50 MHz Amplifier

Utilising 3@ 06-40 Valves: 300-350 W PEP

Preamble:

I wanted a 50 MHz amplifier that would be capable of delivering reasonable power. In VK “ADVANCED CLASS” licensees may use 400 W PEP in the 52-54 MHz band and in some parts of VK they can use 400 W PEP in the international allocation of 50.000 - 50.300. Unfortunately in the Eastern states of VK, we are only allowed to use 100 W PEP due to the continued use of Channel 0 TV.

Most modern HF/6m transceivers are capable of 100 W PEP at 50 MHz. However there are still a lot of very good, but older transceivers on 50 MHz that run only 3-20 W. A TS690 puts out 50 W and is an excellent 6m radio. Amateurs with these lower power radios will find this amplifier an excellent addition to the shack!
Having an amplifier that produces in excess of the legal limit, means that when run at reduced power, it “loafs” along and the tubes are operated well inside their specs. Lifetime operation is a real bonus!

Please consider your license operating conditions and ALWAYS operate within your privileges!

So having said all of that, why an amplifier based around an old “non-QRO” tube such as the 06-40? Why not a “real tube” such as a GS35b or a 3-500z?

Well I chose the humble but ubiquitous 06-40 (or it’s variants) because of the following:

**Availability.** There are still lots of these valves kicking around. The bases are cheap and you’ll see plenty at hamfests. A new but unopened valve is worth about $20 US.

**Rugged.** These tubes can take a real hammering! You can make the anodes glow “cherry red” and they’ll happily come back for more. You can exceed the specifications and get away with it. As an example the specs say a maximum Anode voltage of 750 V. I have quite happily run 1200V on the anode of my 144MHz amplifier whilst it was coughing up 120W key down for 30 seconds. It’s great watching the cherry glow of the anodes and purple corona around the tube!
**Simple Cooling requirements.** Muffin fans are more than adequate to provide modest airflow to help take hot air away. The anode ratings are limited by the transfer of heat from the anode across the “vacuum” to the glass envelope.

**Proven Designs.** Look through old magazines and you are sure to come across an amplifier using an 06-40, however most use push-pull circuits: more on that later.

The following is a description of an amplifier that I had immense pleasure in designing and building from the ground up. All in all it took 2 weeks from conception to completion: testament to the theory and simplicity of it’s design. It can be adapted to ANY band below 6m very easily and makes for a GREAT mono-band amplifier for ANY HAM BAND.

……..BUT FIRST…………..

**********DISCLAIMER**********

**WARNING: HIGH VOLTAGES ARE DANGEROUS AND CAN KILL YOU!**
IF YOU HAVE NOT WORKED ON VALVE AMPLIFIERS BEFORE, OR IF YOU ARE NOT EXPERIENCED AT WORKING WITH HIGH VOLTAGES>>>DO NOT ATTEMPT TO BUILD THIS AMPLIFIER!

The voltages in the power supply unit and the amplifier will kill you if you do not have the necessary skills.

Whilst this is an “AMATEUR” hobby, working around high voltages requires the highest “Professionalism” or you pay the ultimate price…..Your life!

OK….now that is out of the way, let’s get to the fun stuff:

**EQUIVALENT TUBES:**

5894, AX9903, QQV06-40A, QQE06-40

The 06-40 is a DUAL TETRODE tube with the 2 SCREENS internally connected.
The Anodes have individual connections on the top of the glass envelope and the GRIDS are separate. PLEASE REFER TO A DATA BOOK FOR THE “PIN-OUT” CONNECTIONS.

POWER SUPPLY REQUIREMENTS FOR THE “VK3NX” 50 MHz AMPLIFIER:

Anode V:  +1200V  (will operate from 600 – 1200)
Anode I: up to ~ 500 mA for 3 tubes @ 1200 V.
Screen V: 250-350 V  The more the better up to 350 V max.
More on this later! Must be able to supply well regulated voltage @ up to 60 mA (for 6 screens).
Grid V: Adjusted and regulated -20 to -35 V +/- 5%  Bias for ~ 30 - 40 mA resting current per tube for Class AB1.
Heater Volts: 13.8 V +/- 5%  AC or DC at 2.8 Amps.

I will not go into a description of the POWER SUPPLY but I will list a few important points:

🎉 Screen Regulation is crucial for good IMD. I achieve less than 6V difference in screen volts under full Key-Down conditions at 50mA total screen current. I use a High power Zener Diode stack. Under dynamic speech conditions the screen supply may have to both “sink” and “source” current so it needs to be a “low impedance” design. Zener diodes work well for this. A large value capacitor on the output also helps under dynamic speech conditions
The Grid voltage is well regulated and adjustable with an adjustable negative voltage 3 terminal regulator. The grid current may also go positive so it too needs to sink and source current. A low value resistor on the output (a couple of hundred ohms) will achieve this.

Try to keep a fairly STIFF Anode supply.

Always employ PROPER safety features in the supply such as fuses (proper types), a series resistor in the +ve rail to limit surge current, -ve rail current metering with high power rated back to back diodes and low value high power resistor to ground in the -ve rail. Always check your ground return. If any of these don’t make sense, then you shouldn’t be building a HIGH VOLTAGE supply just yet. (Please go and learn from someone who knows and you trust. Your life depends on it).

I use soft start on the anode, and filament supplies. This is “kinder” on the HV transformer, and “kinder” to the tubes.

The power supply and switching arrangements must NEVER ALLOW SCREEN VOLTS TO BE PRESENT WITHOUT ANODE VOLTS. If this happens you will instantly fry the screens and kill the tube.

Switch OFF the screen volts when amplifier NOT in TX mode. This will reduce heat and NOISE in the receiver. The Grid volts DO NOT need to be biased differently in Rx mode for an O6-40. Taking screen volts off will cause Anode current to fall to zero.

Valve protection features, such as shut down in excess Grid or Anode or Screen current wasn’t employed. These are rugged tubes and more importantly, “cheap” to replace. The added expense and complexity wasn’t warranted in my opinion.
Amplifier Schematic:

RC1 = 40 kΩ. ≈ 20 nF capacitors on ½ inch grid. Rin.
RC2 = 20 kΩ. ≈ 20 nF capacitors. R1 and R2 values.
Important Features:

- 3 tubes in parallel. Only 1 tube shown
- Grids all feed to common point
- Amplifier can be considered as “voltage fed”
- Larger Drive power required than Push-Pull arrangement
- Class AB1 means NO Grid Current. Therefore the grid bias voltage that is applied is the LIMITING Drive voltage that can be applied before Grid current is drawn and the amplifier begins to operate in Class AB2 (Worse IMD)
- RFC2 IS VITAL FOR SAFETY....CONSTRUCT IT AS SUCH
- Input 50 ohm resistor is a high power low inductance type (such as found in microwave Power Amplifiers)
- A Grid Current Meter was added in my final design by measuring the voltage across 1 of the Grid series 470 ohm resistors
- The 68 ohm resistors in the anode lines are Parasitic Suppressors. They are very important!
- All feed through capacitors must be suitably rated!
- The 0.1 uF Bypass capacitor directly connected to the screens were REMOVED!!! It interferes with the “self-neutralizing” properties of the internal construction of the 06-40. Initially it was thought that this feature is not required in a PARALLEL design. It is! THEREFORE mount the tubes through the chassis so the internal screen is LEVEL with the chassis. The valve bases will therefore sit ~ 20 mm BELOW the chassis
Design of output Pi Coupler:

(Theoretical description........skip to final values for Pi Coupler if you find this BORING!)

The design of the output Pi coupler was calculated using Tables in the RSGB handbook and formulas in the ARRL handbook. These are fairly straight forward.

The tube specs are as such:

\[ C_{\text{out}} = 2.1 \text{ pF per section} \]
\[ C_{\text{gp}} = 0.08 \text{ pF per section} \]
\[ C_{\text{in}} = 6.7 \text{ pF per section} \]

Therefore the C out for 3 tubes in PARALLEL = 12.6 pF

\[ V_p = 1200V \]
\[ I_p = 500mA \text{ for 600 W DC input} \]
\[ K = 1.6 \text{ for SSB class AB1} \]

Optimum RL =\( \frac{1200}{(1.6 @0.5)} \) = 1500 ohms

\[ X_{\text{c out}} = 252 \text{ ohms @ 50 MHz} \ (C= 12.6 \text{ pF}) \]

\[ QL = 1500 / 252 = \sim 6 \]
This Loaded Q of only 6 is a little low which means theoretically that the circulating currents will be lower than the standard $Q_L = 12$ and also Harmonic Suppression may not be as good.

It was going to be interesting to see if I could get good ENERGY TRANSFER out of the Pi Coupler.

After going through the “look up” tables and taking into account the estimated STRAY CAPACITANCE of the physical circuit layout, I settled upon certain values for:

\[
\begin{align*}
C_{\text{tune}} &= 8 \text{ pF} \\
L &= 0.376 \text{ uH} \\
C_{\text{load}} &= 150 \text{ pF}
\end{align*}
\]

I replicated Varying Load resistors and with no power applied I placed these resistances across the Anodes to gnd and used an ANALYSER feeding back into the OUTPUT circuit to see how the SWR or matching was. Initially the circuit would not tune higher than about 40 MHz with these values. It appeared that my circuit STRAY capacitances and/or Inductance levels were higher than first anticipated. This was not surprising given the physical construction.

So after careful experimentation I found a value of $L$ that would match the Load Resistances from 600 – 1500 ohms into the 50 ohm output. This involved reducing $L$ substantially.
FINAL OUTPUT Pi-COUPLER NETWORK VALUES:

\[ C_{\text{tune}} = 8 \text{pF} \]
\[ L = 3 \text{ turns 1 inch long 1 inch Diam Airwound with 3mm diam. copper wire} \]
\[ C_{\text{load}} = 150 \text{ pF} \]

\( C_{\text{tune}} \) MUST BE a wide space transmitting type capacitor to prevent ARCING.

To make OUTPUT TUNING easier, a vernier drive/dial was used. The Output Loading control was a direct 1:1 connection. At 50 MHz the tuning and loading controls were at half mesh indicating PLENTY of adjustment available in the system. The final amplifier tuned easily across the entire 50 -54 MHz band!

Cleaning up the Output Amplified Signal.

Because of the concern with TVI an output LOW PASS FILTER is an excellent idea and a simple COAXIAL notch filter for the 2\textsuperscript{nd} Harmonic at 100-108 MHz which is in the Broadcast FM band. Both designs were taken from the “VHF-UHF Dx Handbook” and implemented into the output circuit.
The Low Pass filter was built with “metal clad MICA” capacitors and air wound coils. The 2nd Harmonic attenuation produced with the filter alone was 41dB and the 3rd harmonic was down >60dB.

The coaxial Notch filter was tuned precisely to 100.2 MHz using a spectrum analyzer and produced a 32dB notch. This was soldered directly to the back panel output coaxial connector.

**Input circuit:**

- Well what could be simpler? Apply RF to a 50 ohm resistor (suitably rated) and pick off the RF volts generated and apply it to as many tubes as you like! The drive power required is certainly a lot higher than a grid driven Push-Pull amplifier configuration normally seen with these tubes, but driving power was never an issue. The input circuit being what can be considered voltage fed, means that the whole design is FAR more stable than a Push – Pull configuration. Some neutralization is required but there is sufficient “self neutralization” in the internal screen of the 06-40 that no additional neutralization is required.

- By having a constant 50 ohm load on the input the exciter always sees an excellent match.

- The maximum drive level that you can apply to the grids before Grid current is drawn and you go from Class AB1 to Class AB2 is the point where the RF volts = the applied Grid volts. Therefore by using a higher Screen volts the gain of the tube is increased and for a given QUIESCENT current, more negative Grid volts need to be applied (less grid volts).
That is why you should use a “sensible” but high screen volts so that you need more –ve grid volts and can therefore apply more RF drive before the level is reached when RF volts = Grid bias volts and you go into Class AB2.

In a single 06-40 at 144MHz and 1200 V on the anode, I have achieved 120 W output in push pull. I would suggest limiting the tubes to this upper limit. With 3 tubes, you could get 360 W LESS losses…that is why I think the upper limit should be 350 W.

Choose high enough Anode and Screen volts so that there is enough grid volts required for a given resting current of ~30-40mA per tube such that you can drive with enough RF volts to stay in Class AB1 and produce your 300-350 W.

This way EVERYONE ON THE BAND will be happier as opposed to going into Class AB2 and theoretically increasing your IMD products.
The completed VK3NX 50 MHz Amplifier:

Anode compartment

. In the Anode / plate compartment, the anode parasitic suppressors are visible as is RFC1 and RFC2.
Output LPF, Notch filter, C/O relay and detector.

The 100 MHz Notch filter is soldered directly to the output SO239 connector. The C/O relay is a CX120-P with a circuit board directional coupler to measure forward RF power. The detector circuit amplifies and drives the meter.
Input side. 3 @ Valve bases

On the back panel is the HV coming into the underside of the chassis and passing via a FT cap into the anode compartment.

Remember, the valve bases have been positioned approximately 20 mm BELOW the dividing chassis plate on standoffs.
Output Pi-Coupler components
Input C/O relay board on the right and DC power in.
Front panel with RF OUT and Grid current metering
Back panel with 2 @ 60mm MUFFIN fans blowing air through the anode compartment and out of a grill on the top cover. The “holes” are RF shielded with wire mesh.

RF TESTING:

Before the application of power, the valves were inserted and filament power was applied for 24 hours to help “recondition” the old tubes. With the application of screen and Plate voltage 1 tube let off a bang! The envelope cracked. Another tube was conditioned and it was fine!

Initially a 0.1 uF was soldered to each screen and ground. It was found that the amplifier would intermittently take off when in Tx mode with the covers removed. It was OK with the covers on but it was soon realized that the screen bypass caps were destroying the self-neutralizing properties of the tubes. So the caps were removed and repositioned on the “cold” side of the screen series resistor. After this the unit proved “unconditionally stable”.
Test Results:

HV = 1050 V
Screen = 286 V
Grid Bias = -27.5 V  for 120mA total ( 40 mA per tube, or 20 A per anode)
For 20 W Drive
Ip = 445mA
Power OUT = 300 W
Grid current was 2mA ( for 6 grids)….Just getting into Class AB2

Efficiency = 64 %

With appropriate loading control between 60 -65 % efficiency was achieved.

I guess the Pi-coupler was doing it’s job after all!

I was able to produce 350 W key down  PEP with grid current getting to 3mA for 3 grids with GOOD IMD.

I believe the amp should be limited to 300 W PEP  with about <2.0 mA grid current ( total for 6 grids)
The Screen current at ~ 300W is 54mA total for 6 screens: so ~ 9mA per screen. The manufacturer’s specs say 16mA max.

At 300 W 2nd Harmonic level out at back panel was ~ -60dB
All other spurii and harmonics were >70dB down!
**2 Tone Testing:**

Proper 2 tone tests were conducted to determine linearity. A Clifton Lab “Panadapter” was used.

AT 300 W  3rd order products were >44dB down from PEP. Grid current 1.2mA with 18W drive

At 350 W 3rd order products still >40dB down from PEP. Grid current 3mA with 22W drive. BUT 5th order products came up 15dB to 44dB below PEP….Still Very GOOD.

As grid current increases we are going more into Class AB2 and IMD performance degrades.

I chose to have 300 W as a limit to the Power Output on the meter scale. At 300 W the IMD levels are exceptional and we are only just into grid current….~ 0.2mA per grid. Having said that I think the amplifier could easily be run at the 350 W level. For the sake of other band users a GRID CURRENT meter is a very good idea to ensure that the amplifier stays closer to Class AB1 BIAS levels instead of AB2.
Conclusion:

In my opinion the amplifier was a worthwhile exercise! I achieved everything I set out to with the criteria I had and now with the Power Supply living under the desk, a “desktop” amp constructed cheaply from aluminium sheet, a few valve bases and some old “rugged” valves, now sits on top of the desk. I would not hesitate to duplicate this design for a monoband HF amp if the need ever arose. **I would probably add a 4th or 5th tube for increased power!**.........Now there’s an idea. The simplicity of the input circuit means only the output caps and tuning coil need changing for use on any band.