The Vintage SSB Special Radio Set – Part 1

By Mike Bohn, KG7TR
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Note: This is an update that consolidates the articles that originally appeared in Electric Radio (ER) magazine in the summer of 2010. Pictures and schematics appear at the end of this document. - MB

Introduction

This is a two-part article describing construction of a homebrew receiver and transmitter for 20 meter SSB operation. The radios are built on scrapped Command transmitter chassis, and can be connected together for transceive operation. The project started out with the transmitter which is covered here in Part 1. Successful results with the transmitter inspired a matching receiver that is covered in Part 2. The units are shown together in Figure 1.

Part 1 – The Transmitter

Background

Every few years I get an urge to homebrew something. I like the satisfaction of creating something from scratch and I always learn a lot from every project. The urge is usually sparked by just the right combination of parts already in the junk box or just acquired from a hamfest, coupled with a vision of what they could be crafted into if I only had one more of these or a few more of those. Want lists are made, treasure collections at hamfests are rifled through, deals are closed, and eventually there's enough stuff gathered to get serious.

Almost 40 years have passed since I homebrewed the four band SSB transmitter that was described in the September '92 issue of ER. I still have it and use it occasionally to check into the Vintage SSB net that meets on Sundays on 14.293 MHz. Reckoning that it's been a long enough dry spell I recently I got another one of those urges, this time to homebrew another SSB transmitter. To keep the design and construction manageable I decided it would be tailored for use on the Vintage SSB net. The only requirement would be coverage of the 20 meter phone band. It would be designed to use a common transceiver power supply. This would make way more sense than trying to find suitable parts to build my own power supply and fit them into the radio. Although building any sideband transmitter can be a challenge, I figured with these simplified requirements I could finish such a project within a reasonable period without losing interest.

I also decided that the new rig would use a phasing type sideband generator. I had done some experimenting with solid-state audio filters and high performance phase shift networks in a basket case Eldico T-102 that I modified into a phasing rig. Results were very good, so I wanted my new Vintage SSB rig to employ these techniques as well. The overall architecture would be along the lines of the tried and true 9 MHz sideband generator mixed with a 5 MHz VFO to get to 20 meters. A pair of 6146s would provide the customary 100 watts output. The whole radio would be a single band HT-37 of sorts, and would be built on a standard rack panel and chassis foundation. However, when I started pricing a new rack panel, chassis and bottom cover it became apparent that this stuff alone was going to cost more than all the other components combined.

I was just about ready to bite the bullet and spring for the high-priced sheet metal when I ran across a couple of scrapped Command transmitters at a hamfest. It instantly hit me that it might be fun to build my new transmitter on one of these old chassis and use the original WW II 1625s instead of the usual 6146 pair. After all, one homebrew rig that had always intrigued me was the "Cheap and Easy S.S.B." unit built by Tony Vitale (W2EWL at that time) in the mid-1950s. This rig was one of the simpler homebrew SSB projects around at the time and was built on a Command transmitter chassis. On the table in front of me at the hamfest was a lot of what I'd need to do a modern re-spin of the venerable "Cheap and Easy S.S.B.". The price of the old parts units was dirt cheap, and there was enough stuff between the two sets to do it. The rest of this article will touch on the six month journey to turn this vision into the finished product shown in Figure 2. This radio is now a regular on the Vintage SSB net and it always returns great signal and audio reports. The transmitter turned out so well that I subsequently decided to build a matching receiver that could transceive with it. But more on that in Part 2 of this article.

By way of history, the original "Cheap and Easy S.S.B." construction article appeared in the March, 1956 QST. It was reprinted in an early edition of ARRL's "Single Sideband for the Radio Amateur" which is where I first came across it in the 1960s. The first page of the "Cheap and Easy S.S.B." article is shown in Figure 3. In the article Tony states that most of the circuit is similar to the benchmark "SSB Junior" rig that appeared in the November-December 1950 issue of the GE Ham News. Certainly many of the circuit elements in the "SSB Junior" were used by scores of homebrewers as well as commercial rigs that include the Central Electronics 10 and 20 series and the Gonset GSB-100. I'm not sure who was the first to come up with the idea of a 9 MHz SSB signal heterodyned with a 5 MHz VFO to produce 80 or 20 meters output – maybe it was Central Electronics. At any rate it became a standard, and is one of the main reasons we use LSB on 80 and USB on 20 as the convention. It's anybody's guess as to how many hams built one of the "Cheap and Easy S.S.B." rigs, but I'd bet it was dozens. I read somewhere on the internet that Tony Vitale became a SK in the 80s or 90s. His call has been reassigned.

Overall Circuit Description

The schematic of the transmitter is shown in Figure 4, and the top, bottom and front panel views are shown in Figures 5, 6 and 7 respectively. The parts list appears at the end of this article. A total of nine tubes are used. The transmitter is designed to use the popular Heath HP-23 series of power supplies, all of which supply the requisite 12.6 VAC filament voltage for the 1625s. Mine is an HP-23B model that has the low/high B+ switch.

At first the HP-23B power switch was used to turn the radio on and off, since no remote power switch was originally installed in the transmitter chassis. Later I installed a SPST switch (S8 on the schematic) to remotely turn on the power supply from the transmitter. This switch is located above the meter and to the left of the power indicator light, and is not shown in any pictures.

Using the “LV” B+ setting, the transmitter will put out about 40 watts PEP of pretty clean SSB. This is enough to drive my Heath SB-201 to about 400 watts without the ALC kicking in. The unit covers 14.150 to 14.350 MHz with no retuning.

The BNC jacks and toggle switches on the sides of the transmitter chassis were added after initial construction to provide switchable connections to the oscillators in the receiver, which control the output frequency in the transceiver mode.

Looking at the schematic, the microphone signal from J1 is fed through a low pass filter to keep stray RF out of speech amplifier V1A. Further voltage amplification is provided by V1B. R1 controls the amount of audio applied to the grid of cathode follower V2A. The low impedance output of this stage is fed to the input of the solid-state audio module, which provides a steep-sided audio bandpass filter followed by a high performance phase shift network. The audio module generates two signals that are shifted in phase by plus and minus 45 degrees from the V2A input signal. Details of this module will be described later. S4 reverses the phase of one of the audio signals to allow selection of USB or LSB output. This is more of a convenience for alignment than an operational necessity for 20 meters.

When S5 is in the NORM position the transmitter is controlling the frequency and V2B generates the 9.0 MHz carrier for the sideband generation circuit. Output from the plate tank circuit is taken from a link on L1 and fed into the RF phase shift network. When S5 is in the TRCV position the 9.0 MHz carrier is obtained from the receiver BFO. The phase shift network consists of R2, R3 and the two 100 pf capacitors, and generates two 9.0 MHz signals shifted in phase by plus and minus 45 degrees from the input signal. The phase shifted audio and 9.0 MHz carrier signals are added together at the wipers of carrier balance pots R4 and R5. RFC2, RFC3 and the four .001 µf capacitors in the circuit keep the audio and RF signals separated so they don’t go to the wrong places and get shunted. The combined audio and 9.0 MHz signals are applied through resistor networks to the two balanced modulators consisting of D1 through D4, which are common silicon signal diodes. The two DSB signals from the modulators are summed in the output tank circuit, where cancelation of the unwanted sideband and carrier occurs. Tank coil L2 is bifilar wound on a powdered iron toroid form and broadly tuned to 9.0 MHz by the 470 pf capacitors. RFC4 provides a return path for the audio signals to allow the diodes to switch but isolates the 9.0 MHz signals from ground. The diode balanced modulator circuit will provide about 50 dB of carrier suppression with very careful adjustment of the balance pots.

All of the various DSB and carrier components combine in L2 to create a 9.0 MHz SSB signal. This is link coupled to the tank circuit at L3 for filtering and then applied to the grid of 9.0 MHz IF amplifier V4. The signal at the plate of V4 works into another tank circuit at L4 for further filtering and is then applied through a link to the grid of V6. This tube functions as a simple but effective twin-triode mixer. The 5 MHz VFO injection signal is applied to the grid of the other section of V6. S6 allows selection of this signal from either the internal V3 VFO in the NORM position or the receiver VFO in the TRCV position. Mixing of the SSB and VFO signals takes place in the common cathode circuit of V6 and the mixer outputs appearing at the plate are applied to the L5 tank circuit, which is tuned to the desired 20 meter output frequency.

The 14 MHz SSB signal on L5 is capacitor coupled to the grid of driver tube V7. This stage amplifies the low level SSB signal at its grid, which is less than about five volts peak-to-peak, to the level required to drive the finals. This voltage appears across the driver output tank circuit at L6 and is capacitor coupled into the grid circuit of the finals. The signal level here is about 60 volts peak-to-peak at the threshold of grid current on the 1625s.

The PA circuit is conventional and uses parallel connected 1625s operating in class AB_1. A pi-network is used to couple the RF output at the plates of the tubes to the load. The circuit is neutralized by adding a little inverse feedback through C6 into the bottom of L6. In the "LV" B+ position and under load, the Heath HP-23B puts about 250 volts on the screens and 775 volts on the plates. With these voltages best linearity was obtained with the PA bias set to produce 40 ma of idle current, which occurred with about -27 volts bias on the grids. Under these operating conditions the 1625s produce about 40 watts PEP at the threshold of grid current, with third-order IMD products over 35 dB down from a two tone test signal. This is a respectable SSB signal from tubes that are over 65 years old! Pushed to their ratings a pair of 1625s is supposed to put out 72 watts PEP in AB_1 service with 300 volts on the screens and 750 volts on the plates.

The VFO is briefly described here since more detail is provided later. V3A is a stable Colpitts oscillator that uses tank circuit components from the 7.0-9.1 MHz Command transmitter. Its output is fed into the grid of cathode follower V3B. The follower provides isolation of the oscillator from the load, and also provides a low impedance source to drive the several inches of shielded wire required to get the signal to the grid of V6. A trap is placed at the output of the follower to attenuate spurious emission of the third harmonic of the VFO that showed up on the spectrum analyzer.

Voltage regulation for the VFO and carrier oscillator is provided by V5 when S7 is in the NORM position. In the TRCV position plate voltage for both oscillators is removed to prevent interference in the receiver. Even though the carrier oscillator is crystal controlled, regulating its plate supply keeps both its amplitude and frequency stable. This in turn helps prevent drift in the carrier balance settings.

The bias and control circuits are pretty straightforward. 12 volt DC relays (K1 and K2) and a rectifier/filter for their coils are used to switch circuits to the transmit mode when the PTT line is grounded. In standby mode, grid block bias of -65 volts is applied to V6 grids and -82 volts to V8 and V9 grids to cut them off. In transmit these voltages drop to zero and -27 volts respectively. 250 volts B+ is also removed from the screens of V4, V8 and V9 in standby.

The extra contacts on K1 are used for switching a linear amplifier and receiver mute. Relay K2 is used to switch the antenna (or linear amplifier) between the receiver and the transmitter, and eliminates the need for an external relay.

To spot the transmitter's frequency or check carrier balance, S1 is used to ground the grid block bias voltage through R6 and a 3.3k resistor, and also apply B+ to the screens of V4, V8 and V9. R6 allows the signal level to be adjusted to suit the receiver's gain. Switch S3 is used to energize K1 and K2 for tune up.

Automatic Level Control (ALC) is implemented, and works like a Heath SB series transmitter. Grid current appearing at PA tubes V8 and V9 on voice peaks is rectified by D7 and D8, and applied to IF amplifier V4 to reduce its gain. The ALC voltage reduces the cathode voltage on V4, which unbalances the bridge circuit from V7's cathode and causes the meter to deflect. ALC from a linear can also be applied through J3. The transmitter meter switch now has an ALC position in place of the previous GRID position. This was a later change which is not shown in some of the pictures.

The metering circuits are also simple. In the plate position of S2 the cathode current is sampled across a 5 ohm resistor and scaled by the 910 ohm resistor in series with the meter to give a full scale reading of 200 ma. In the ALC position the meter reads the voltage across V4's cathode as described earlier.

The only thing unusual about the filament circuits is the use of a #47 pilot lamp across the parallel connected filament of V1. V1's 300 ma filament is in series with V3's 450 ma filament, so the lamp adds another 150 ma to equalize the voltage across each tube. That's it for the general description. Construction details will follow after a few words about those great old PA tubes.

The Once-Ubiquitous 1625

Since the centerpiece of the transmitter is its pair of 1625s, I thought a little history of these tubes would be appropriate. But about all I knew about the 1625 was that it appeared somewhere around the beginning of WW II and that it shared the same internal construction as the 807 and 6L6G. At the suggestion of ER editor Ray, NØDMS, I corresponded with Lud Sibley, KB2EVN, about some background. Lud is an old tube buff and cheerfully volunteered the following information for this article:

"RCA introduced the 807, with suitable fanfare, in late 1936. The 1625, and its Command Set companions the 1626 and 1629, appeared on a much stealthier basis. I don't have access to RCA records on the 1625, but the 1626, in development as of mid-1938, was rated "Confidential" in accordance with the company's general practice on tubes for military use. The classification was off by March 1941, when the sheet on the 1625 was issued for the HB-3 data manual and RCA was ready to make this type. We have to assume that the Aircraft Radio Corporation, then designing the first Command Sets, collaborated with RCA as to the features of the new tube.

A production figure of "millions" is no stretch. Gordon Elliott White's article "The Command Set Story" ("CQ," Nov. 1964) quotes "at least 1,450,000" transmitters and receivers being produced. Using a ratio of two transmitters to three receivers, adding a 1625-based modulator for each two transmitters, and allowing for a mass of spare tubes gives a huge number. This is in addition to use of the 1625 in the Navy ATB, TCS, and AN/ARC-2 (at four tubes per set in the latter two cases), plus a couple of less common sets and the AN/ART-13.

This was really an "Arsenal of Democracy" tube, made by Ken-Rad, Hytron, National Union, Raytheon, and Tung-Sol in addition to RCA. It was to our military electronics what the similar-sized Telefunken RL12P35 was to the German effort. It was on the Army-Navy "preferred" lists for 1943 and 1944. By contrast, I'm hard pressed to cite any (non-amateur) civilian use of the tube.

Incidentally, I think that the seven-pin base, which was not needed electrically, was a way to get greater resistance to sidewise mechanical shock than the 807's five-pin base."

In the course of this project I collected up more than a dozen 1625s from various sources, including some New Old Stock (NOS) tubes still in their original boxes. The most prevalent brand among them is RCA, but I also have a couple from Sylvania and one from National Union, which is shown in Figure 8. The military contract or acceptance dates on all the boxes are 1942 or 1943. Most of the tube bases are dark brown, but a couple of them are light brown. I agree with Lud that the seven pin base was probably implemented to keep the tubes firmly in their sockets in the rugged military environment.

It's been said that brand new surplus 1625s were going for as little as 25 cents apiece after the war, more evidence that a lot of them were produced. I remember buying a couple of them in 1961 at the newly opened Gateway Electronics store in St. Louis (they are still in business). The price was indeed twenty five cents each. One of them found its way into my homebrew Novice transmitter which used a 6AG7 for the crystal oscillator and a 1625 for the power amplifier.

That Novice transmitter was probably the last time I gave much thought to a 1625 until this project came along. Now that the Vintage SSB Special is finally on the air, I have to admit that I had a lot of fun working with these old tubes. They are like time travelers from a different era when factories hummed day and night and selfless people stepped up and did the things that needed to get done. It's a thrill to light up a pair of these old guys that have been sitting around for over six decades and watch those heaters give off a soft orange glow. On some of the tubes there's pretty little blue spots that show up on the inside of the envelope as a few high speed electrons sneak past the plate and smash into the glass - nothing unhealthy there, just a "feature". Talk about real radios glowing in the dark! At long last the Vintage SSB Special was finished and the old soldiers came to life, pushing some RF out of the antenna and allowing me to communicate with other hams who appreciate those days gone by…

Alas, but the old 1625s weren't completely trouble free. Most of the tubes I collected tested good on my Eico tube tester and worked fine in the rig. A few had good emission but showed a couple of hundred kilohms of heater to cathode leakage, which I didn't think would make a whole lot of difference. And that's where I think the problems occurred. The original PA circuit had both cathodes tied together and a 10 ohm, 0.5 watt resistor from each cathode to ground. Ohms law said that should be a high enough power rating for the 75 ma or so of maximum sustained cathode current that was expected in each tube. However, in the course of testing these resistors burned open for no apparent reason. I replaced them with wirewound 2 watt units and the same thing happened again.

It occurred to me that I might be getting intermittent heater to cathode shorts on some of the tubes I tried. No other voltages in the PA circuit could source enough current for a long enough period to cause that type of failure mode. Of course the tubes most suspect would be the ones that showed H-K leakage on the tube tester, but I was never able to get any of these to actually go all the way to a short while being tested. Just to be safe those that exhibited any H-K leakage at all were quarantined. As a final preventive measure, a chassis mounted 5 ohm, 5 watt resistor was installed in the cathode circuit in series with a one amp fuse. The fuse protects the cathode resistor and is arranged so that if it blows no current will flow through the 910 ohm resistor in the meter circuit when it's in the plate position. The tubes that are in the rig now have been working fine so I intend to leave them alone. I suppose this could have been a common problem with these tubes, but was probably not so noticeable with a grounded cathode. If an intermittent short did occur, it may have just burned itself open with no ill effects.

Construction Details

Prior to construction each of the scrapped transmitters was completely stripped of all remaining parts except for the 1625 sockets. The chassis, covers and VFO parts to be reused were sprayed with 409© All Purpose Cleaner and then thoroughly brushed, rinsed and allowed to dry in the hot Arizona sun. One of the chassis was selected for the transmitter project. The other was initially set aside as a spare but ended up as the receiver. To accommodate the 9 pin miniature tubes at the rear a piece of .125 aluminum sheet was cut to size and installed over the octal socket holes, and then smaller holes drilled and filed out for the new tube sockets.

Various layouts for the tubes and circuits were considered, but in the end it was decided that keeping the output of V7 close to the grids of the PA tubes would be the overriding concern. If V7 was mounted at the rear the high level RF grid drive would have to get around the VFO capacitor somehow, and this sounded like trouble. So V7 was located just in front of the PA tubes. This meant that the rest of the RF circuits would also need to be in the front of the chassis. Looking at the top of the chassis in Figure 5, the audio module is right behind the front panel in the minibox and V4 is next to it. In the next row of tubes V6 is in the center flanked by V5 (with no shield) and V7. Behind these are the two 1625s in their original sockets and the VFO shield. Behind the shield is V1 in the center with V2 and V3 on the sides.

The narrow and deep form factor of the chassis dictated the need for several shielded wires running up each side to get signals from one end to the other and around the buckets for the PA tubes. C9 and C10 were not installed until all wiring in the rear of the chassis was completed and the circuits checked out. During construction C9 was set into place periodically to make sure adequate clearance was being maintained. For initial VFO testing and rough frequency adjustment a 150 pf mica capacitor was connected across L8. When everything was finished and working correctly C9 and C10 were finally installed and connected up. The temperature compensating capacitor was installed at the top of C10 during final testing.

To drive the VFO capacitor I initially tried the original flex shaft coupled to a metal shaft extension, just like the original "Cheap and Easy S.S.B.". The result was a somewhat sloppy drive mechanism that caused very slight carrier imbalances and signal noise when the knob was moved or touched due to intermittent grounding of the shaft extension at the front panel. To solve the problem I used a 0.25 inch diameter fiber rod riding in a front panel bushing running the full length back to C9, as shown in Figure 6. I figured that if the balanced modulator was that sensitive there was no point in fooling around with any kind of moving metal in its vicinity. Suitable reducers and couplers had to be fashioned to use the fiber rod, but now the tuning is very solid, smooth and electrically quiet.

Input power comes in at J5 mounted on the rear of the chassis. The bypass capacitors are arranged around the socket and grounded to busbars. The T/R relay is super-glued to the side of the chassis behind the VFO tuning capacitor. Two miniature terminal strips are used for high density wiring in the microphone filter and T/R relay circuits, and are mounted on the side of the chassis. Standoffs are used for all the other circuit junctions. Ceramic trimmers are used to resonate the various RF circuits, and are mounted using aluminum spacers, #4 hardware and fiber insulating washers on both sides of the ceramic body. C2, C3 and C4 are mounted on the chassis bottom, and C1, C5 and C11 are mounted on the sides. There are a total of six toroid coils used in the low level circuits that will be described later.

I always use Teflon insulated hookup wire and shielded wire to the maximum extent possible. In any project like this there is going to be a lot of experimentation and rework, and Teflon wire stands up to soldering heat like no other. It is expensive to buy new, so for years I have been scooping up whatever scraps I can find at hamfests, including a recent score of a roll of 22 gauge white wire. A high quality, sharp pair of wire strippers or a hobby knife is needed to remove the insulation, but other than that I find it to be trouble free. After the insulation is removed, I lightly tin the fine strands to keep them from unraveling before making the actual connection. For shielded wire it can't be beat – there's no worry about melting through the inner conductor's insulation. And if I need a piece of "spaghetti" to insulate a solid bare wire I just use insulation stripped off of a Teflon wire.

Topside the only thing worth mentioning is L7, the final tank coil. Standoffs are mounted on the two stator terminals of C7, and L7 is soldered to these.

The original top cover from the rig was pretty mangled, so it was straightened out as much as possible. Most of the top surface was then cut out and a piece of expanded metal was mounted using a strip of 0.125 x 0.5 bar stock down each side. This keeps fingers away from the high voltage, holds stray RF inside and allows good air circulation to keep the rig cool. The bottom cover was reused without modification. A new front panel was cut to size and fastened around its perimeter with short #4 sheet metal screws. After all front panel holes were drilled the panel was removed, painted flat black and dry transfer lettering applied. A final light coat of matte clear coat was applied to protect the labels and then the panel was reinstalled. The rest of the external metal was lightly sanded, primed and then sprayed with aluminum paint.

About Those Toroids

A lot of homebrew and commercial rigs of the 50s and 60s used slug tuned solenoid wound coils, and the original "Cheap and Easy S.S.B." was no exception. While I have several slug tuned coils and blank forms in my junk box, it seems that no two are alike. I wasn't really up to the task of winding and pruning a solenoid wound coil for each individual circuit using a bunch of different slug tuned forms with unknown characteristics. As the saying goes, "Been there, done that". A little bit of research on the Amidon website (www.amidoncorp.com) convinced me that toroids would be the way to go for all of the low level circuits. Toroid cores are inexpensive, the coils are easy to wind because the wire doesn't unspool everywhere when you let go, and you get predictable inductances from the equations on the website. You just have to keep in mind that when winding a toroid, a turn is counted every time the wire passes through the center of the core. Another distinct advantage is that toroids are mostly self-shielding, which is important given the close quarters in this rig.   Using the information on the Amidon site, I determined that the popular T50-2 powdered iron cores were just the ticket for the frequencies involved and the real estate available. Amidon also sells quarter pound spools of magnet wire for reasonable prices, the kind you can just burn the enamel off of with a hot soldering iron and get a good tin.

The disadvantages of toroids are that you need a variable capacitor to resonate them in a filter circuit, and they are somewhat awkward to mount. For the various tank circuits I used small rectangular pieces of perforated ("perf") board to mount the coils. Each board was mounted to the chassis on a 0.5 inch aluminum spacer, and a small standoff was used on each corner of the perf board to make connections to the coil. Other small components in the circuit were also mounted on the boards and connected to the standoffs where convenient to simplify construction. Toroids were glued to the perf boards with a couple of drops of epoxy, which also served to secure the windings to the core. Each tank circuit was resonated using a ceramic trimmer mounted next to its associated coil, and a fixed capacitor connected in parallel with the trimmer. With the exception of C5, the rotors of all trimmers are connected to ground. This allows them to be adjusted with a metal tipped alignment tool or even a small screwdriver without the setting changing when the tool is removed. For C5 the rotor had to be connected to the low side of the circuit to avoid adverse effects on the neutralization circuit. It can still be adjusted with a metal tool, but caution must be exercised as it has B+ voltage on the rotor. When it came time to tune each circuit, a test mica capacitor was tacked across the appropriate standoffs and the trimmer spun around to search for resonance. When a capacitor was found that produced the desired double peak in a single rotation, it was soldered in permanently. A frequency counter was loosely coupled to the circuit to make sure the correct frequency was being tuned.

The balanced modulator components including the L2 toroid were mounted on a larger piece of perf board as shown in Figure 9. A 15 pin "D" connector was mounted on the bottom of this board. This plugs into a mating connector mounted on standoffs on the bottom of the chassis that is wired to the carrier balance pots, RF, IF and audio signals. This arrangement allowed easy removal for modifications. Like the other boards the toroid was secured with epoxy. A small grounded brass shield was placed over J9 and S5 near the rear of the balanced modulator to keep the signals away from V7.

The Amidon data predicts Qs on the order of 200 for the toroids used in this radio, which was confirmed on my ancient Heath Q Meter. These Qs are higher than what you can normally achieve for solenoid wound coils of comparable inductance and size. A lesson learned the hard way is that high quality, NPO type trimmers should be used for all of the tuned circuits. I had initially used some very small, inexpensive N1500 ceramic trimmers that were purchased new for this project. They were compact enough to mount directly on the perf boards, but proved to be totally unacceptable due to thermal drift and difficulty of adjustment. It took some doing, but I was able to retrofit larger Erie trimmers scavenged from a piece of junk test equipment into the spaces available near each toroid perf board.

The VFO

The VFO components used in Command transmitters were the hardware of choice for virtually all of the homebrew sideband rigs of the 50s and 60s, and with good reason. The new SSB technology demanded stable frequency control and the capability to make very small changes in frequency with minimal backlash. Even though they were designed prior to WW II, the Command transmitter VFOs were ideal for the purpose. The VFO coils were large and wound on stable and sturdy threaded ceramic forms. All four of the variable capacitors were made of Invar (at least all of them I've ever seen), which is a nickel-iron alloy specially formulated for low thermal expansion. The two main tuning capacitors also used anti-backlash worm gear drives with a reduction ratio that provided a comfortably slow tuning rate. With very little extra work you could get a first class VFO for a sideband rig.

All Command transmitters used the same four variable capacitors; only the VFO, PA and loading coils differ between the various units in the series. A lot of the old homebrew rigs, including my first SSB transmitter, used the front worm drive capacitor for the VFO because it also had a nice dial drive mechanism with lots of bandspread. The original dial was easy to repaint and label, and made for a nice looking front panel. However, it wasn't until I built this rig that I realized the rear capacitor is actually much better suited for a SSB rig. This capacitor has a threaded adjustment on the rear of the worm drive and a thrust ball bearing on its front. The threaded portion is factory adjusted to put a slight preload on the thrust bearing, with the result that there is zero play fore and aft on the worm. I would have to say that it is one the finest VFO tuning capacitors ever made, and like the "Cheap and Easy S.S.B." it's the one I used in this radio. And not having a dial is no big deal. A calibrated frequency readout is impractical on this radio given the lack of physical space, and is not even necessary if the frequency is just going to be spotted to the receiver anyway. After cleaning the variable up and applying Lubriplate© to all the bearings it is silky smooth with absolutely no backlash detectable during zero beating. By comparison, the front capacitor uses a spacer shim that can exhibit a very slight amount of play. This translates into a small amount of backlash when tuning the VFO, which has plagued my other homebrew transmitter since day one.

For this rig the VFO coil from the 7.0-9.1 MHz transmitter works well because the Colpitts circuit adds a lot of tank capacitance and brings the resonance right down to the desired 5 MHz range. To minimize external influences on VFO stability all of the ancillary windings on the coil were removed, as well as the tuning slug in the shield assembly. The high end tap on the coil was set using a heavy tinned wire that was adjusted to provide the required frequency coverage. A close up of the VFO coil is shown in Figure 10. The two 910 pf mica capacitors in the tank circuit are mounted on the coil as shown. The output of oscillator V3A is taken from the plate and loosely coupled to cathode follower V3B, which buffers the oscillator from the load.

The VFO was temperature compensated over several warm ups from a room ambient start using a frequency counter. If you've never done this you don't know what you're missing - talk about a science project! This effort does reach a point of diminishing returns when you realize that even if the compensation is perfect for a particular frequency, if you QSY in either direction the oscillator will now be over or under compensated because the total tank capacitance has changed. And as a practical matter, the range of values and availability of new temperature compensating capacitors these days is extremely limited. I had to settle for whatever combinations could be made from the junk box inventory, and ended up with a 14 and 30 pf in parallel, both N750. My best guess is that the optimum value of N750 capacitor for this rig is somewhere in the 47 to

68 pf range. As currently compensated, after a 15 minute warm up the VFO drifts less than 100 Hz per hour. I can live with that.

The Audio Module

I will confess right up front that the audio module is not hollow-state. It uses solid-state op amps, linear regulators and associated circuitry that were available in the 70s, and allows this phasing rig to generate a SSB signal that competes with filter rigs. Phasing rigs from the 50s and 60s had little or no audio filtering for high frequencies, which resulted in a pretty broad RF signal by today's standards. Their phase shift networks typically provided about 25-30 dB of unwanted sideband suppression over an audio range of 300 to 3,000 Hz, and perhaps 35 dB at a couple of discrete frequencies. I wanted my rig to produce a respectable SSB signal in accordance with modern standards, and I knew that would take some solid-state analog electronics.

The audio bandwidth was addressed by using eight pole Butterworth high and low pass filters that provide an audio passband 2.5 KHz wide at -3 dB and 6.5 KHz wide at -60 dB. These bandwidth characteristics are similar to a Collins F455FD-25 mechanical filter. And the solid-state audio filter is actually superior to crystal or mechanical filters in that there is no amplitude ripple within the passband. The filters were designed using Texas Instruments FilterPro$_{TM}$ software available free from their website. The measured performance was exactly as predicted by the design tool. Following the filters is a sixth order phase shift network that produces 45 to 60 dB of unwanted sideband suppression over the audio passband. This network circuit was in the ARRL Handbook for years and may still be for all I know. It is advertised as providing 60 dB of unwanted sideband suppression. In my rig the suppression varied a little bit from this over the audio pass band, based on observations on the spectrum analyzer, and is probably due to stray circuit influences resulting from a practical installation and limitations of the RF phase shift network.

The schematic of the audio module is shown in Figure 11. The parts list is provided at the end of this article. The unit was built using four perf boards as shown in Figure 12. Most components were installed vertically to save space, and then epoxy was dripped onto them to keep them from getting bent back and forth during handling. The boards were then stacked vertically and wired together for installation into a 3.25 x 2.13 x 1.63 inch minibox, as shown in Figure 13. The completed module is a tight fit, and in retrospect use of smaller audio transformers would have helped. The audio circuitry uses one percent resistors throughout. These resistors are only pennies apiece from Mouser Electronics, which is about the same price as quarter watt carbon resistors were 50 years ago! The rest of the electronic parts are also very inexpensive.

The U5 audio stage that follows the phase shift network is right from the Handbook schematic. I added another stage at U6 that incorporates a gain adjust pot in one channel to allow vernier adjustment for best sideband suppression. This ended up being set just about in the middle anyway, so I'm not sure this extra feature was even needed.

The power supply works off the 12.6 VAC filament voltage. The two half wave rectifiers, filters and linear regulators provide plus and minus 12 VDC for the op amps. The audio module will also operate off of a 6.3 VAC supply for use in other applications by using 5 volt regulators. The maximum peak to peak audio output will be reduced by a little more than half, but there should still be plenty for most balanced modulators. With a 6.3 VAC input, U7 and U8 would become part numbers MC78L05 and MC79L05 respectively. The electrolytics could be reduced to 16 volts units at the same time.

Final Alignment and Testing

A lot of time was spent getting each circuit to work right, but afterwards the final alignment was straightforward. As always, extreme caution must be exercised when working with live plate voltage on the PAs. For initial alignment and testing of the low level circuits, the +800 volts is disconnected and the PA tubes removed. If the PA tubes are installed for any reason with the plate voltage is disconnected, the screen voltage must also be removed or you can quickly ruin a set of tubes.

I would consider the following test equipment essential for alignment: 1) Oscilloscope with at least 50 MHz bandwidth, 2) RF voltmeter, 3) Low distortion two tone audio oscillator, 4) Selective general coverage receiver, and 5) 50 ohm dummy load, at least 50 watts. A spectrum analyzer, frequency counter and low distortion audio oscillator are also nice-to-haves for performance measurements, and a dual-trace scope will allow observation of the phase shifted signals. I use an Elecraft model 2T-gen for my two tone oscillator. This is a nifty little unit sold in kit form that runs off a nine volt battery. Each tone can be turned off independently. It produces clean audio signals that are indispensable for working with linear amplifier circuits. Its output is at microphone levels and was injected directly into J7 for testing and alignment.

To align the low level circuits, first remove V6 to prevent interaction with the VFO signal until it has been set up properly. Also remove the balanced modulator module and set R2 and R3 to about 175 ohms, which is the approximate reactance of a 100 pf capacitor at 9.0 MHz. Mark these positions for reference, as the final adjustments should be close to this value, then reinstall the module. Place all transceive switches in the NORM position, apply power and allow the rig to warmup. Then adjust C1 by monitoring the signal at the L1 link using an RF voltmeter or scope. As the trimmer is adjusted the output should suddenly jump to a peak and then drop off. You should be able to get two such peaks in a single rotation. To assure reliable operation, the trimmer should be adjusted so that the output is just below the peak on the side that continues to oscillate. After this it should be possible to detect some RF at the link of L3 that changes with adjustment of the carrier balance pots. With S1 in the OP position and S3 in the TUNE position, the RF voltage is sampled at the L4 link and C2 and C3 adjusted for maximum. Each trimmer should exhibit two peaks during a full rotation if the parallel capacitor has the right value. As mentioned previously, the signal needs to be monitored with a loosely coupled receiver or frequency counter to make sure the circuits are being peaked at 9.0 MHz.

The balanced modulator can be aligned next by putting a scope probe on the link of L4. Set S4 to the USB position. The carrier balance pots are adjusted for minimum signal, and then a single audio tone in the range of 1,000 to 2,000 Hz is injected at the microphone input. The mic gain is advanced until some modulated RF shows on the scope. A very low level is needed to keep distortion down. The RF phase and audio balance pots are then adjusted for minimum ripple on the scope. It should not be necessary to move the RF phase pots very much from the initial settings or the audio balance pot from its midpoint. The carrier balance pots also need to be constantly readjusted for minimum carrier. At this point, a selective receiver or spectrum analyzer should be loosely coupled to the link of L4 and the sidebands tuned in or observed. The upper sideband should be much stronger than the lower. If the lower sideband dominates, you will need to reverse the leads on S4 or rotate it a half turn. When S4 is showing the right sidebands, select LSB and repeat the adjustments for minimum ripple. Go back and forth between USB and LSB repeating adjustments until the ripple in both positions is minimized. The receiver or spectrum analyzer can then be used to make the final adjustments for best unwanted sideband rejection. When finished it should be possible to get a good two-tone pattern on the scope using the two-tone generator. At this point set S3 to OP.

The VFO is tested and adjusted next. Output is monitored at pin 2 of V6, with the tube still removed, using a frequency counter or general coverage receiver. The position of the tap on the high side of L8 is alternately adjusted with C10 to provide the desired 5.15 to 5.35 frequency coverage over the center of C9's travel. When the cover is installed over the VFO components the frequency will change quite a bit, so this has to be taken into account. You may want to make sure C10 ends up close to its midpoint such that you can use the original arm and lock screw arrangement. The total frequency range of C9 should be almost 500 KHz. When the VFO is behaving correctly, reinstall V6 in its socket. Set the VFO to 5.25 MHz and S3 to tune, monitor the RF at the grid of V7 and peak C4 at 14.25 MHz. Then sample the RF at the grids of the PA tubes and peak C4 and C5 at 14.25 MHz. As before, there should be two peaks for each trimmer at 14.25 MHz. C3 should also be peaked at this time for maximum RF.

The PAs should now be reinstalled and screens reconnected if required. Connect the dummy load and the scope probe to J2. Prior to applying power, set R7 for maximum bias on the PAs and make sure S1 and S3 are in the operate position. Turn the radio on, and after the tubes are glowing set R6 fully CCW and S1 to spot. Slowly advance R6 and adjust C7 and C8 for a maximum output of a few volts RF. Then adjust the carrier balance pots for minimum output. When this is done set S1 to operate and S3 to tune. Advance R7 until about 40 ma of cathode current is flowing with S2 in the plate position. Readjust the carrier balance pots for minimum plate current, and then readjust R7 for 40 ma. Adjust one of the carrier balance pots to get about 60 ma of plate current and quickly repeak C5 for maximum output, keeping plate current below about 60 ma. Then adjust C7 and C8 for minimum plate current and maximum RF output. These two conditions will probably not occur together so adjust C6 a little bit at a time until they do, using enough carrier unbalance to produce about 100 ma of plate current at maximum output. Rebalance the carrier and inject the two tone audio signal at J7. By adjusting the mic gain it should now be possible to get about 120 volts peak-to-peak RF across the dummy load when the peaks begin to flatten. Some adjustment of C7 and C8 may be required to get maximum output. Placing S2 in the grid position should show a slight amount of grid current when the peaks start to flatten. Turn the mic gain to zero, loosely couple the receiver to the RF output, tune it to the third harmonic of the VFO at 15.75 MHz and adjust C11 for minimum signal. As before, there should be two minimums to a full turn of the trimmer. Alternately a spectrum analyzer can be loosely coupled to the output and used for this adjustment. The spectrum analyzer can also be used to check the output at this time by advancing the audio gain and observing the two tone signal. Note that spectrum analyzers use low impedance inputs and must never be connected directly to RF voltages that exceed about one volt rms or the mixer diodes and attenuator can be damaged.

Figure 14 shows the desired two tone RF output in the time domain at the threshold of PA grid current. Figure 15 shows the same signal in the frequency domain as observed on a spectrum analyzer. The third order IMD products are more than 35 dB down from the two tone peaks, but rise rapidly when grid current increases. Figure 16 shows an interesting spectrum analyzer trace for a "white noise" audio input.

In Conclusion

Although it took some time and patience, this rig has met all expectations from the original vision. And as always, I learned many things getting it to the final configuration. See Part 2 for the matching receiver article.

Parts Lists for the Vintage SSB Special

Transmitter

C1-C5, C11	4.5-25 pf ceramic trimmer, NPO or Type A temperature characteristic	
C6	10 pf miniature air variable	
C7	25 pf air variable	
C8	410 pf air variable, single gang, BC band type	Allied 61H009
C9	Command Xmtr VFO variable, rear unit, 150 pf	
C10	Command Xmtr VFO variable, range set, 180 pf	
D1-D4	1N914 or 1N4148, matched with ohmmeter for forward resistance	
D5, D6	100 PRV GP silicon, 1N4002 or similar	
F1	Fast acting fuse	
J1	Microphone jack, Collins type used here	
J2	SO-239 UHF Jack	
J3	Coax relay jack, Cinch-Jones 4 pin used here	
J4	As required, banana jack	
J5	11 pin chassis mount plug to mate with power supply cable	
J6, J7, J8	RCA phono jack, chassis mount	
J9, J10	BNC jack, chassis mount	
K1	3PDT or 4PDT, 12 VDC coil, 180 ohms minimum	
L1, L3, L4	22 turns #24 on T50-2 toroid form, link 5 turns #24 over cold end	
L2	6 turns #24 bifilar wound on T50-2 toroid form. Link 2 turns #24 or #26 magnet or hookup wire over center, see photo	
L5, L6	19 turns #24 on T50-2 toroid form	
L7	15 turns #20, Teflon insulated, close wound on .875 inch form, about 3.7 µH	
L8	Command Xmtr VFO Coil, 7.0-9.1 MHz, modified; see text and photo	
L9	28 turns #26 close wound on .25 inch insulated rod	
M1	0-1 ma meter, 1.5 inch diameter	
PC1, PC2	3 turns #18 space wound on 47 ohm, 2 watt carbon resistor	
R1	Panel mount, audio taper	Mouser 31VJ601-F
R2, R3	Miniature trimmer, composition	Mouser 531-PT10V-250
R4, R5	Panel mount, linear taper, composition	Mouser 31VA205-F
R6, R7	Panel mount, linear taper, composition	Mouser 31VA305-F
RFC5, RFC6	Pi-wound choke, 400ma	National R-300
S1-S7	Miniature toggle, SPST, SPDT or DPDT as	

	required	
S8	SPST toggle, 6 amps at 125 VAC	
Y1	9.0 MHz crystal, exact frequency not critical	

General Notes for Transmitter Parts:

1. Fixed capacitors: Capacitors marked with an asterisk are silver mica, 500 volt rating. Capacitors with a plus sign are electrolytic. All other capacitors are disc ceramic, 500 volt rating except as noted. Capacitors used in low voltage circuits such as the balanced modulator may be 100 volt rating.
2. Fixed resistors: Unless otherwise noted, all resistors are 0.25 watt, 5 percent tolerance, carbon composition or carbon film. 0.5 and 1.0 watt are 5 percent tolerance, carbon composition or carbon film. 5 watt and 10 watt are wire wound.
3. RF Chokes: Except for RFC5 and RFC6, all chokes are miniature epoxy coated, Mouser/Fastron type 434-23-xxxJ, where xxx is the inductance.
4. Ceramic trimmers should have rotors connected to low side of circuit.

Audio Module

D1, D2	100 PRV GP silicon, 1N4002 or similar	
T1, T2, T3	Miniature audio transformer, 500 ohm CT to 500 ohm CT	Mouser/Xicon 42TM009-RC or 42TL009-RC
U1-U6	Dual 741 Op-amp, 8 pin DIP	MC1458
U7	12 volt positive regulator, 100 ma	MC78L12
U8	12 volt negative regulator, 100 ma	MC79L12

General Notes for Audio Module Parts:

1. Fixed capacitors: 1000 µf/25 volt capacitors are electrolytic. 1.0 µf/20 volt capacitors are tantalum. 680 pf capacitor is 5% ceramic, 100 volt rating. All other capacitors are radial polyester film, 5% tolerance, 100 volt rating, Mouser/Xicon type 140-PEI2AxxxJ-RC, where xxx is the capacitance.
2. Fixed resistors: 10 ohm resistors are 5 percent carbon composition or carbon film, 0.25 watt. All other resistors are 1% metal film, 0.25 watt, Mouser/Xicon type 271-xxx-RC, where xxx is the resistance.
3. 2.0 kohm pot is miniature composition trimmer type.

Figure 1: The Vintage SSB Special Radio Set Connected for Transceive Operation

Figure 2: The Vintage SSB Special Transmitter

Cheap and Easy S.S.B.

ANTHONY VITALE, W2EWL

The author's interests have been directed at mobile s.s.b. operation, because the boost in "talk power" for a given power supply one gets with s.s.b. really works to advantage in mobile work. W2EWL has been on 14-Mc. mobile s.s.b. since 1953, and during that time has participated in four-way QSOs involving ZLs and VKs, and a 7-way involving two African countries, one European country and three W call areas.

The exciter/transmitter to be described is not a one-of-a-kind deal, but represents a design that has evolved over the years. It is built around the v.f.o. portion and on the modified chassis of a BC-458 (or T21/ARC-5), which tunes 5.3 to 7.0 Mc. in the original unit. These units sell from \$3.95 to \$7.95 in the surplus market, depending upon their condition. The design to be described uses the original output stage of the BC-458; the output will vary with the available plate voltage, and will be about 100 watts peak with a 1000-volt supply. The current W2EWL rig uses only one of the two 1625s in the original output stage, with 300 volts on the plate, to drive one 837 that in turn drives four 837s in a grounded-grid amplifier. The exciter hangs under the dash of the car, and the amplifier mounts in the trunk.

The Circuit

The photographs show two different units; one is for 14 Mc. only and the other is switchable to either 14 or 3.9 Mc. If you want only 3.9- or 14-Mc. operation, you can omit the unwanted circuits and a couple of toggle switches, but the rest of the circuit remains unchanged.

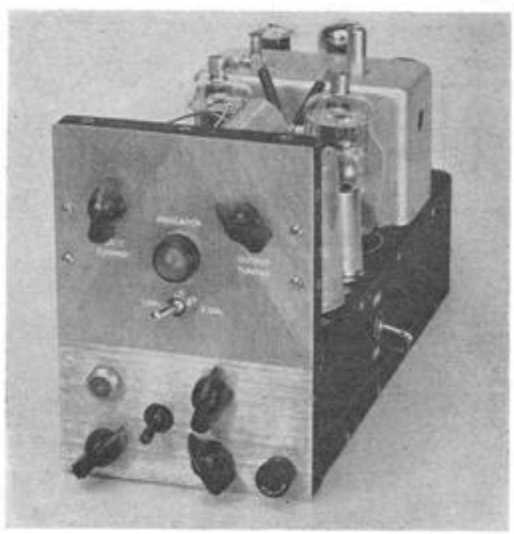
From *QST*, March, 1956.

The circuit of the exciter is shown in Fig. 1. Much of the circuit is similar to "S.S.B. Jr.," the excellent design published some years ago.[1] The s.s.b. signal is generated at 9 Mc. and heterodyned to either 14 or 3.9 Mc. by beating against the v.f.o. unit of the BC-348. To change bands, it is only necessary to flip two toggle switches and change the v.f.o. setting.

Running through the circuit, the microphone signal is amplified through V_1 and V_{2A}. The gain is controlled by the setting of the 1-megohm gain control. The audio signal is then coupled through T_1 through a low-pass audio filter to an audio phase-shift network. This network isn't shown in the schematic, but J_2 is the octal tube socket it plugs into. For anyone who has fears about the complexity of an audio phase-shift network, forget them; the B&W Model 350 is inexpensive, comes sealed in a metal tube envelope, and all you do is plug it into the socket.

The phase-shift network requires two audio signals of different amplitudes in the input to give equal signals in the output, and the 500-ohm potentiometer across the output of the audio filter is included to obtain the proper ratio. The two output signals, of equal amplitude but differing in phase by 90 degrees, are applied to the grids of V_3 for further amplification. To insure equal gain through V_{3A} and V_{3B}, the 500-ohm audio-balance control is included. The two signals are coupled to the balanced modulators through T_2 and T_3, and these transformers are shunt-fed to

[1] In the November–December, 1950, issue of *G-E Ham News*.



This two-band mobile sideband transmitter is capable of up to 100 watts peak output, depending upon the power supply. Built on the chassis of a BC-458 transmitter, it uses the original v.f.o. portion and the two output tubes. The phasing type of sideband generation is used, and the audio amplifier has adequate gain for use with a crystal microphone.

On the panel, the upper knobs control output stage tuning and loading. The indicator light is used instead of a plate milliammeter, and the upper toggle switch is one of the two band switches. (The other bandswitch can be seen on the right-hand side of the chassis.) The lower left-hand knob is for the audio gain control, the toggle switch selects the sideband, and the two pointer knobs next to the switch are for carrier balance adjustments of the balanced modulator. The remaining knob tunes the v.f.o.

Figure 3: The Original "Cheap and Easy SSB" Article

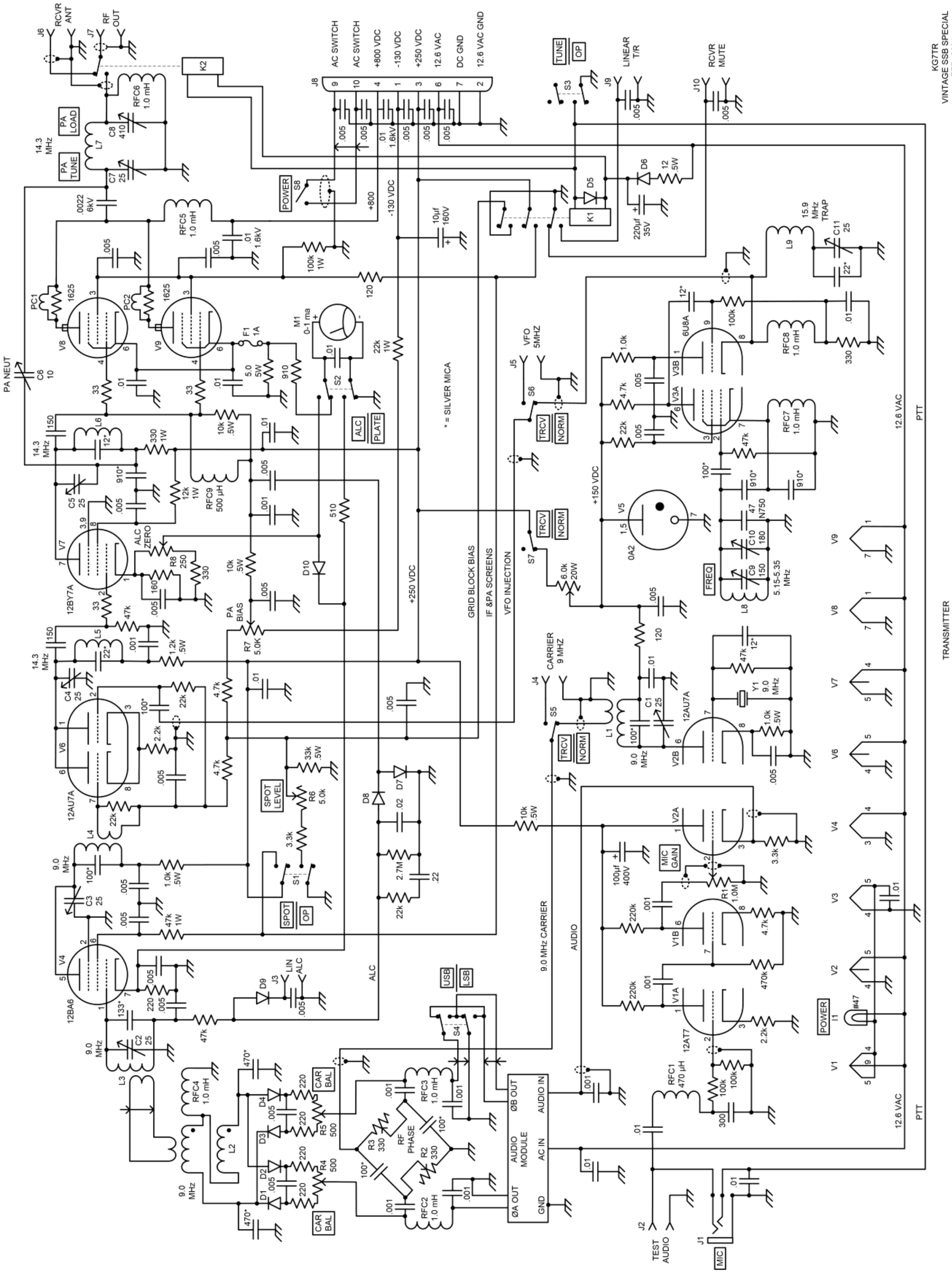


Figure 4: Transmitter Schematic

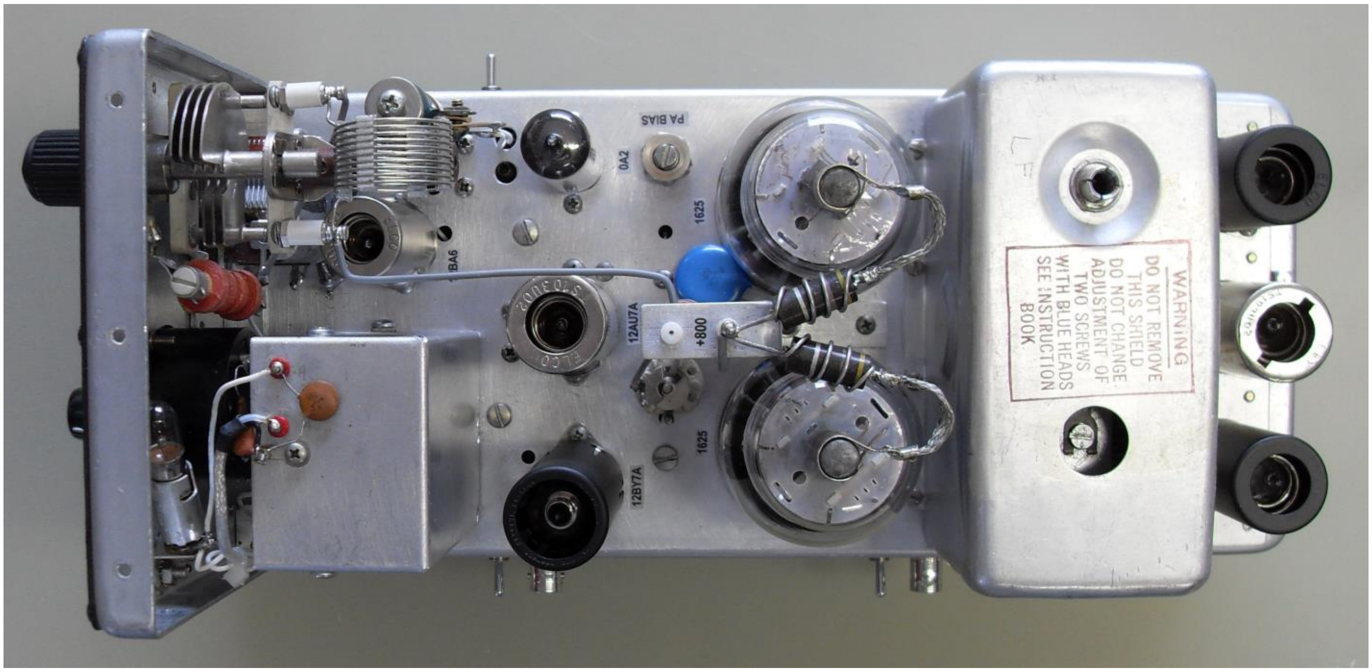


Figure 5: Chassis Top View

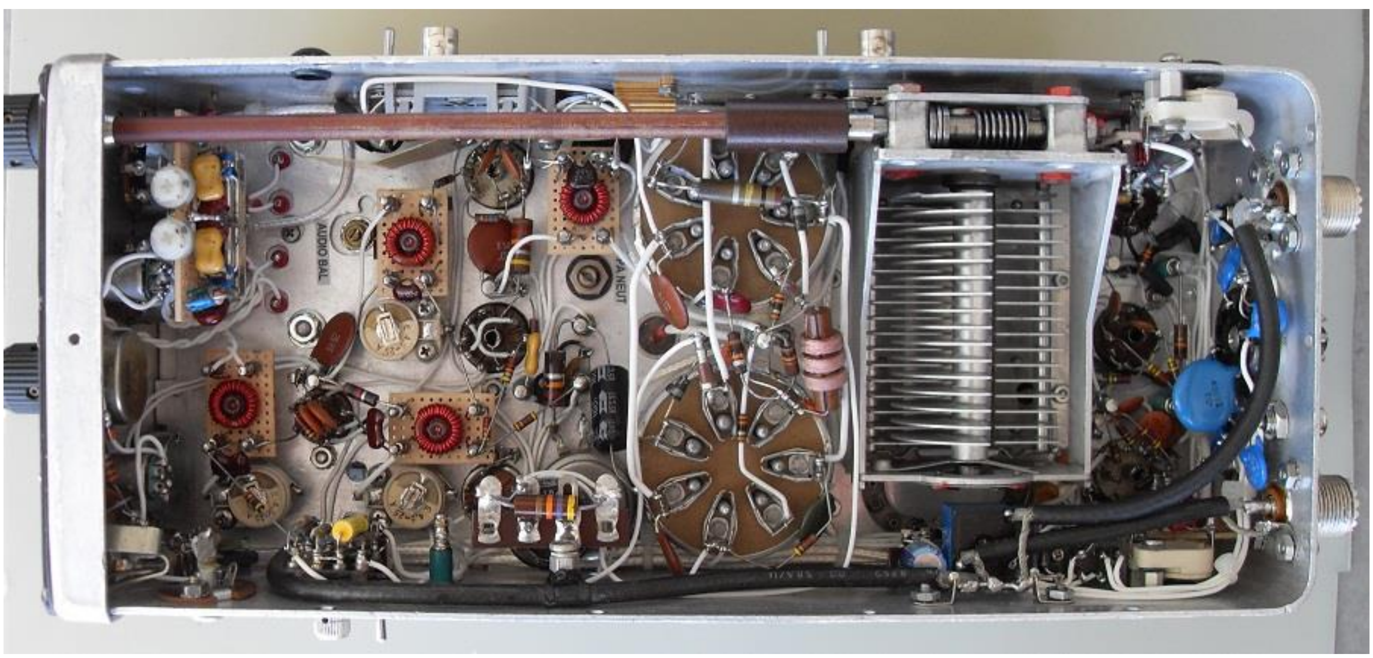


Figure 6: Chassis Bottom View

Figure 7: Front Panel. Meter scale is home made using computer drawing program.

Figure 8: The 1625 Beam Power Tube

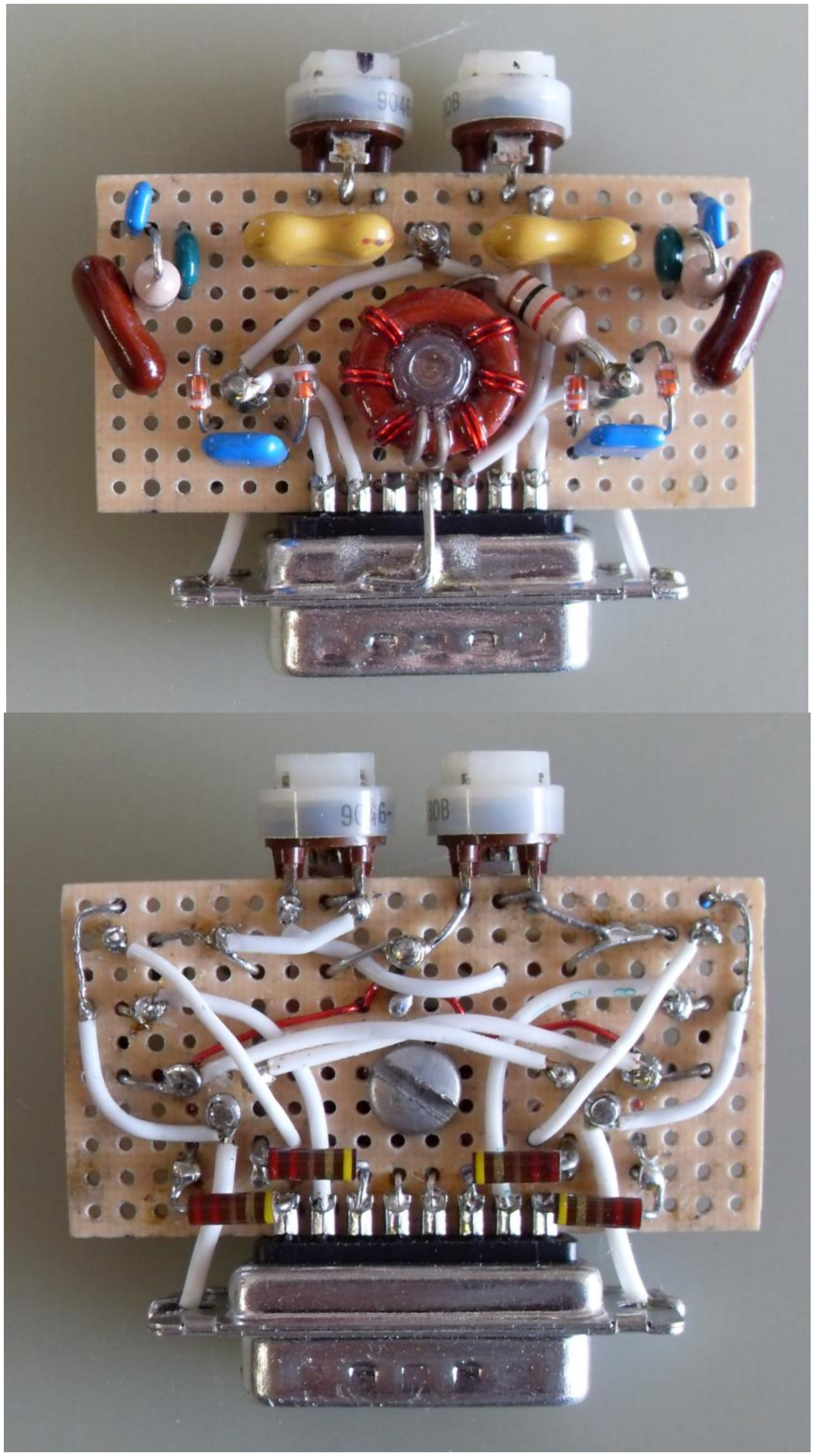


Figure 9: Balanced Modulator, Front and Rear

Figure 10: Details of VFO Coil

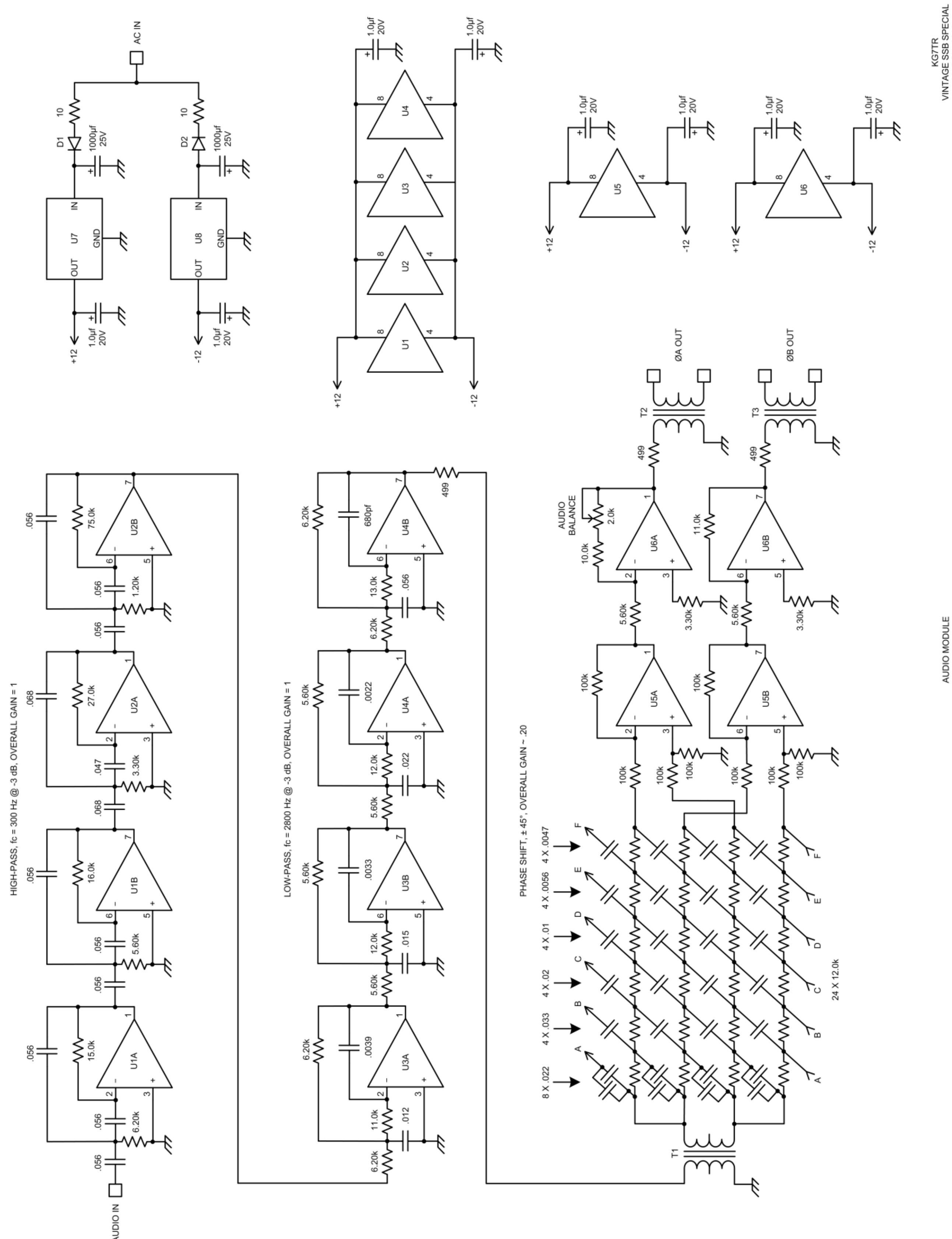


Figure 11: Audio Module Schematic

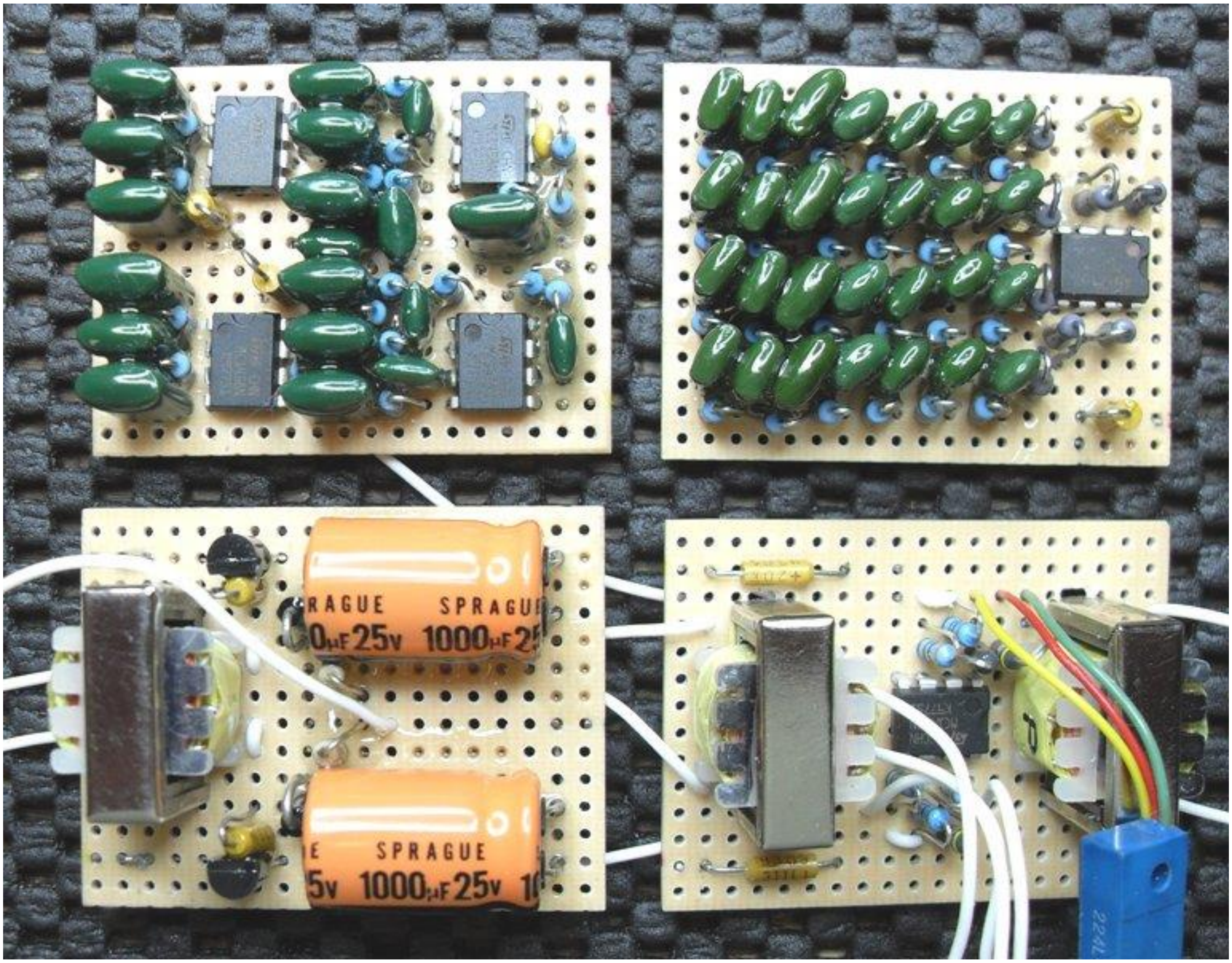


Figure 12: The Four Audio Module Boards. Clockwise from top left is the bandpass filter, phase shift network, output amplifier with T2 and T3, and power supply with T1.

Figure 13: The Assembled Audio Module in Minibox Enclosure

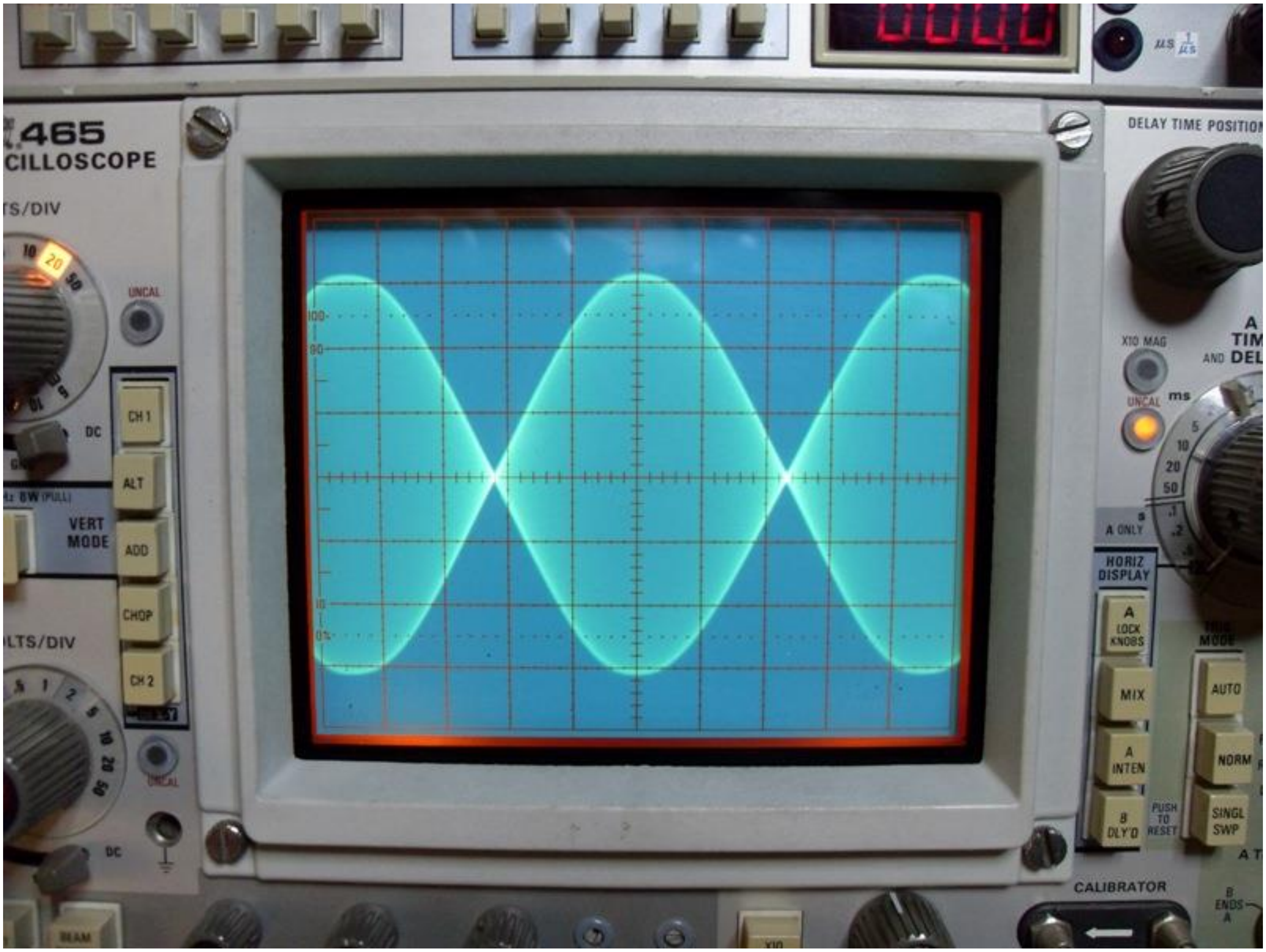


Figure 14: Two Tone Scope Pattern at RF Output

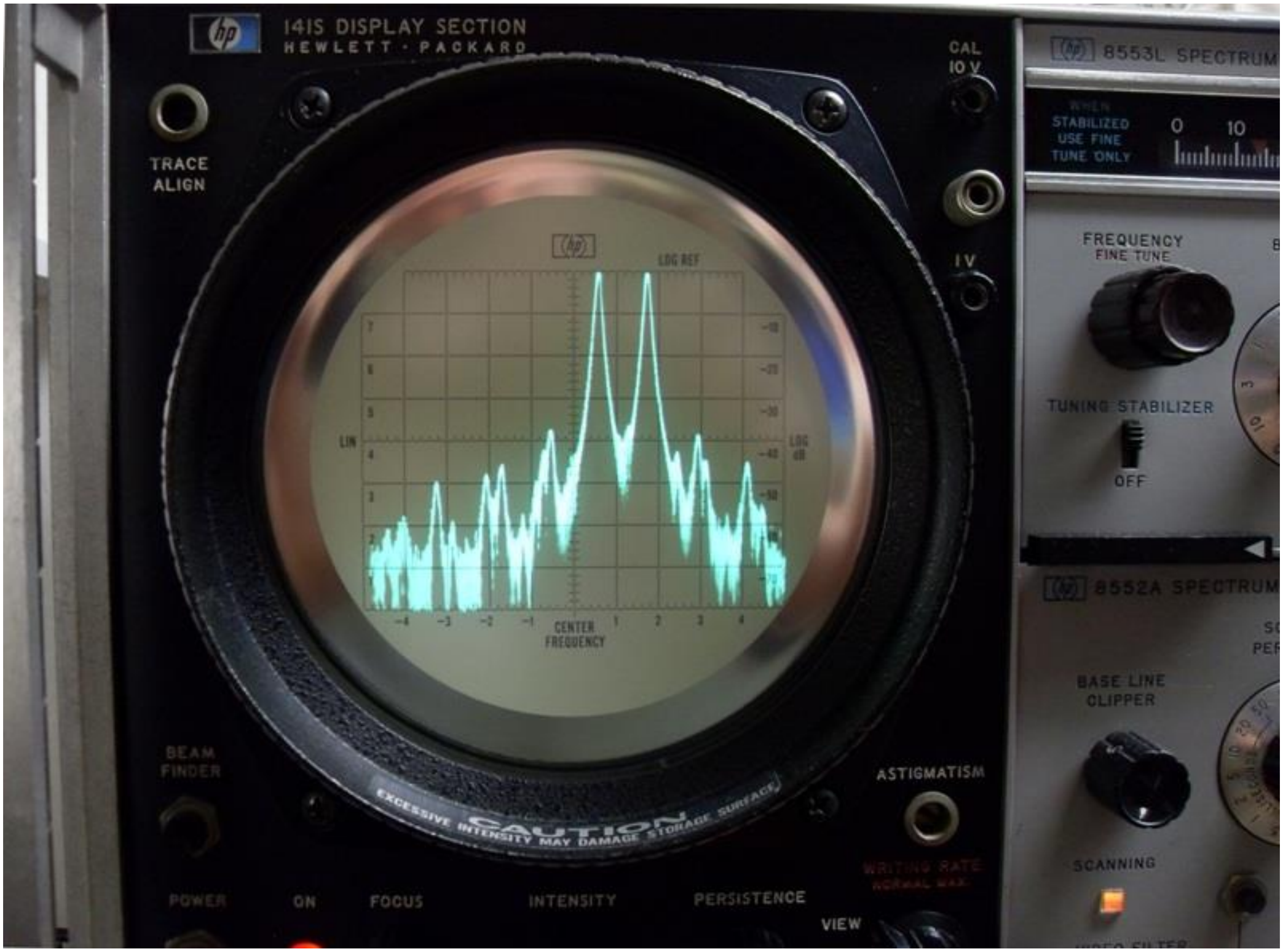


Figure 15: Two Tone USB Output on Spectrum Analyzer. Horizontal scale is 1 KHz per division and carrier is at center. At threshold of PA grid current third order IMD products are over -30 dB and unwanted sidebands are over -45 dB.

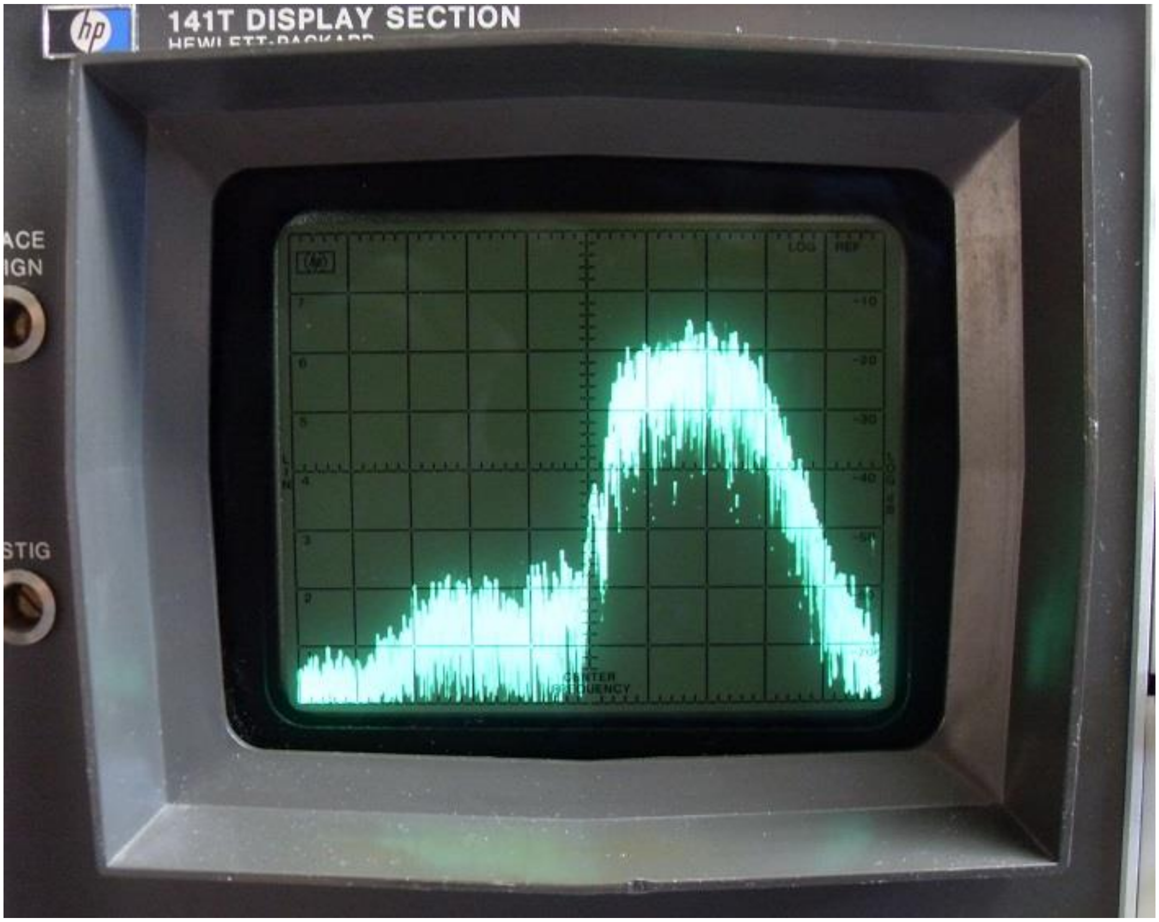


Figure16: This was done just for fun to see what would happen. I tuned an FM radio off station so it would produce white noise and put the transmitter's mic against the speaker. Then I looked at the RF spectrum at the dummy load on my old HP spectrum analyzer. The carrier is at the center and each horizontal division is 1 kHz. You can clearly see the audio (and resultant RF) passband is about 2.5 kHz wide just as predicted.