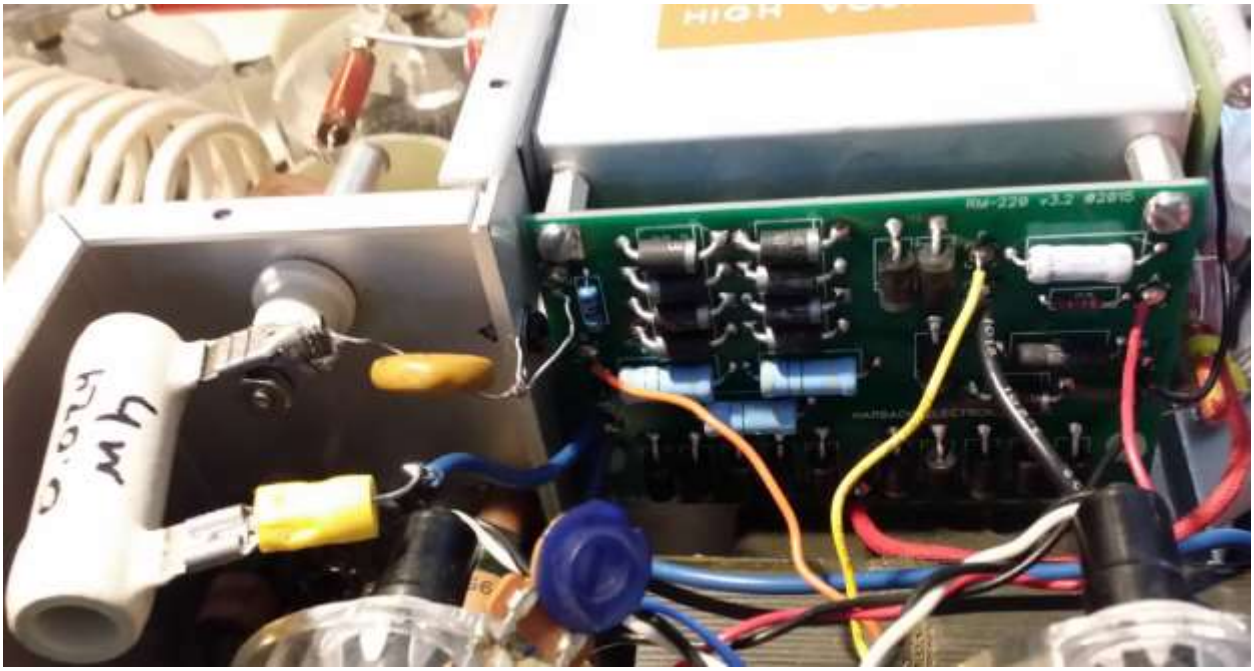
Glitch and HV Fault Protection

This next series of modification protects both anode (plate) and cathode (filament) and B- protection.

Plate Glitch Resistor

Any 10-20 ohm 10-50W power resistor can be used note how it is wired in series with B+ and first RFC, also change the 0.01uf capacitor to 10KV.

Glitch Resistor and Harbach RM-220 board in SSB-220/221.



Cathode Glitch Resistor

This resistor does several things it improves negative feedback reducing possibility of parasitic oscillation and it acts as a fuse. The input cap is replaced as well and its voltage rating increase to 10KV. There are 2 non inductive (yes we put them on RLC bridge and measured their inductance.) 3W 10 ohm MOF resistors in parallel then between input coax and input capacitor.

B – Protection

This consists of a 1N5408 diode wired from B – on Harbach or Heathkit meter/RM board to chassis ground with a 0.01uf 50V cap wired in parallel to the diode. During a fault the capacitor shorts dumping the high voltage and current impulse saving amp components.

We also wire back to back 1n4007 diodes across both meters, and put 0.01uf 50V capacitor across those as well.

We have completed the primary restore and optimizations.

Take hour and check all your work, ideally with fellow ham. A miss wire or short will cause a lot of damage.

Final test

At this point your ready to start testing we break this down into three tests.

HV and PTT Test

- Remove tubes if installed
- Insert rubber stopper between HV shorting strap
- Connect station ground to amp, radio
- Connect SWR meter between Amp RF Output and dummy load
- Connect 2500W dummy load 50ohms to SWR meter
- Check RF deck for loose solder, wire or other materials
- Setup HV probe and DMM for 3500VDC measurement
- Do not connect radio at this time leave RF IN put disconnected but connect to T/R Rly RCA jack the PTT from your radio.
- Make sure bench is clear, you have no distractions, follow ARRL 2018 Handbook safety procedures for RF and HV.
- Set CW/SSB to CW
- Set Plate to 40M
- Set Load to 3
- Set Bandswitch to 40M
- Set Meter to HV
- Plug in power
- Turn on power switch observe for smoke, odd noises turn off immediately if unexpected things occur be sure to follow safe capacitor discharge procedure and make sure zero volts on your DMM and front panel meter.
- What we should see is 2500V on right meter with its switch in HV position
- Switch to grid current setting should be zero
- When it turned on you may notice a pause on HV meter swinging up that is the soft start, and you will hear the relays click on power up and when you turn off power. If you see 2000V or so and it stays your relays did not work and you need to investigate why. Usually the diode is backwards in Step Start PCB.
- Now you can put 100W dummy load on your radio and set output to lowest setting, then put radio in CW mode, hit transmit button, the PTT send to the amp T/R Rly RCA jack now turns on the QSK, you will hear reed and vacuum relays click when the transmit button was hit when you release the transmit button they will click again. If that occurs your polarity for PTT is good and your QSK is working except you have not adjusted the plate idle current yet. If not follow the safe capacitor discharge procedure and make sure zero volts on your DMM and front panel meter. The do detailed inspection of your wiring of the QSK, Reed Relay and Vacuum Relay. Remember in previous step we verified that amp in receive mode not keyed RF IN and RF OUT center conductor will be zero ohms, when QSK keys the will be connected to tank and tuned input. This is a key step to insure your radio is not damaged.

Assuming HV looked around 2500VDC, step start relays clicked (they are not loud), radio PTT made QSK, Reed Relay and Vacuum Relay click on and off following transmit button your ready for next test.

Presetting Bias Pot on QSK board

- Carefully install 3-500ZG tube making sure not to scratch or break them, wiggle them into the sockets gently.
- Install the plate caps and insure parasitic resistors and coils have enough clearance to not arc to chassis or components in RF deck. Should look like below. Note use of non-inductive 5W 47ohm MOF resistors mounted outside the 3.5 turn original coil.

- Connect radio RF OUTPUT to RF IN on amplifier
- Connect PTT cable to T/R Rly RCA jack on amplifier
- Connect amplifier to SWR/Power meter with 2000W capacity
- Connect SWR meter to dummy load 2500W 50 ohms.
- Set CW/SSB switch to SSB
- Set Meter to HV
- Set Plate to 40M
- Set Load to 3
- Set Bandswitch to 40M
- Power up amp
- Should see 3175VDC on multimeter (right)
- Set radio to CW mode
- Set radio to 25W drive
- Set radio to 7200Mhz (40M mid band)
- Hit the transmit button on the radio, this send PTT turning on the QSK, placing the amp in transmit mode no modulation which is what is needed to perform plate idle adjustment.
- When the transmit button is hit, you should see about 50-80ma on the plate meter if you centered the 10K pot at 5000 ohms when you built the QSK board.
- To increase the idle current to 120ma, you turn the pot clock wise in ¼ turn increments however do not do this with power plugged in. You measure note the current measurement, disconnect power plug, complete the safe capacitor discharge procedure you have been already using verify the front meter is in HV position reading zero volts, use insulated screw driver to short between plate cap and chassis several time until no sparks. (insures caps are drained), Then turn clockwise ¼, power up amp, hit transmit on radio note new idle current, repeat process until correct plate idle current is set 100-120ma is normal range.

BE EXTREMELY CAREFUL, DO NOT DO THIS ADJUSTMENT WITH POWER CONNECTED OR ON, YOUR 3-500ZG TUBE CANNOT BE RUN HORIZONTALLY. SO YOU MUST FOLLOW THIS PROCEDURE. YOU WOULD ALSO BE EXPOSED TO LEATHAL VOLTAGES AND RF BURNS WHICH MAY KILL YOU IF YOU POWER THE AMP WHILE ADJUSTING IT.

NOTE: W7RY shared no damage will occur if the setting is not correct, tube will not be damaged at any setting, the tube will just not turn on.

At this point your new QSK and relay modification is ready for use and your plate idle current is correctly set for normal operations.

Amplifier system test

At this point amp is done, you need to start with 25W drive for each band and practice peaking power and insuring grid does not exceed 200ma and plate 400ma consistent with the candidate verification process at the beginning of this document.

For new 3-500ZG burn in, power up amp and let them sit for few hours this help getter them. Keep eye out for arcing, or blue flashes, popping noises.

Once burn in is done repeat tuning procedure per Heathkit manual at 70W drive, you will see over 600W in CW(low power mode), 1200-1300 in SSB mode (high power).

Now that your testing is done connect your tuner and antenna system.

Verify that SWR your tuner presents SWR near 1:1 for your amp, you radio may see high SWR on some bands and fold back resulting in no or low output.

There are couple of things to check, first use your internal tuner and hit tune to match SWR between radio and amp, then tweak Antenna tuner on amp output, watching grid current 200ma and plate current 400ma.

Peaking for maximum power at 200/400ma in CW mode on radio, using transmit and keying hand key with ½ second down pulses.

Watch your tube dull red is OK and normal bright orange or yellow, grid and plate currents will be too high because amp is not tuned correctly. This is where the glitch resistors come into play they limit current and act as shock absorbers during tuning easing the stress on your tubes and RF components.

Mission accomplished your SB-22X is ready for many years of faithful service.

Appendix

Figure 1 Annotated Heathkit Schematic for SSB-220/221

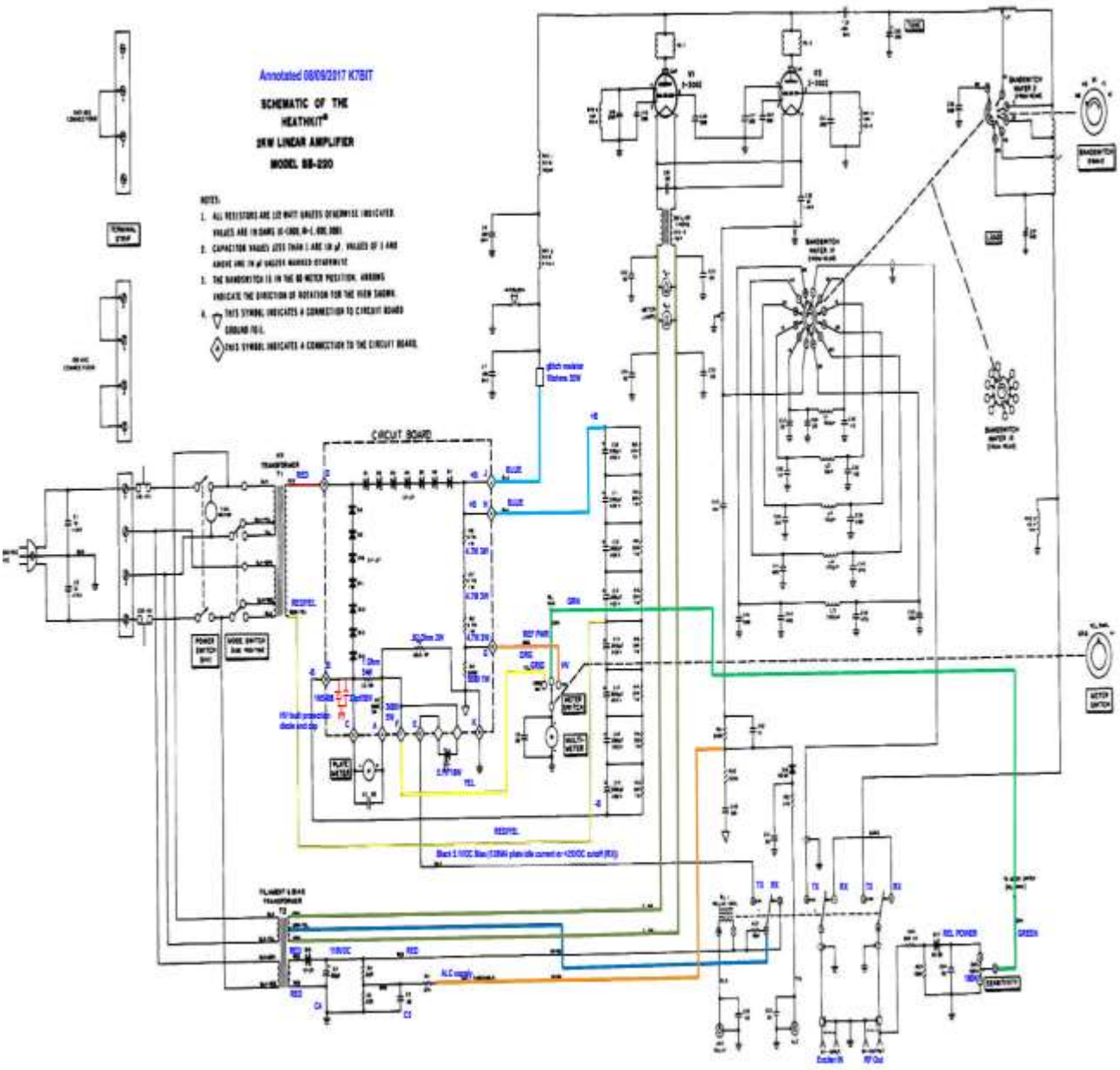
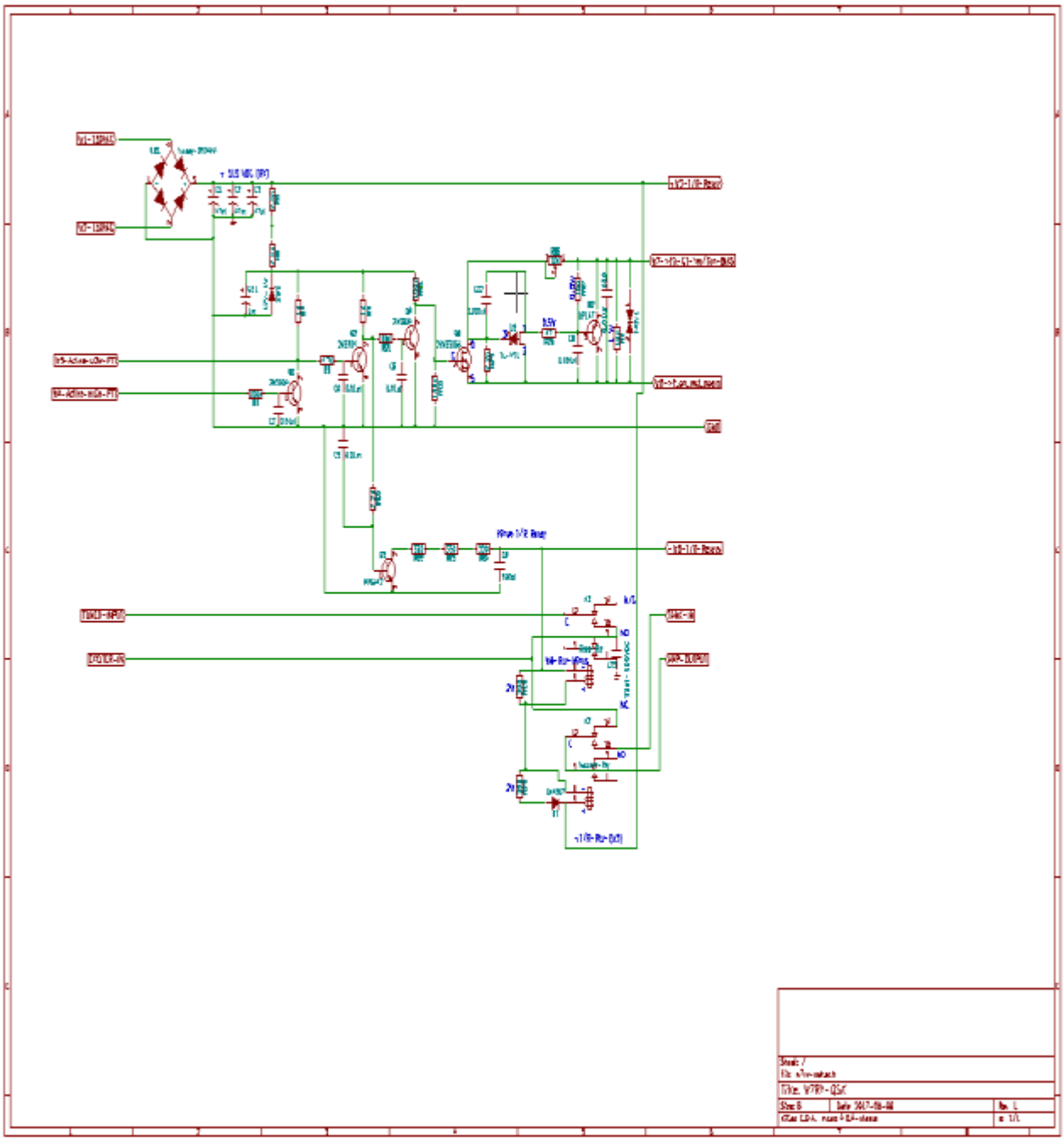


Figure 2 W7RY Integrated schematic QSK and Reed Relay board



Useful information for SSB-220/221

Low power mode 860*2=1720*1.41=, 2425VDC, @ .7 amps 1697W input power

High power mode 1171*2=2342*1.41= 3302VDC, @ .7 amps 2311W input power.

The filament transformer 90VAC winding normally is 285 ohms.

Per Heathkit do not exceed plate current of 400MA, grid current of 200MA. Yes pair of 3-500ZG or Z can run as a pair 200MA grid and plate current of 600MA, however if your goal is long term service life, follow Heathkit recommendation.

Peter Dalh Replacement Heathkit transformer specifications.

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HEATH SB-220 / SB-221 - FILAMENT XFMR
REPLACEMENT TRANSFORMER

CORE) EI-137 X 1.375 STYLE #) 05 E-I LAMINATED CORE
PR) 120/240 VAC 50/60 HZ 1 PH

S1) 5.0 VCT @ 30A CCS

S2) 90 VAC @ 0.1A CCS

DM) HT = 4.125 WT = 4.125 DT = 3.108 MD = 2.750 MW = 2.375
PRICE) $190.00 Plus S&H FOB Buffalo, NY WEIGHT) 6 LBS
NON-STOCKED PART - HAMMOND Part Number: PWDF13057
==========
HEATH SB-220 POWER XFMR
EXACT REPLACEMENT FOR SB-220 / SB-221 / HL-2200

CORE) EI STYLE #) 02 E-I LAMINATED CORE WITH END BELLS
PR) 117/234 VAC 60 HZ HI-LO TAPS
S1) 860/1171 VAC @ 0.7A CCS

DM) HT = 5.25 WT = 4.375 DT = 5.875 MD = 4.50 MW = 3.5625

PRICE) $295.00 Plus S&H FOB Buffalo, NY WEIGHT) 23 LBS
STOCKED PART - HAMMOND Part Number: PWDP13034
==========

Vacuum Relay specification:

VHC-1 ceramic vacuum relay, SPDT contacts

This relay is made by the same manufacturer as the VC-2 relay, shown elsewhere on this page.

This is a direct, very cost-effective drop-in replacement for the popular Jennings RJ1A-26S, Kilovac HC-1, and Gigavac GH-1.

Peak Test Voltage	5 KV	
Peak Operating Voltage	3.5 KV	
Current Carry Amps (RMS)	25 amps @ 60 Hz	
	7 amps @ 32 Mhz.	
Contact Close Speed	6 MS (Milliseconds)	
Contact Release Speed	6 MS (Milliseconds)	
Rated Life Operations	2,000,000	
Coil Specs Two types available		
Coil Voltage	26.5 VDC	12 VDC
Coil Resistance	335 Ohms	80 Ohms
Important Dimensions		
Max length	1.36 in / 35.00 mm	
Max Diameter	0.92 in / 24.00 mm	
Mounting Hole Diameter	0.55 in / 14.05 mm	
Weight	1.00 oz / 28.00 grams	