Feeding a Tube Transmitter Obsession

VE1ZAC r6 May 2021

I have always had a fondness for amateur tube equipment and have acquired, rebuilt, operated and donated lots of pieces of tube gear in my ham career. I also have a few operating Heath rigs that are fun to operate and maintain.

If you look around this website, you will find a short story about building a low power tube rig, ostensibly with my son, to revisit the tube “Era” . This rig was built from my over extended junk box. That project was completed after much effort and then sat on a shelf since the 90’s. Occasionally it was hooked up and operated. It still worked but it was never a very good piece of transmitting equipment.

"The Three Tube Mini Boat Anchor Experience"

Link :
https://www.ve1zac.com/The%20Three%20%20Tube%20%20Mini%20Boat%20Anchor%20Experience.htm

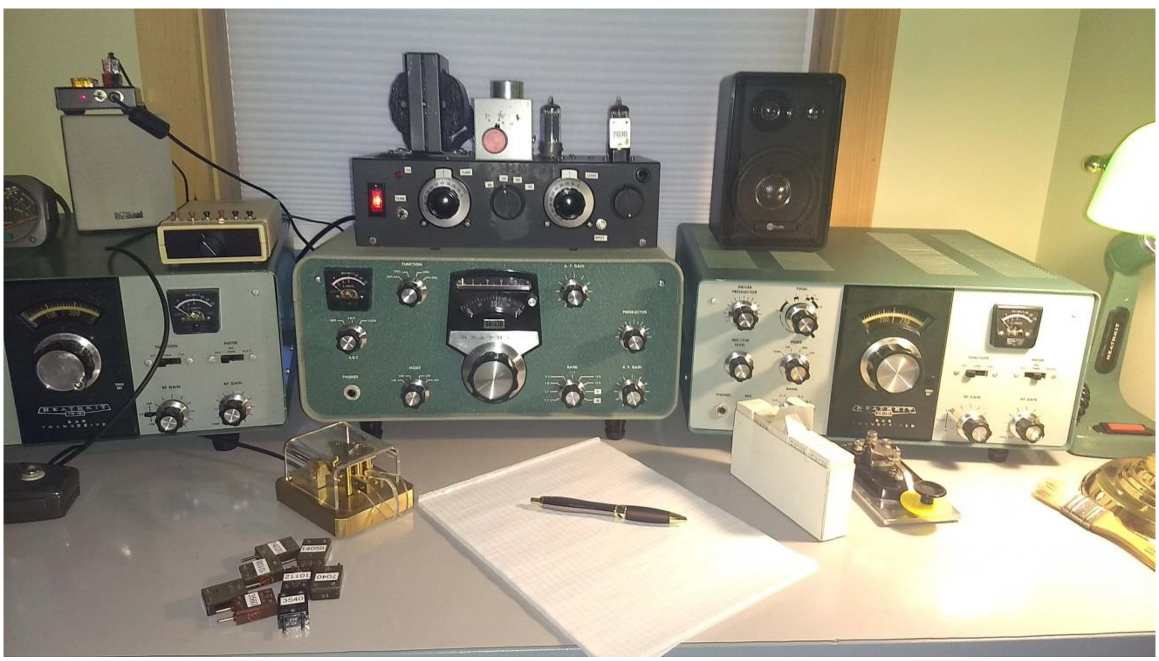
This rig had 5763’s for finals and was, at best, capable of 5 watts output. The oscillator was an issue requiring some awkward fixes to make work. I acquired a handful of FT243 crystals and might have made a dozen contacts with the rig during its entire lifespan.

Which brings us up to now.

First … a Caveat Emptor :

> ***"Warning: this transmitter uses a power supply with potentially lethal medium voltage AC-DC power supplies. Care must be taken when working with all power supplies and transmitter circuits like this. The reader engages in this activity at their own risk."***

I have rekindled an urge to operate with an all tube setup, vintage or updated vintage and vintage novice level power. I have in my Heath collection a nice SB310 receiver that is a delight to operate. It works ham bands on 80, 40 and 20 meters, and I have converted the 9 MHz SWL band to 30M. Mine is equipped with the AM, SSB and CW filters.



A companion tube transmitter and this receiver would be a fine pair to meet my operating requirement. I could hunt down a piece of surplus transmitting equipment, but it occurred to me it was time to take the aforementioned 3 tube mini boat anchor project and rebuild it into a proper piece of transmitter equipment.

So, first task was to dismantle the entire mini boat anchor project. It didn't take very long and I had a pile of used parts on the bench.

Now what ?

I rummaged through the parts pile and kept the tube sockets, the variable caps, the crystal socket, the power transformer, the plate choke…and discarded everything else.

Now to figure out what I really wanted to do with this transmitter rebuild. Or redesign, which is more accurate.

Crystal and Oscillator Issues

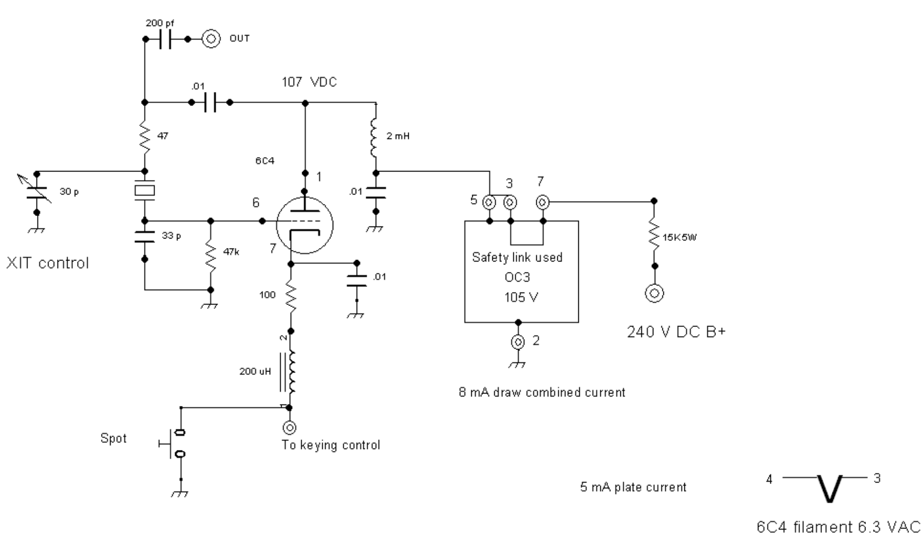
Let's start with the crystals. I liked the idea of keeping with the FT243 holders but they aren't cheap, and the ones you can get from a few EBay suppliers are actually HC49 crystals, or in some cases HC6 crystals mounted in a salvaged FT243 holder. A little online research suggested that these newer crystal conversions might not work in some classic tube oscillator designs. And their resonant power capabilities are significantly less than the older quartz crystals. I found a couple of articles that suggested the oscillator circuit could be run at lower power effectively with these modern crystals. A typical 6C4 with a 100 volt plate voltage in the Pierce configuration was used as an example. That seemed like the likely place to start.

Bread-boarding.

I wanted to have this entire transmitter circuit lashed up on the bench for testing before starting a real build. And, a piece of pine board actually turned out to be a practical method to create an experimental circuit. That was amusing… a real bread-board !

I put a Pierce oscillator together with a 6C4 and tested the circuit with a handy Heath IP23 tube power supply I have in my collection of useful tube equipment. The oscillator worked well with 100 volts on the plate with HC49 crystals as reported. The 6C4 plate current was 5 mA. Opening and closing the cathode with a key provided very clean starts and stops.

My power transformer has a 355 VAC center tapped secondary. Providing 100 volts from that arrangement might be difficult. A tube regulator ? Rummaging through my collection I found an OC3. It serves as a 105 volt shunt regulator. Hooking it up with a suitable dropping resistor to a 250 volt plate supply produced 107 volts for an oscillator power supply. Everything worked fine. This regulator has a handy internal link inside you can use to provide a safety in case the tube is pulled or fails while power is on. It protects the lower voltage oscillator circuit.



This scheme produces approximately 12 volts peak output on my desired bands of 80,40, 30 and 20 meters.

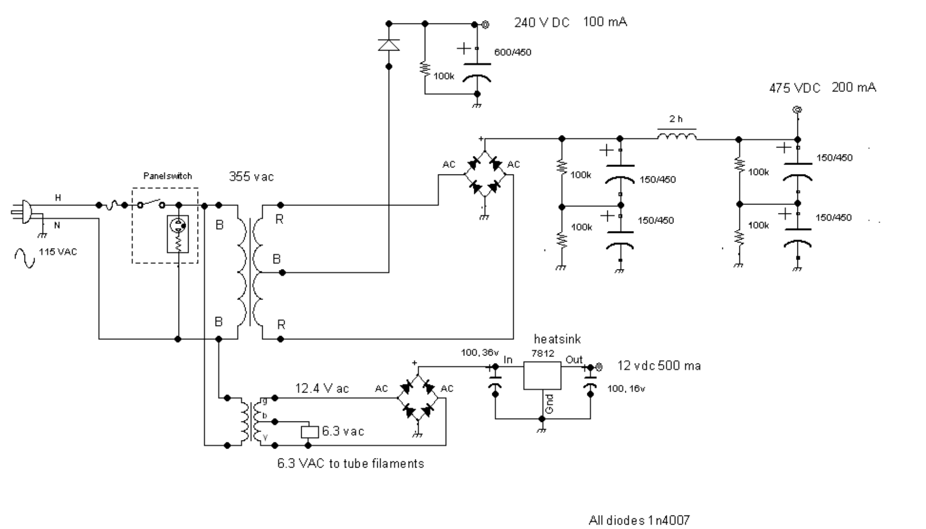
What next ?

The driver and final PA or the power supply ?

The PA and eventual performance limit is going to be determined by the power supply, so best to get that sorted. Here is my first deviation from a classic all tube design. I decided to use a rectifier bridge to produce the B+ for the finals plate supply. That netted a 475 V dc supply with low ripple. This supply is easily capable of 200 mA or more. The center tap was used with a single diode and a return from the bridge to produce a 240 VDC supply for the oscillator and driver tube use. The transformer has a 12.4 V AC with a center tap. This worked out fine for the tube heaters and another bridge was used to provide a 19 VDC supply that is then regulated with a conventional 7812 3-terminal regulator for use by relays and other control items as needed.

I have a home Eagle Cad license and a small milling machine to rout circuit boards. This was put to use for the power supply.

Power supply schematic



PA and Driver

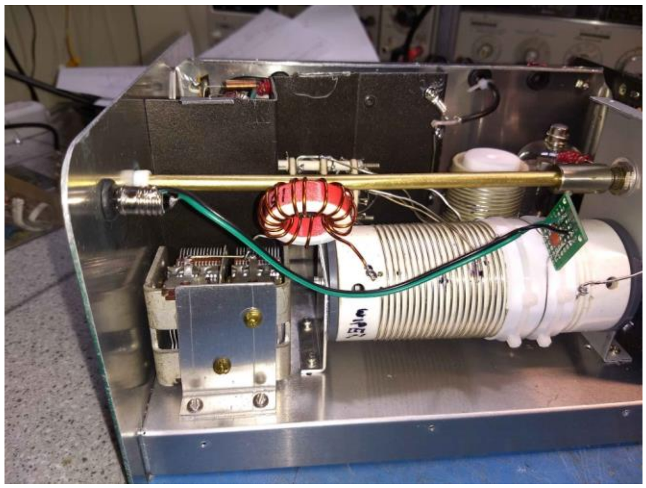
I started off with the parallel 5763's I had used previously but wound up with a problem with the plate supply. What I really needed was a single tube that could generate 20 watts or so comfortably with a 475 VDC plate supply. Another rummage in my stash of tubes and out popped a 6146 in good condition. Looking up the references in the RCA Transmitting Tube Manual gave values for screen and grid resistors and other important parameters. Looked like a winner and I wouldn't be driving at the hard limits. A good choice.

What about the driver ? A 5763 would work but a classic pentode would be more suitable. Voltage gain is more important than power gain for the driver. More tube rummaging and out popped a 6CL6. I found out later that I had just about recreated the Heath DX60 transmitter. It has a 6CL6 driving a 6146. Surprise ! That turned out to give me some performance comparisons when my transmitter came alive.

Tanks

The grid tank is a parallel LC with a 150 pFD variable and an inductor wound on a #2 (red) mix powdered iron core. I tried to calculate this thing but the final version came about more by experimentation than anything else. This worked fine. My operating bands are the CW portions of 80, 40, 30 and 20M. The bands switch is setup with four positions.

The output tank is a PI-L type. I had two nice ceramic coil forms in the junk box. No idea where they came from, but they were perfect for this tank. I used the popular GM3SEK Excel calculator to deal with the tank. I made a mistake the first time around by inputting the wrong plate voltage, but even after catching that mistake, the tank came out fine. I had to add a toroid inductor at one end of the tank to get the 80M coverage. It worked properly when fired up. Nothing gets hot in the tank.



(You can also see the eventually rejected peak indicator pickup in this picture)

Checking the tank resonances with a classic Millen Grid Dip Oscillator..the real deal !

Neutralizing

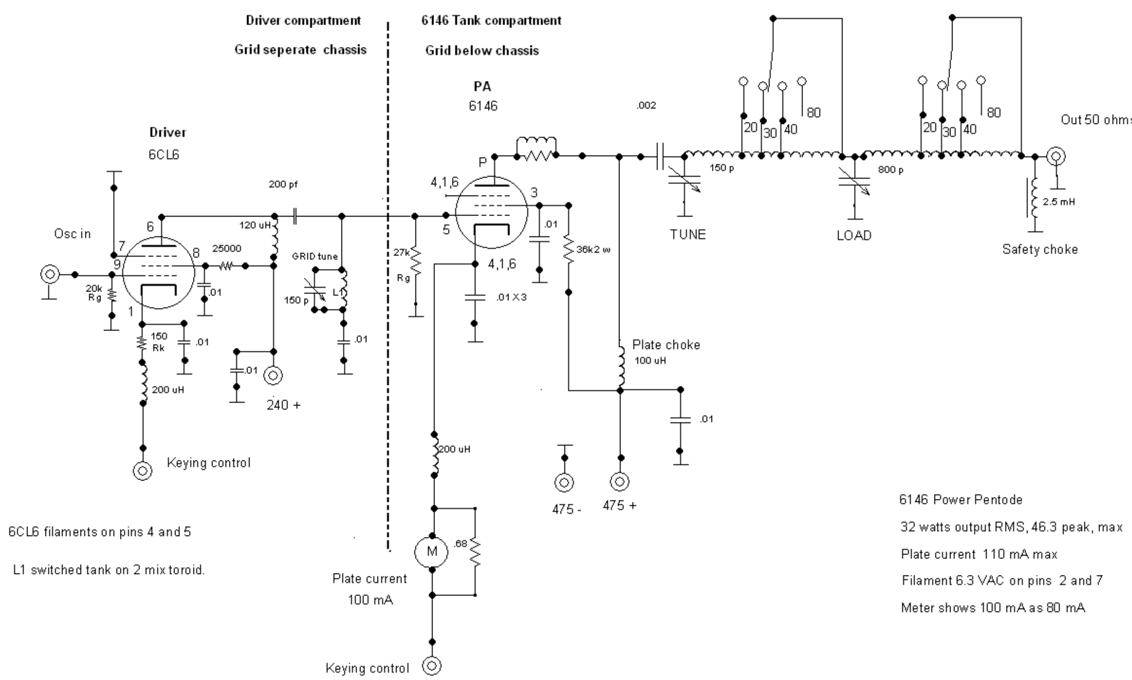
Research indicated the 6146 typically needs some HF neutralization scheme, but normally only on 15 and 10M. Since I wasn't building for those bands I decided to skip this step. When I was finished construction I did make some tests for neutralization and it didn't seem necessary to include it.

Plate Chokes:

This was a problem as I really had nothing suitable on hand. I did have some nice Teflon chunks however. I calculated some 150 uH single layer chokes with suitable current capability and built a couple. They worked fine when fired up. Note there is a hole at the top to insert a small piece of ferrite to use for tuning, if required. I used a grid dip meter to insure the resonance was above the 20M band, and the choke would still have 150 uH of inductance in my desired operating bands.

Final Schematic

Here is a shot of the breadboard mess on the bench and then the final developed schematic.

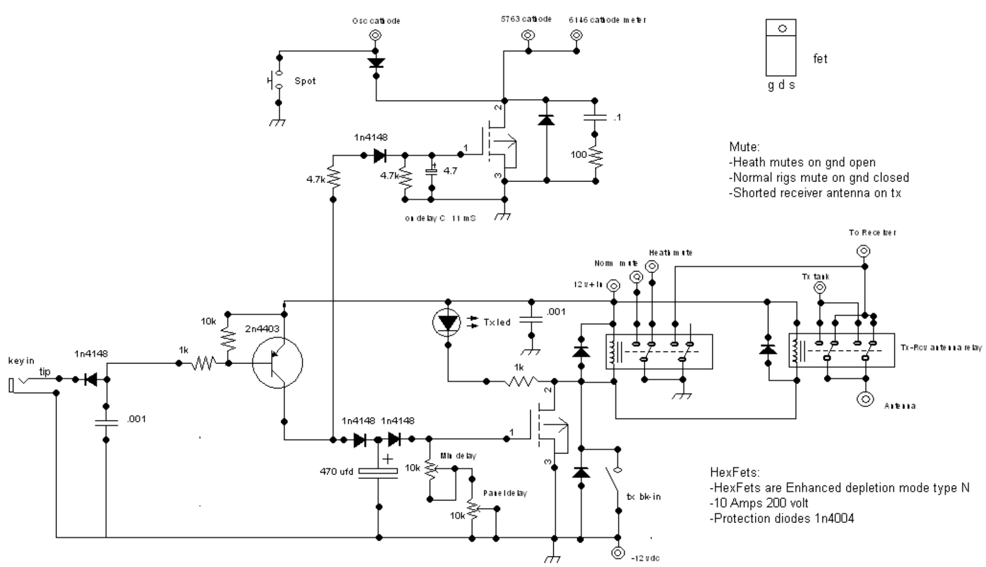


Keying and relay control

Here is another area where I deviated from classic design in favour of operating convenience. I wanted a spot control for the oscillator to allow easy receiver adjustment, and then used a power N channel hexfet to take the tube cathodes to ground. I also added a simple semi break in circuit to make it easy to operate on CW, with a manual transmit switch in case you wanted to defeat the semi break in feature. The steering diodes are used to ensure fast attack-slow decay and isolate the relay and cathode keying functions.

The same control board has two sealed relays to provide antenna switching, and receiver muting for Heath receivers or for more modern receivers if used with this transmitter.

Again, Eagle Cad produced a suitable one sided board layout for the transmitter control.



Metering

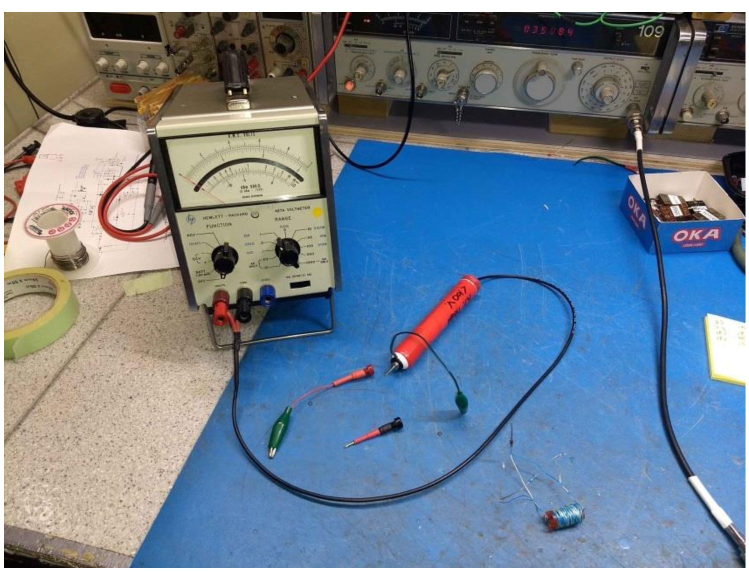
I found a suitable surplus 100 mA meter to use on the plate cathode line for the 6146. However, it turns out that I wanted to run slightly beyond it's range. A suitable .68 ohm resistor across the terminals gave me , essentially, a 130 mA meter.

I also had intentions of adding a simple tank pickup and a panel incandescent bulb to be used as a peak indicator. I built one with a single turn coil but it took away noticeable power from the tank and I decided to scrap the idea in favour of a future output indicator and pickup on the antenna output line. (I also gave myself two painful RF nips during the testing of this device..so I am now prejudiced even further against the idea !)

For the present, it is necessary to have an external meter on the output.

An RF voltmeter

My occasional needs for measuring RF voltages is taken care of with a classic DIY RF voltage probe and a dandy old HP427 high impedance voltmeter. This works very nicely for taking measurements in circuits like this. My oscillator output was in the range of 12 V peak and the driver at 30 to 40 V peak. I also used this meter across an accurate dummy load resistor to measure the eventual power output of the transmitter.



Crystals

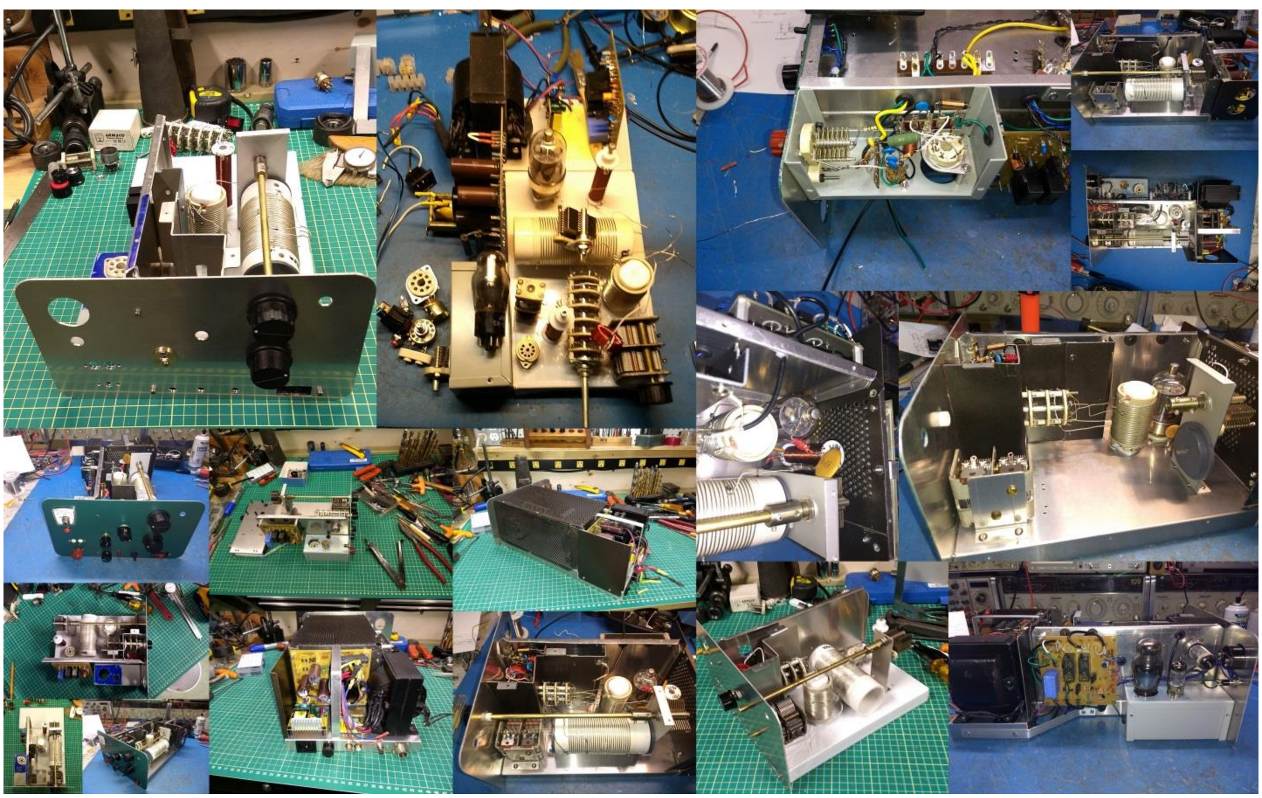
I have a limited supply of FT243 converted crystals but discovered this is easy to do yourself. I found a very nice assortment of HC49 crystals from John Clements, KC9ON at www.3rdPlanetSolar.com I received a great assortment of frequencies for the bands I wanted and even had enough to share with a friend who is also working on novice style tube transmitters. After looking at these little crystals, and at the somewhat expensive and large FT243 holders, I realized the lead spacing of the crystals was 0.200 " which is easily accessible via DIP IC socket pins. I cut a "machined" type socket apart and mounted it in one of the holders and it is easy to insert the crystals in this modified "Crystal socket". I have several of these now and set them up with my favoured frequencies. This scheme provides much better mileage of the FT243 holders and works very fine in practice.

The 6C4 oscillator with 105 volt plate supply has worked perfectly with every one of the HC49 crystals I have tried, any of my HC6 crystals and any FT243 crystals I happen to have.

Construction

Time to figure out what I wanted for packaging. It would be nice to have some sort of case on the desk that matched the SB310 classic Heath case style. A tall order but I did find a pair of SB604 speaker cabinet halves that came as a pair. Turns out they would allow plenty of room for my components and provide a suitable match for the SB310 receiver.

Here is a series of construction pictures that speak for themselves. I did make a panel layout mistake in advance of the case arrival. I assumed the corner radius would similar to the early SB line cases but Heath changed this at some point in favour of a smaller radius. I will have to make another panel but that is not hard to do. I used a small CNC mill I have in my shop to make the panel and it is a not difficult job to make another panel to fit the case perfectly. That will happen in the future.



And here is the final unit happily operating beside the SB310.
(No panel lettering yet, that will happen with the final panel)

How does it work ?

Turns out this thing is happy putting out 30 watts on all 4 bands. Nice. That is more than I hoped for and quite suitable for the “Tube” operating I want to do. I have worked stations on all bands so far all over NA and EU. If you hear VE1ZAC calling in the upper CW portions of the bands, please give me a call and let me know how the transmitter is working. The receiver and the keying control setup is very comfortable to work with. One feature missing is a side tone from the receiver. I use the monitor tone from my CMOS 3 keyer instead. I can live with that.

Spectral Purity

I decided to do a reasonably rigorous look at the spectral purity of the transmitter output. Rather than just doing an RF air “Sniff” with my HP3589A analyzer I made a direct antenna connection with a 100:1 divider (100K and 1 K ohms) and then a 10:1 probe to the analyzer’s 50 ohm input.

For the moment, these are “Relative” readings, but I can calculate the power in spurs or IMD if I do a little more math.

What are the needed levels ?   Here is a reprint of US standards, which should be nearly identical to Canadian requirements.

47 CFR Part 97 Section 97.307 reads as follows:

Part 97.307 Emission standards.

(a) No amateur station transmission shall occupy more bandwidth than necessary for the information rate and emission type being transmitted, in accordance with good amateur practice.

(b) Emissions resulting from modulation must be confined to the band or segment available to the control operator. Emissions outside the necessary bandwidth must not cause splatter or keyclick interference to operations on adjacent frequencies.

(c) All spurious emissions from a station transmitter must be reduced to the greatest extent practicable. If any spurious emission, including chassis or power line radiation, causes harmful interference to the reception of another radio station, the licensee of the interfering amateur station is required to take steps to eliminate the interference, in accordance with good engineering practice.

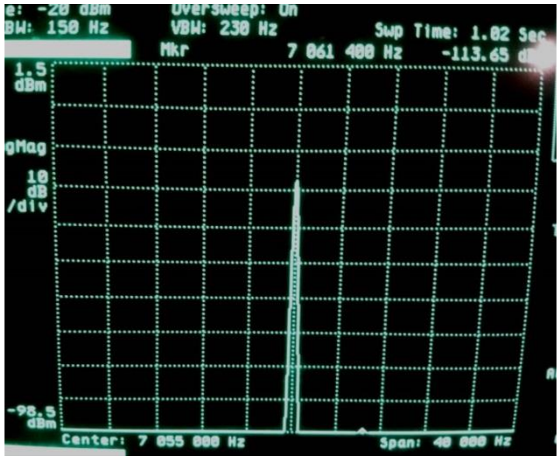
(d) For transmitters installed after January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency below 30 MHz must be at least 43 dB below the mean power of the fundamental emission. For transmitters installed on or before January 1, 2003, the mean power of any spurious emission from a station transmitter or external RF power amplifier transmitting on a frequency below 30 MHz must not exceed 50 mW and must be at least 40 dB below the mean power of the fundamental emission. For a transmitter of mean power less than 5 W installed on or before January 1, 2003, the attenuation must be at least 30 dB. A transmitter built before April 15, 1977, or first marketed before January 1, 1978, is exempt from this requirement.

My load for these tests is a precision 10 watt ceramic style 50 ohm air cooled resistor.

Note: IMD purity is a bit different than looking at harmonics, or spurs. I will do both.

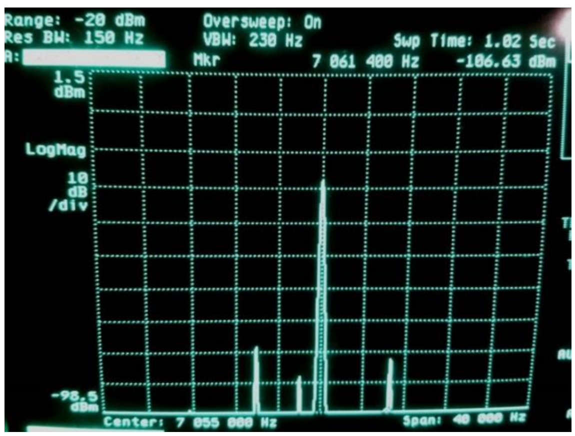
IMD:

Here is a “Brick on key” continuous look with a scan bandwidth of 40 kHz. All transmissions from here on are at 7.055 MHz Apologies for cell phone pictures of screen. (Couldn’t locate the direct hookup cable for the analyzer in a pinch.)



You can see there is no discernable IMD activity as there is essentially no modulation. The RBW is 150 Hz. Could go very low with RBW and get an essentially straight up and down line but takes a long time for a scan.

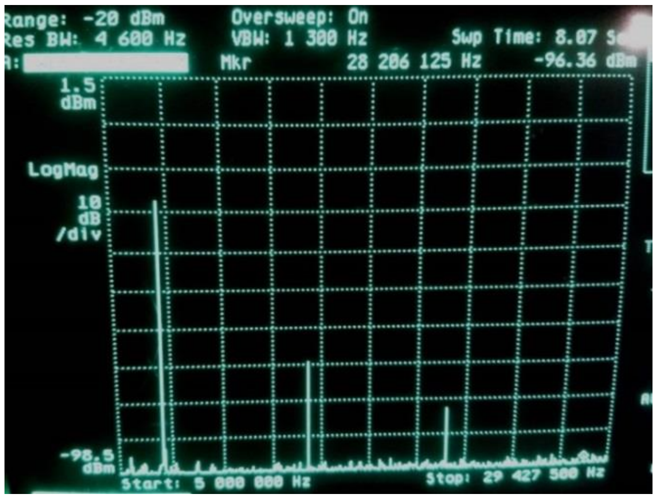
Here is same scan but with a bunch of manual dits going with a hand key as fast as I can. This is actually a decent test as the spacing is kind of random, representing a worst case modulation.



<u>Observations</u>: nothing less than 50 dB below primary emission. Horizontal axis is 4000 Hz per division…good example of how modulation smears the frequency spectrum, even for CW.
<u>IMD Conclusion</u>: this TX is very good for IMD products. IE, not a problem.

Harmonics

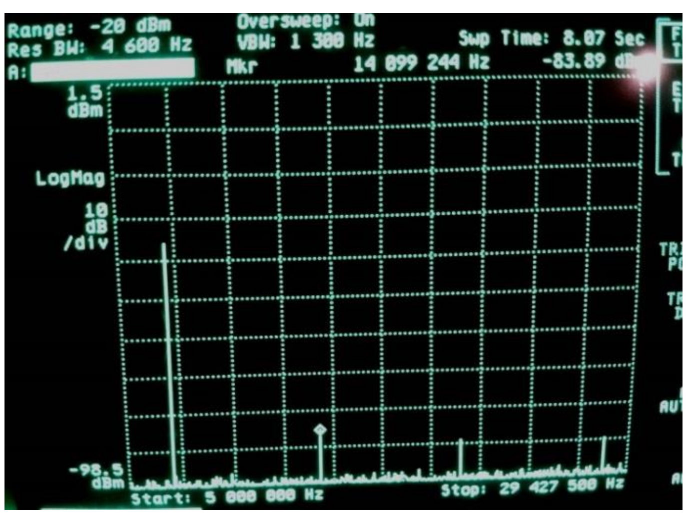
Here is a look at the harmonic scan up to 30 MHz for a 30 watt output from the PI-L tank.



The actual readings (At the analyzer input) are:

Primary 7.055 MHz is -25 dBm
1st harmonic @ 14.099 MHz is -67.8 dBm, or 42.8 dB down
2nd harmonic @ 21.22 MHz is -81.31 dBm, or 56.3 dB down

Here is another look with a 3 Watt output:



The readings are:

Primary 7.055 MHz is -34.69 dBm
1^{st} harmonic @ 14.099 MHz is -83.89 dBm, or 49.2 dB down
2^{nd} harmonic @ 21.22 MHz is -87.45 dBm, or 52.76 dB down
3^{rd} harmonic @28.2 MHz is -88.15 dBm, or 53.46 dB down

<u>Harmonic Conclusions</u>: Nothing to worry about with harmonic suppression either.

Interesting to see more harmonics at lower power. This is likely because I didn't actually tune the PI-L tank at the lower power, just unloaded the output cap to bring the output power meter down. If I had gone through the proper process, I am sure the 3^{rd} harmonic would disappear.

This is a fun to use setup and perfect for recreating a modern version of the "Novice" experience for the 60's. (I will do an update with the new front panel)

This is also why amateurs are so possessive of their "Junk boxes". Good things can come from collecting old parts.