A National Radio HRO-500 Restoration Story

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Initial appraisal

My restoration work on this receiver strated in early November of 2011 when Connie, the XYL of Owen Hawkins, K6FOH (sk), called me and wanted to know if I would be interested in buying an HRO-500. She had done some investigation on the web and came to think it might be quite valuable. Which it could be I suppose, if it's in good condition and most important, it is in working order. I had checked it out earlier in the year when I helped her liquidate some of Owen's more modern ham equipment. I don't know if Owen used this radio much, there are some wiring diagrams in the original manual that indicate he may have used it with a Drake T4-X transmitter.

I'm not an avid collector of vintage communication gear nor am I driven by any possible financial gain. I suspected this radio would take many hours of trouble shooting and rebuilding before it would be functional and any profit motive would make no sense. Also there was the possibility that some vital component was damaged beyond repair and the radio would have to be scrapped for parts at best or become landfill at worst. My interest was in understanding how this ancient piece of gear worked and restoring it so it could continue to be a functioning example of our best technology of a period in history. (Note: A full discussion of the radio characteristics, schematics, and theory of operation is available from more than one source on the web).

On first examination, it looked to be in fair shape. I'm not an expert collector so I'm not up on criteria for establishing the condition of vintage equipment. My estimation is its condition as I received it wouldn't rank good or excellent by any means since some of the control shafts were frozen and a look under the hinged lid revealed the usual pitting in the tin-plated steel chassis that's pretty typical for radios of this vintage. I'm not sure it even would get a fair rating since it wasn't functional. There wasn't a power cord so I couldn't even tell if the pilot lights lit. There was the original manual that had the same serial number as the radio.

One problem, which plagues this boat anchor and other such similar gear, is that they are large and a bit heavy. So as a result, they are often not stored properly. This radio must have sat on a back shelf in the basement of the house on the San Francisco Bay Peninsula for decades. Lying unprotected in a basement for many years will take its toll on every part in a radio especially the metal parts including the ferrite material in the coil tuning slugs.

I had offered Connie $150 earlier that year, realizing that it probably needed quite a bit of work or maybe was un-repairable for some reason. As I said, I'm not that interested in owning a boat-anchor radio myself.

She had made some attempts to sell it herself, but after dealing with several potential buyers and dealers decided that was not a course of action for her. Apparently, the potential buyers were only interested in the radio if it was verifiably in working condition; otherwise I suspect she got a low-ball offer just like mine. One broker would accept the radio and evaluate it if she shipped it back east. Shipping a big radio correctly takes some effort.

Some months had passed and she was getting anxious to free up the space in her basement and made a new proposal. She had found an IC-720a in the box and together with HRO-500 would take $300. Together it was pretty good deal so I went for it. Before you accuse me of ripping off the widow, I would like to say that the IC-720a needed some work on the electro-mechanical band switch. All things considered, I honestly feel she received a fair deal.

Mechanical restoration

I was not in a big hurry to dive into this project for fear it would be a long slog (and it was). I was anxious to find out how bad it was though.

The first thing to do was to get the controls working. The function switch (Off, Standby, AM, CW, SSB) control shaft was frozen in the switch shaft bearing. I could tell it wasn't completely seized but it was very tight. I've seen this problem before on old test equipment. Seems whatever they used for lubricant turns to a hard waxy substance after time and disuse. The Pre-selector tuning shaft and Band Switch had a similar problem but not as bad.

I'm not sure what the best method for loosening up these shafts is. Mechanically working the shafts by clamping vise-grip pliers to the shafts was helping. Some sort of solvent seemed to be called for here. Alcohol is pretty safe but was having no affect. One of my ham buddies recommended gasoline. As a side note, I actually think gasoline is probably a pretty good choice but there are some obvious drawbacks. I compromised and used lighter fluid, (who has lighter fluid these days?), that worked the best.

The chassis didn't look too bad but there is pitting in the tin-plated steel that I'd like to remove someday if I can find the right technique. I did take the front panel off to thoroughly clean it in detergent. That required removing the HRO vernier dial. I soaked and cleaned the all the knobs at the same time. The band switch knob was missing the aluminum dress cap. I had one made at a local machine shop, defy anyone to tell it's not original.

There are a few tricks to getting the big HRO vernier dial and knob back on at the right shaft setting. I'm sure there is a correct procedure but I found that setting the tuning capacitor to mid position and installing the dial so that 250kHz was showing in the tuning window worked for me. It's an interesting mechanism and I expected it to be silky smooth. I think we are all a little bit spoiled by the feel of more modern equipment.

Power Up

There was no ac power cord provided with my radio. The ac input requires a 2-pin cord similar to the ones used for vacuum tube TV sets of the same era. The common "cheater" cord would be ideal but I haven't seen one of these in a long time…My buddy Bob Baldwin finally tracked one down for me.

I brought the radio up on ac power using a Variac (General Radio' s trade name for an ac auto-transformer) so as not to shock the remaining life out of any of the power supply electrolytic capacitors. Amazingly, the power supply was ok, the 5V, 7.5V, 10V, 11V, and 12V supplies were within the specifications noted in the manual (more on this later). The solid-state voltage regulator was doing a good job and there was no detectable hum in the audio so I assumed the large filter capacitors were good.

I connected a short piece of wire to the high-z antenna input terminal and tuned around. Good news and bad news. Band news; I couldn't hear anything from the speaker, just a slight hiss and maybe a few birdies as I tuned around. Good news; the synthesizer lock light would go out indicating locked condition at about the right spots. Footnote: If you look around on the web and see HRO500s for sale often times the big red lock light will be lit. This is really not so good since it means its synthesizer isn't locked, at least not when they took the photo, FYI. If you have or get an HRO-500 with synthesizer problems, don't get discouraged, they are not too difficult to sort out. The synthesizer uses no microprocessors (obviously) or obsolete digital electronics so any failure should be repairable.

At this point I could see that I was not going to be able to just replace a few pilots lights, find a power cord and oil the shafts and I'd have a fine piece of vintage communications equipment up on 40 meters. Getting this machine running properly was going to take a concentrated effort.

Prep

I don't like poking around equipment with ac power supplied. In the case of the HRO-500, you don't have to since it also accepts 12Vdc. I made up a dc power cord from a Jones socket I purchased at Jameco for $3. I used lab bench power supply so that I could keep an eye on the current. Typically the current is only about 150mA with the panel lamps off and the audio gain at minimum. A 2 amp power supply is recommended and it should also be capable of supplying +12.7Volts minimum (more on that later) for best performance.

The radio uses germanium PNP and silicon NPN transistors. The manual has a voltage chart for every transistor emitter, base, and collector. It's handy and will help you find failed stages with only VOM. My experience is that the chart isn't completely accurate and you should expect some variations, maybe +/- 0.5V from the published voltages. Calculating the transistor terminal voltages won't give you the chart values either. I suspect the chart values were determined empirically from measurements taken on a couple of radios.

The important thing is to look for approximate base voltages and correctly forward biased base-emitter junctions. If that looks good then look at the collector or emitter resistor voltage drops to confirm that the transistor is drawing current. Most stages are biased near 1 ma.

Also, I found some difference between the schematic in my manual and the schematics I've seen on the web. The differences are pretty minor but look for:

1. The RF gain pot wiper should be connected to C135A
2. The RF amplifier, Q1, collector circuit has a 390 ohm resistor not shown on my schematic.
3. Many of the RF and IF stages have 100 ohm decoupling resistors in the positive supply not shown on the schematic.

You will find some notes on the web about resistor values that have drifted high. I can confirm this and would add that in my case the resistors seem to be high by a fixed mount, approximately 100-200 ohms. This is not a problem for resistors above 4.7k ohms but it's a significant amount for 100 ohm bias resistors. You can save some time by checking all the low value resistors before aligning this receiver.

I also found a reference on the web stating that the black disc ceramic capacitors where likely to be bad but I didn't find any bad ones in this radio. I did check all of the aluminum electrolytic capacitors and found a few bad ones but surprisingly most (but not all) were still quite good.

Power Supply Notes

The power supply input can be either 115 ac or 12Vdc. If you decide to use an external dc supply, set it to 12.7-13.0V to compensate for the extra drop of the series input reverse voltage protection diode. Also, the stability of the external dc supply is important, as there are a number of circuits that use the 12V, 11V, and 10V supply rails. There is an internal 12V regulator but is only used with ac power and is bypassed in the dc supply mode. As a result, any change in the external 12Vdc input will have a direct effect on the 12V, 11V, and 10V supply rails since they are unregulated when using the dc supply. The 7.5V and 5V rails are zener stabilized.

In my receiver, the 11V supply measured 10.1V. Since there is a separate 10V supply rail, I thought this value might be too low. Suspecting R119 had drifted high, I measured it in-circuit and amazingly found it to be in tolerance at 21.8 ohms (should be 22 ohms 10%). Further suspecting the in-circuit measurement was showing the value of R119 incorrectly, I removed one lead of the resistor and verified the value was still 21.8 ohms.

The 12V supply rail was set to 12.0V by adjusting the external dc power supply, then the current through R119 was found to be (12V-10.1V)/21.8ohm = 87mA. That seemed like a reasonable current considering the 11V, 10V, 7.5V, and 5V loads were all sourced through this resistor. I changed R119 to a 12ohm 1-watt carbon composition resistor and now the 11V rail is much closer to 11V as it should be.

With 115V ac power applied the 12V supply rail measured 11.98Vdc. Line regulation with 105~125Vac input resulted in lest than +/- 60mV change in the 12Vdc supply.

2-Stage Audio Section

Assuming the power supply is functional, the place to start debugging a lifeless radio receiver is at the last stage and that's usually the audio amplifier. This radio's audio section consists of a low-level class-A driver and push-pull output. There's not much to it and there's a convenient audio input on the 18-pin Jones plug socket on the back. I put and audio signal in and was able to get good, undistorted audio out. I replaced the speaker with a 4-ohm load and tested the audio section to the published spec. R133 should be 1.8k ohm but was 2.11k ohm. Changing this resistor raised the quiescent bias current in the push-pull output stage slightly and may have improved the cross-over distortion a bit.

230kHz 2nd IF amplifier section

After confirming the audio section was working, I started testing the 2nd IF stage. I followed the manual, which says to inject a 230kHz signal into the base of the 2nd mixer. This quickly led to the discovery that the 3rd transistor, Q14, was providing no gain. Some dc checking found the transistor had appropriate base bias but no collector current. Q14 is the last stage in the 2nd IF and does not get AGC voltage. Q14 also has fixed bias and so I thought I could replace this germanium transistor with a silicon PNP 2N2907. That fixed the lost gain but a slight instability was noticed. The higher cutoff frequency of the 2N2907 combined with the relatively long point-to-point wiring around this stage is likely to be unstable. Replacing the 2N2907 with an NTE160 fixed the stability problem and restored the gain.

There is another reason not to use a silicon transistor if you don't have any germanium PNPs lying around. The AGC control signal is shared by the 1st and 2nd IF amplifiers. The AGC control threshold is a relatively narrow range and the Vbe difference between the transistor types will have an affect on the gain distribution in the receiver. If you did change all the IF transistor to silicon then you most likely would also need to modify the control range of the RF gain control as well. For now, NTE germanium replacement transistors are readily available and I would recommend using these if you find a faulty transistor.

The 230kHz IF has three amplifier stages and so I was expecting 25dB per stage or a total of 75dB. With the bad Q14 replaced the gain was only about 50dB, which seemed a bit low. I did some signal tracing with a scope and found significant gain on Q12 and Q14 but hardly any on Q13. The bias voltage looked okay which led me to suspect a faulty bypass or coupling element. The 5uF emitter bypass electrolytic capacitor was my suspect and probing the emitter with a scope verified that this capacitor was open. I replaced it with an available 4.7uF.

The junction of C156 and R74 at the output of the 2nd amplifier provides a convenient point to make relative receiver gain measurements. This is also a good place to see the AGC action. With the AGC on, you will see the IF signal maintains a constant amplitude of around 0.7Vrms (2Vpk-pk) with varying input signal. You can also verify the receiver is providing sufficient IF gain by injecting a 50uVrms, 230kHz signal into the base of Q6 while measuring the output at C156 and R74 with the AGC off. Be sure to terminate the generator at the end of the cable in 50 ohms in order to make accurate measurement. The output signal should be around 0.5Vrms, which corresponds to a gain of 80dB for the 2nd IF. The total receiver gain should be about 100dB so that leaves 20dB that the RF amplifier stage in 1st mixer will need to supply.

Variable passband tuning

The HRO-500 has four IF bandwidths, 8kHz, 5kHz, 2.5kHz, and 500Hz. The two narrowest, 2.5kHz and 500Hz, have a tunable center frequency controlled by the front panel PASSBAND tuning knob. Theses two passband tuned IF filters are six-pole, L-C filters. Each is gang-tuned by a six-section, variable air capacitor.

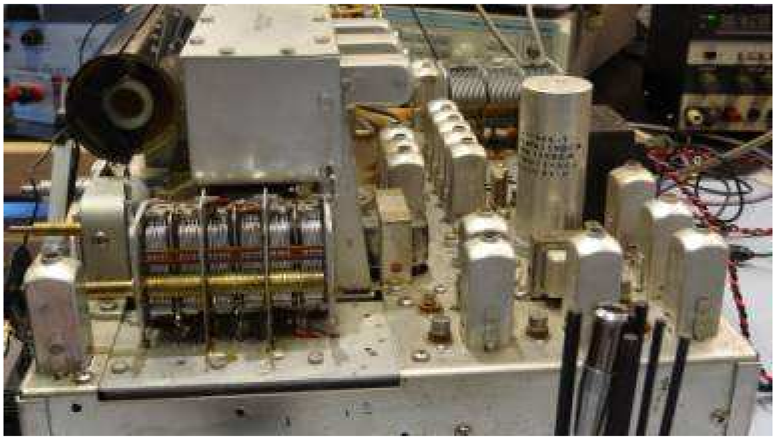


Figure 1 Passband tuning six-section variable air capacitor shown with shield cover removed in order to align the plates

In this receiver, when either the 2.5kHz or 500Hz tunable filters where selected, the receiver went dead. The problem was traced to the six-section, variable air capacitor. Over time, apparently, the plates on two of the rotor sections had become misaligned and were shorting to the stator sections. It is easy to locate which section is bad with an ohmmeter since the stator is capacitor coupled to the filter circuit. What is more difficult is to find which of the dozen or so plates in each bad section are shorting to the grounded stator.

What I did was set a dc power supply to 30V and connect one lead to the rotor side lug and one lead to the chassis ground. Now, when turning the PASSBAND knob, I could clearly see tiny sparks just as the rotor plates were breaking contact and identify which plates needed tweaking.

It is not an easy matter to realign these plates as the gap is only maybe 20-25mils. With some judicious bending and patient prying, I was able to get the plates satisfactorily realigned and restored the function of the 500Hz and 2.5kHz PASSBAND tuning.

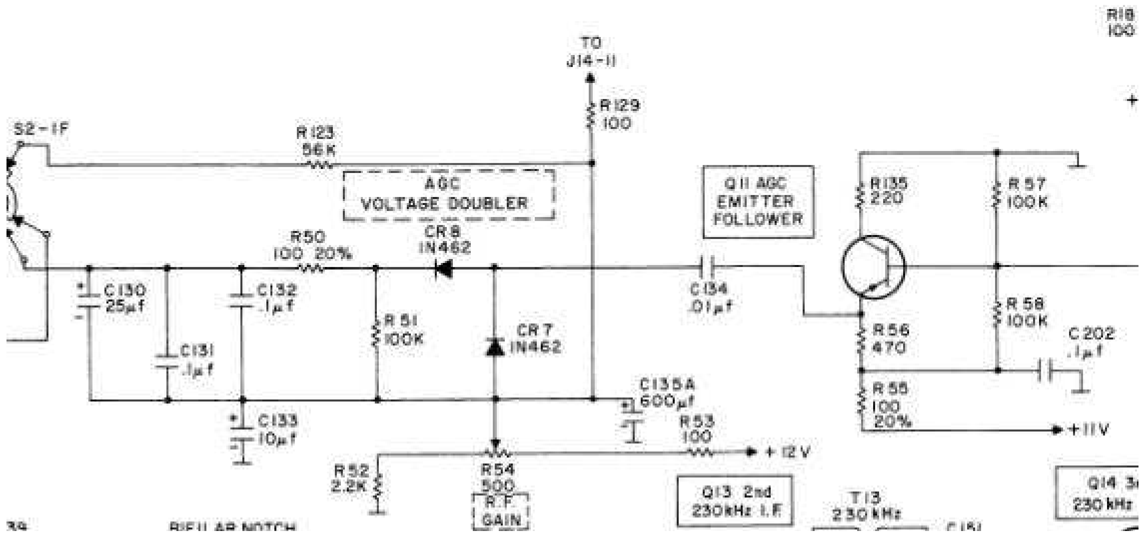
The National manual provides an alignment procedure for this filter but specifies a mechanically swept signal generator. Fortunately, these are no longer available. Instead, I used the FM function on an HP-4332B signal generator. This signal generator provides precise FM with selectable ramp modulation making this alignment procedure much faster and accurate.

Tunable 1st IF (2.75MHz to 3.25MHz)

With the 230kHz 2nd IF working correctly, I then injected a 3.0MHz, 100uV RMS signal into the base of the 1st mixer at Q3. 1mV of injection signal was required to regain the S9 meter indication. This indicated that there was a loss in gain where at least another 10dB of gain should have occurred. The problem was found by checking the bias voltages on Q3, Q5, and Q6. Q5 had unusual base and emitter voltage. Replacing this 2N2672 PNP germanium with a NTE160 restored the tunable IF amplifier gain. This stage alignment was checked and found to not require much if any adjustment.

RF Gain Control

With the 1st and 2nd IF amplifier sections working, the next place to turn our attention is to this little area of the RF gain control. Its called the RF gain control but really it controls the gain of three IF amplifiers and only the one the one front-end RF amplifier. The only signal processing stages that aren't affected by the RF gain voltage are the 1st mixer, 2nd mixer, tunable passband IF filter buffer, and the last IF amplifier in the 230kHz IF.



If this AGC section of the radio has any problems it can drastically affect the apparent sensitivity of the receiver. Test this circuit by applying dc power. The voltage on R53 will be about 11.3Vdc since there is a protection diode in series with the dc power supply input. Now check the voltage on C135A. That should be at 8.9V, if it's much higher, then R52 has probably changed value and shifted high.

AGC and S-Meter

All of the testing, debugging, aligning took place with the AGC off and the RF gain control set to maximum. The last thing to test is the AGC function and then the S-meter function and accuracy.

With a 230kHz signal applied to Q6 base, switching the AGC switch from off to on made no difference in the S-meter reading. Looking at the AGC voltage on C135A, I could see that there was no change with signal level. A little signal tracing led me quickly to Q11, the AGC emitter follower. The base voltage was resting at about 10V when it should be at VCC/2 or about 5.5V. Q11 is also a germanium PNP but in this application any general-purpose silicon PNP such as a 2N3906 or 2N2907 should work well because the base bias is set by the two 100k ohm resistors R56 and R57. The Q11 emitter voltage will be 0.4V higher than with a germanium but his will make little difference since the emitter supply is at 11V and the output is an ac coupled IF signal.

The AGC circuit is a refinement over what you might find in transistorized broadcast receiver, but not by much. The AGC is derived from the last IF output, is buffered and then rectified. The rectified voltage is added to the set point voltage provided by the RF gain control and then sent out to the various "AGCed" stages. Since this circuit does not have an AGC amplifier and reference, it is incapable of holding the IF signal constant at the detector input. Instead it relies on the non-linear gain vs. bias function of each of the various controlled amplifier stages. The result is the amplitude of the IF output into the detectors and S-meter will be a pseudo-log compressed signal.

The S-meter circuit takes advantage of and depends on the fact that the output signal of the last IF is not held constant by the AGC action. This small change in the IF output is what the S-meter circuit detects linearly and amplifies in a meter bridge circuit in order to register a 100dB signal range (but not very accurately). The S-meter bridge circuit depends on the +12V supply rail to be stable. Any change in the 12V supply changes the meter offset. This is not too big a problem as long as you are running on ac power since the there is an active 12V regulator with ac operation. But if you are running on external 12Vdc (12.7V to 13V is best because of the series protection diode) source, the S-meter offset can swing quite a bit. If you are running on batteries, expect to re-zero the S-meter continuously.

Overall the AGC and S-meter circuit is not as sophisticated as one might expect from such a renowned receiver. Any judgment about signal strength depends on band and is very relative.

Synthesizer

The most interesting thing about this radio is the synthesizer topology. This radio uses two crystals, 500kHz and 4.75MHz to synthesize 52 discrete, 500kHz increments beginning at 7.25MHz and ending at 32.75MHz. It is noted that there are sixty 500kHz bands beginning at 0Hz and ending at 29.5MHz but 8 of these increments are reused with the 26MHz oscillator and separate mixer to cover bands 1 and 2. The synthesizer is used to stabilize just the high frequency local oscillator (HFO), the VFO (main tuning knob) is a free-running oscillator and the BFO is a separate crystal oscillator.

The amazing thing about the synthesizer is that it uses no, not one, digital component. No digital dividers, no logic gates, no microprocessors, no memory of any kind. No back-up batteries to die and forever loose the program memory, no rotary encoders to fracture and fail, no irreplaceable obscure custom logic chips. Every functional element is analog and conceivably could be maintained long after more complex machines are beyond repair. But that's the only good news.

One of the novelties of the HRO-500 synthesizer topology is the use of a 4.75MHz comparison amplifier as part of the synthesizer. The HRO-500 mixes a selected harmonic from the 500kHz harmonic generator, with the output from the voltage controlled HFO to produce a 4.75MHz comparison frequency. This amplified comparison frequency is applied to a phase detector that use a 4.75MHz oscillator for a reference. The output of the phase detector steers the HFO over a very limited range.

You might be inclined to ask, why not just apply the selected harmonic from the harmonic generator directly to the phase detector along with the output of the VCO in order to get the tune control signal needed.

I think there may be a number of reasons for this plan. One of course is to get the correct offset frequencies for each band. If you examine the frequency plan you see that the first increment is at 7.25MHz, then 7.75MHz and so on. But I think if you look closer you will see that the synthesizer is not a true phase lock loop. To actually get phase "lock" you have to have an integrator in the feedback loop filter. Integrators are infinite gain amplifiers at dc (0Hz), (in control theory jargon, that would be an infinite pole at the origin) and it's my assertion that the National engineers weren't up to the task of designing a low-noise, high gain integrator using the available transistor technology at the time. What they were good at is designing high gain IF amplifiers especially at 4.75MHz. Mixing the HFO with a selected harmonic at an offset of 4.75MHz provided a convenient comparison frequency that was easily amplified. This amplified comparison frequency was of sufficient amplitude that it could be applied to the phase detector which could now produce a tune signal with a 5 volt swing. The result is exceptionally low phase noise oscillator signal for the first LO with no pesky dc amplifiers required. The only draw back is exact phase lock could not be achieved but I'm sure no one ever noticed.

Synthesizer High Frequency Oscillator Alignment

The synthesizer on this radio was actually functional as stated earlier but misaligned. I followed the recommended alignment procedure except that I used a spectrum analyzer to look at the tuned buffer amplifier output at the input to the 4.75MHz synthesizer IF amplifier. This is a far better method than using the manuals recommendation if you have a spectrum analyzer available.

The alignment was going well until I got to band 3. This required turning the slug in HFO coil, L308 (top). The slug was difficult to turn with a plastic hex alignment tool. I used a steel hex wrench to see if I could break the stuck slug loose. This did not go well and resulted in turning the coil form on its base instead and ultimately breaking the coil wires on not only L308 but also the bottom section L310 coil. I've seen this problem before with tunable inductors. It seems as though the ferrite slug forms a molecular bond with the coil form. I have not found a solvent or penetrating oil that will loosen the slug. Its been suggested that oil of wintergreen is a very active solvent with good penetrating action but I can not confirm that it will dissolve whatever is binding these slugs to the forms.

This was pretty discouraging, and I was thinking this might end up as a parts radio instead of a restoration. I remember seeing an eBay add which oddly had HRO-500 coils for sale. L308/L310 was not listed but I did purchase one that was listed as a 30MHz RF coil. I was able to use the coil form and slugs from this coil and transfer the windings from the original bad coil. With a little soldering and glue, I reinstalled this modified coil back into the L308/L310 spot and was delighted to see the HFO operating at the correct frequency.

Many of the negative issues surrounding the HRO-500 are related to a large degree on the ability of the synthesizer to "lock" on all bands or more typically, it won't lock on portions of some bands. The calibration of the synthesizer tuning is critically dependent on the alignment of the HFO. You don't need to concentrate too much on peaking the tuned buffer amplifier (unless you replaced a component) as that circuit is not very critical.

The HFO alignment procedure was written in a time when spectrum analyzers and frequency counters were not generally available. You can use that method but it's very tedious. And not very convenient or informative if something is defective. I recommend the following setup:

1. Remove only the phase detector dc amplifier transistor, Q310. You don't need to disable the blocking oscillator Q301, burst generator Q301, or unijunction sweep transistor Q311. Leave the 4.75MHz crystal X301 in as well. If fact, leaving the harmonic generator circuit operation is helpful when you are using a spectrum analyzer.
2. Connect a dc power supply, preferably one with a digital display, to the collector socket pin of the phase detector dc amplifier at Q310. You will be injecting a dc voltage at this point. Set the power supply to approximately 5V. This will be the HFO bias used instead of the method shown in the manual in Figure 31. More on this below.
3. Connect the spectrum analyzer to the input of the 4.75MHz comparison IF amplifier at R324. This will allow you to observe the HFO output signal frequency as well as the harmonic output from the burst generator. You can see a full range of these spectrum plots at http://valontechnology.com/HRO500/spectrum/
4. Connect the frequency counter to the HFO output RCA jack on the receiver rear panel.
5. Connect (somewhat optional) an oscilloscope to the emitter pin of the unijunction sweep transistor Q311. This will allow you to monitor the sweep function.

The manual has you set the HFO bias (varactor tuning voltage) to 5.0 while aligning the HFO. This assumes that 5.0V is the midrange voltage for the HFO. This is probably not the case and I recommend you find the exact midrange voltage by doing this:

1. While monitoring the unijunction emitter (this is essentially the HFO tuning voltage and will be similar to the power supply voltage connected in step 2 above), increase the power supply voltage until the unijunction triggers and starts the sweep ramping. This should occur at 8.2V (mine was at 7.7V). By the way, this unijunction threshold voltage will be dependant on and proportional to the receiver 10V supply voltage. Make a note of this voltage.
2. Decrease the power supply voltage until you find the low limit clamping voltage. This should be around 3.0V.
3. The optimum HFO bias voltage will then be the mean value or in this example (8.2 + 3.0)/2= 5.6V. This value will ensure better tuning range centering than the arbitrary 5.0V recommended.

The alignment sequence is important, follow the recommended order shown in the table in the manual in **Figure 32**. The alignment of L308 on band 5 affects the alignment of band 1 and band 2. It is important that the low end of each band be set last as indicated. The reason you want to adjust the low end of each band last is because the varactor has minimum tuning range at the low end of each band and you want the setting to be a close as possible here. The table below shows the relationship between HFO frequencies, the tuning sensitivity of the varactor (kHz/V), and the pull-in range for each of the bands. For example, on Band 3, the lowest frequency for the **Synthesizer Tune** is 4.0MHz; the HFO will be required to lock at 7.25MHz, the tuning sensitivity is 22kHz/V, and the maximum range the varactor can pull the synthesizer into lock is 88kHz.

Table 1 High Frequency Oscillator tuning sensitivity

	Band 1		Band 2		Band 3		Band 4		Band 5	
Synth tune (MHz)	0	1.0	1.5	3.5	4.0	9.5	10	19.5	20	29.5
HFO Frequency (MHz)	29.25	30.25	30.75	32.75	7.25	12.75	13.25	22.75	23.75	32.75
HFO tuning sensitivity (KHz/V)	30	58	15	58	22	50	23	50	15	58
Pull-in Range (KHz)	120	232	60	232	88	200	92	200	60	232

From **table 1** you can see Band 1 and band 2 will likely be the most troublesome in terms of getting the frequency number to be centered or even appear in the **Synthesizer Tune** window. Band 2 will definitely be a problem because not only is the varactor tuning range very limited (60kHz), but also the accuracy of the **Synthesizer Tune** drum markings are probably off. If you align Band 2 at the end points as suggested, 1.5MHz and 3.5MHz, you will probably find that 2.5MHz and or 3.0MHz will not be centered in the **Synthesizer Tune** window. I aligned band 2 not at the end points but at 2.0MHz and 2.5MHz and **Table 2** below shows the result (HFO bias voltage connected), this method gave the best results. As you can see from the table, with 1.5MHz centered in the **Synthesizer Tune** window, the center of the HFO center frequency is 77kHz high. With only about 60kHz "pull-in" range, the synthesizer will appear not lock. You must then adjust the **Synthesizer Tune** below the 1.5MHz number indicated to the point where it may not even be visible.

Table 2 Band 2 HFO alignment results

Synthesizer Tune (MHz)	HFO Frequency	Nominal Frequency (MHz)	
1.5	30.827	30.750	
2.0	31.257	31.250	Alignment point
2.5	31.695	31.75	
3.0	32.254	32.25	Alignment point
3.5	32.851	32.75	

This may also happen to a lesser degree at 2.5MHz and probably not at 3.5MHz. I simulated this circuit to verify that what I was seeing was indeed the design. I measured inductor L308 at 0.32- 0.47 uH, assumed the air variable capacitor C332A and C332B had a range of 15-150pf, and the varactor had a range of 20-50pF over the 3-7volt range.

It's clear to me that this is a design defect and caused by the use of L308 for more than one band. L308 should have just been used for band 5 while separate inductors used for band 1 and band 2. Using separate and larger valued inductors on band 1 and especially band 2, would have allowed the capacitor ratios to be such that the varactor would have more range. Alternatively, since band 5 and bands 1 and 2 have similar frequencies, just adding a second set of windows to the drum dial calibration would have also worked with only some potential user ambiguity as to which window to read. In any case, if you are struggling to align your HRO-500 on band 2 without much success, take solace in the thought that it was probably never quite right and can't be made right with the existing design.

As a final note on the subject, I suspect that many failure to lock problems are misdiagnosed. The real culprit in some cases may simply be that **Synthesizer Tune** calibration will not allow the lock to occur at the dial indication. Turning the **Synthesizer Tune** control beyond where the frequency appears in the window will usually find the correct lock point.

Spectrum Generator

I found no significant problems with the Spectrum Generator function in my receiver. The output levels of the harmonics where improved when I replaced the 100 ohm and 150 ohm resistors. For reference, I've included plots of the actual Spectrum Generator waveforms and compared them to illustrations from the manual.

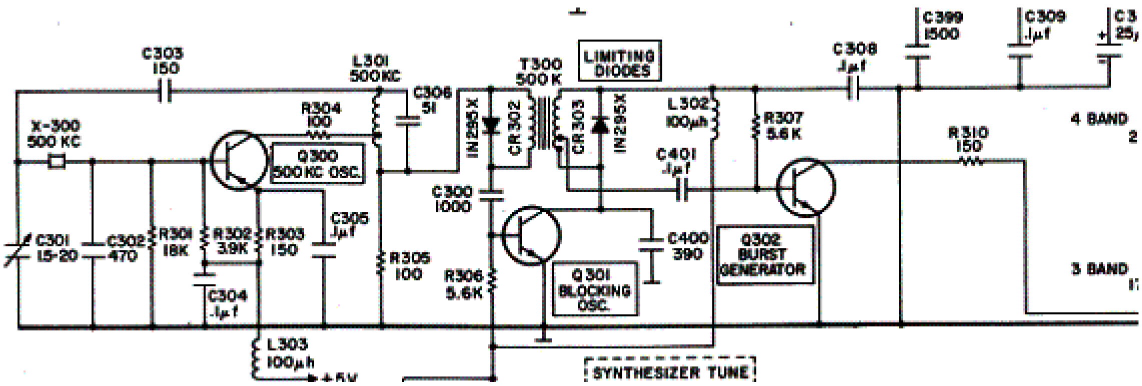


Figure 2 Synthesizer harmonic generator

The following plots show the actual oscilloscope waveforms recorded for the harmonic generator circuit shown above. Compare these plots with those shown in the National manual.

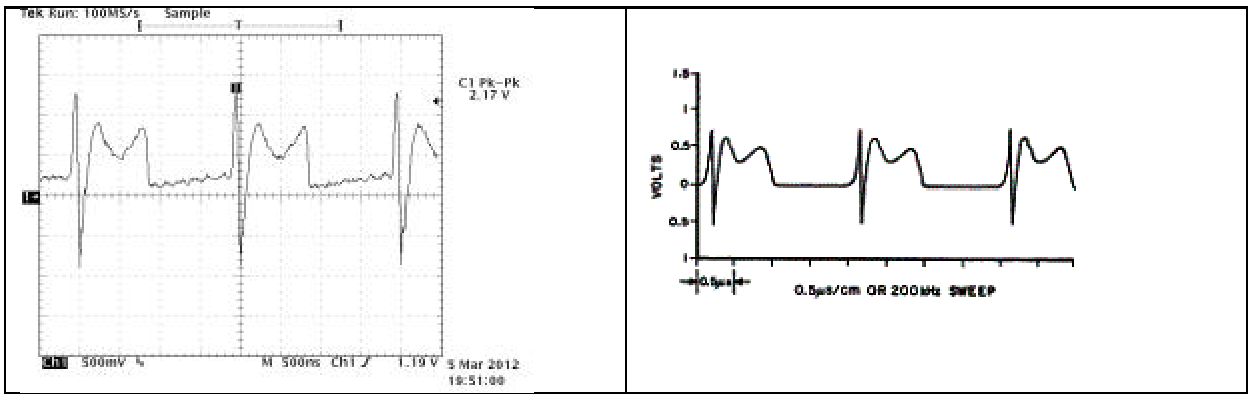


Figure 3 500kHz oscillator waveform as seen at R305, left, and as illustrated in the manual Figure 21, right.

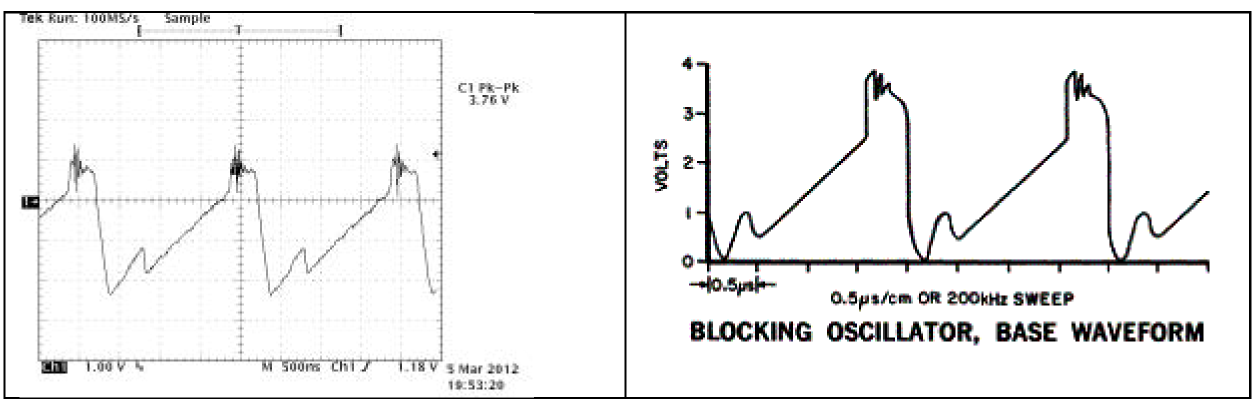
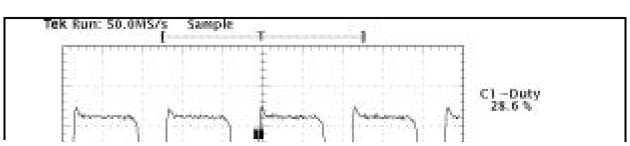


Figure 4 Q301 blocking oscillator base waveform as measured, left, and as illustrated in the manual as Figure 22, right. Note that the manual illustration does not show the actual dc offset of the base waveform but does represent the amplitude correctly. The actual waveform has a large negative component due to the base conduction on positive peaks.



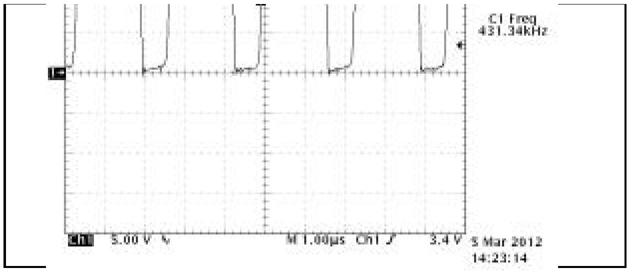


Figure 5 Q301 blocking oscillator collector with 500kHz crystal removed. Notice that the free running frequency is 14% lower than when the blocking oscillator is synced to the 500kHz reference oscillator. This is normal and a good check of the blocking oscillator operation.

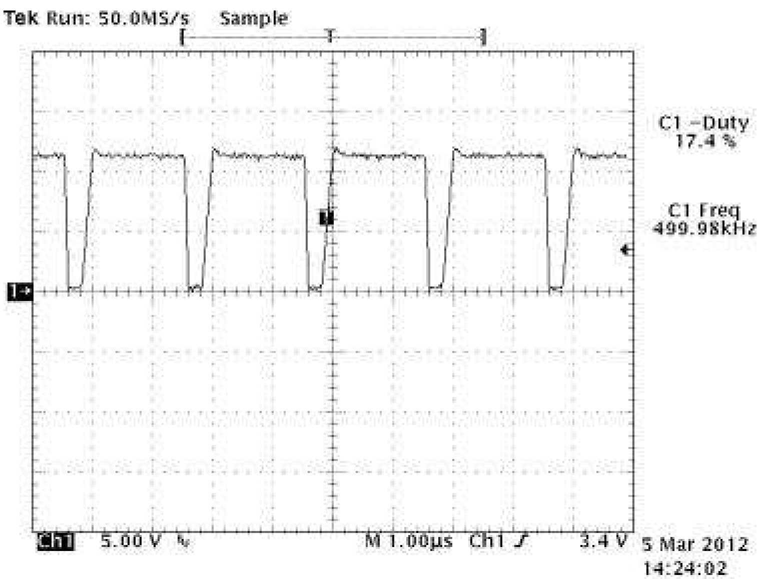


Figure 6 Q301 blocking oscillator collector normal operation

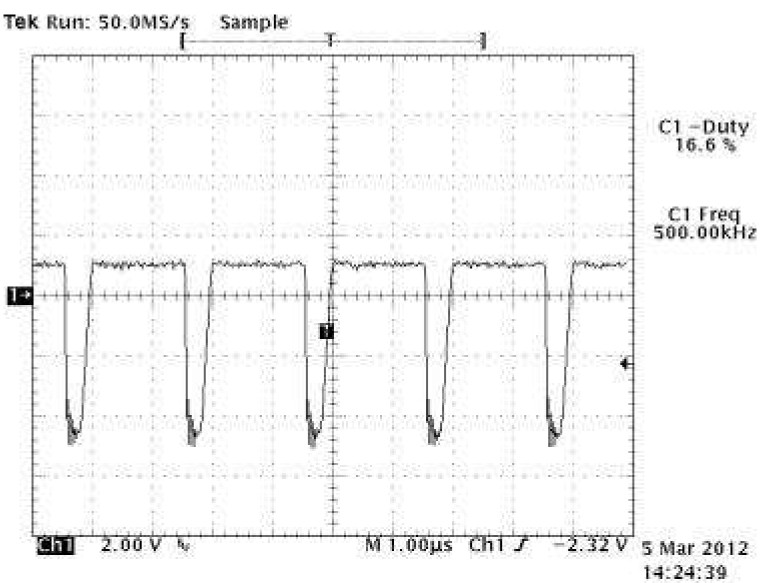


Figure 7 Q302 burst generator base

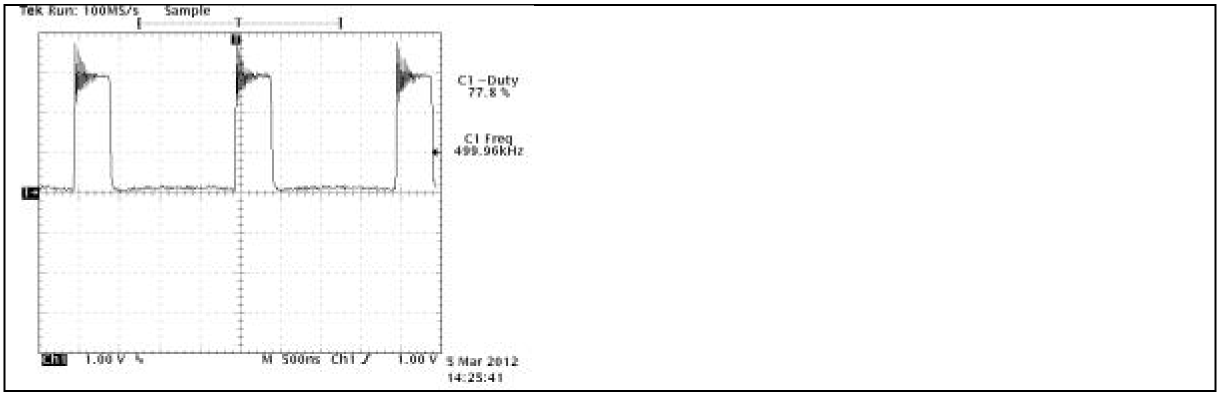


Figure 8 Q302 burst generator collector waveform

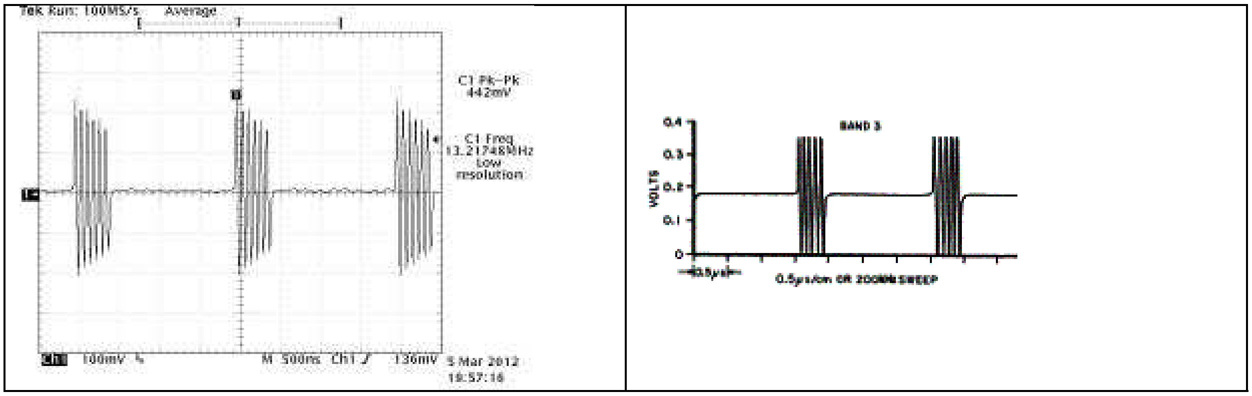


Figure 9 Spectrum generator output for Band 3 as seen at junction of C345 and C346, left, and as illustrated in the manual Figure 24.

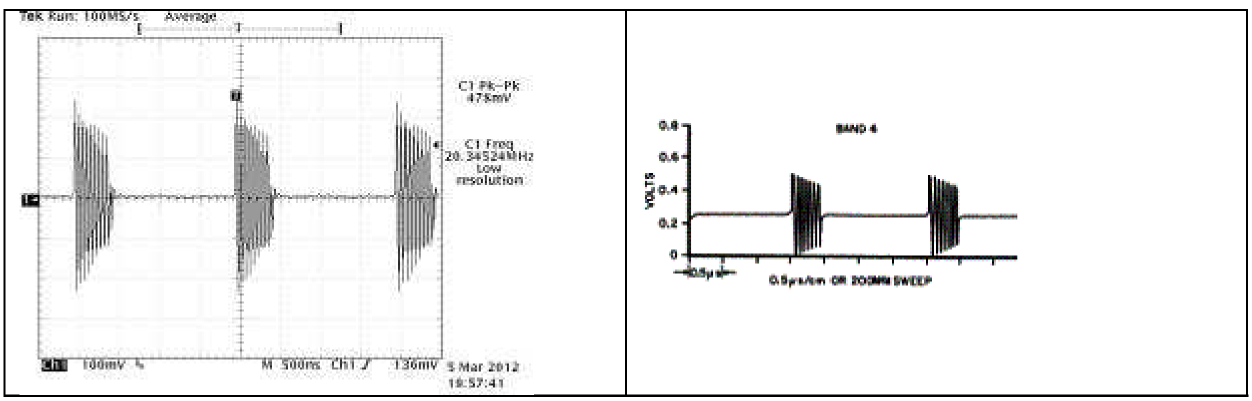


Figure 10 Spectrum generator output for Band 4 as seen at junction of C345 and C346, left, and as illustrated in the manual Figure 24.

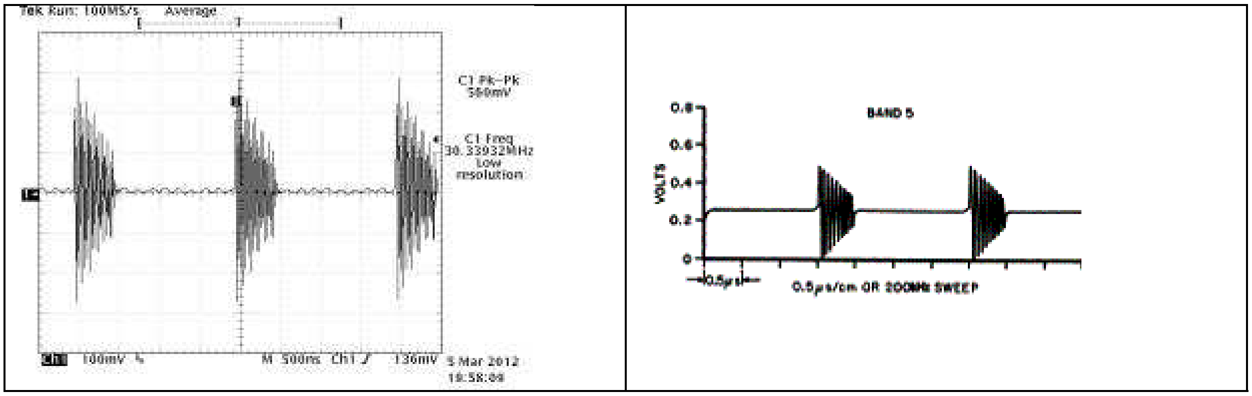


Figure 11 Spectrum generator output for Band 5 as seen at junction of C345 and C346, left, and as illustrated in the manual Figure 24.

Overall, the amplitudes of the measured waveforms compares well with the illustrated waveforms in the manual except for the implied dc offset shown in the illustrated waveform.

The manual refers to synthesizer sweep checks (page 43 fig. 33 and fig. 34) when trouble shooting synthesizer lock problems. Q308 is the last amplifier stage in the synthesizer's 4.75MHz comparison amplifier and a reference point for looking at the sweep/lock operation. When locked, this will be a constant amplitude, 4.75MHz, cw signal. When near locked, the waveform will be 20Vpk-pk, 4.75MHz burst pulse at the sweep rate. The manual only illustrates the waveform at Q308 when the near locked condition is approached from the low frequency side as shown below.

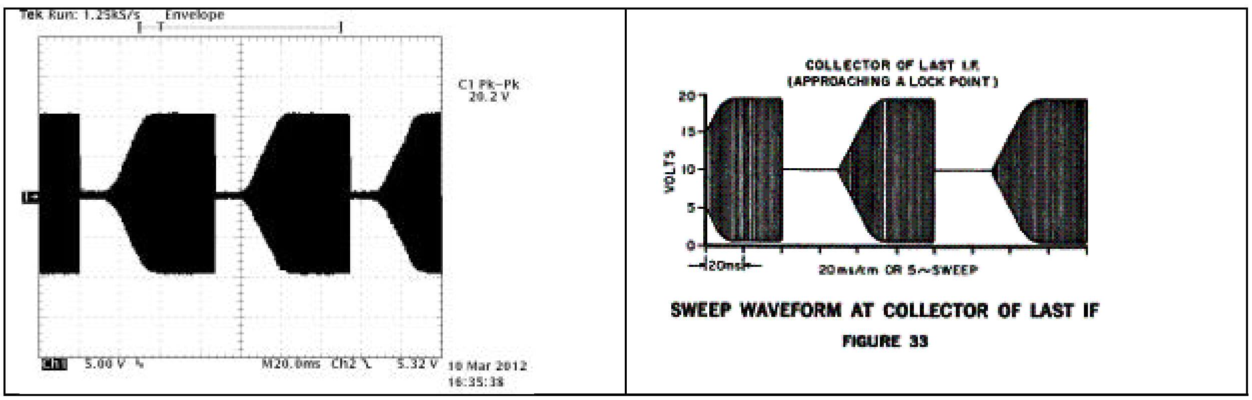


Figure 12 Q308 collector waveform as the synthesizer is approaching lock while adjusting the **Synthesizer Tune** control from the low frequency side. Actual measured on left and illustration from manual on the right.

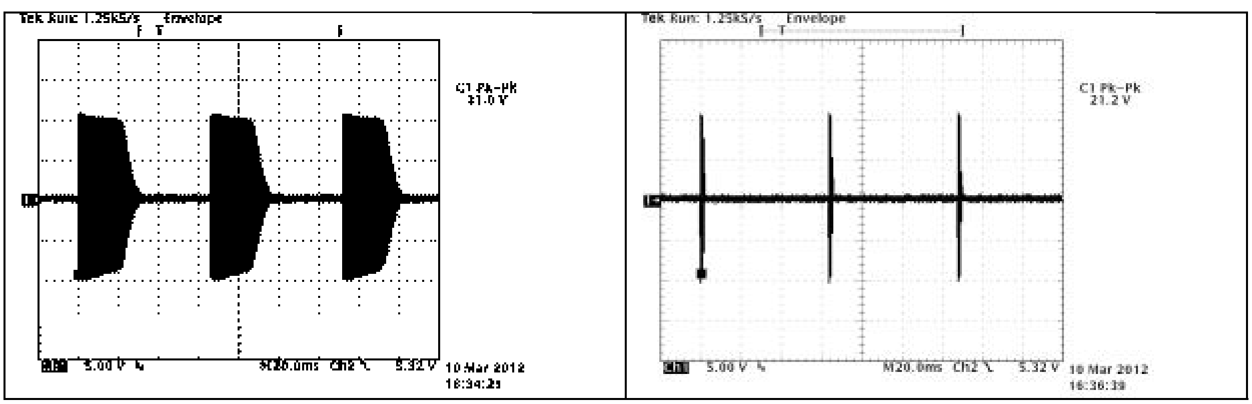


Figure 13 Waveform at Q308 collector as the synthesizer is approaching lock while adjusting the **Synthesizer Tune** control from the high frequency side left. Waveform at Q308 collector when the **Synthesizer Tune** control is adjusted away from a nearby lock point.

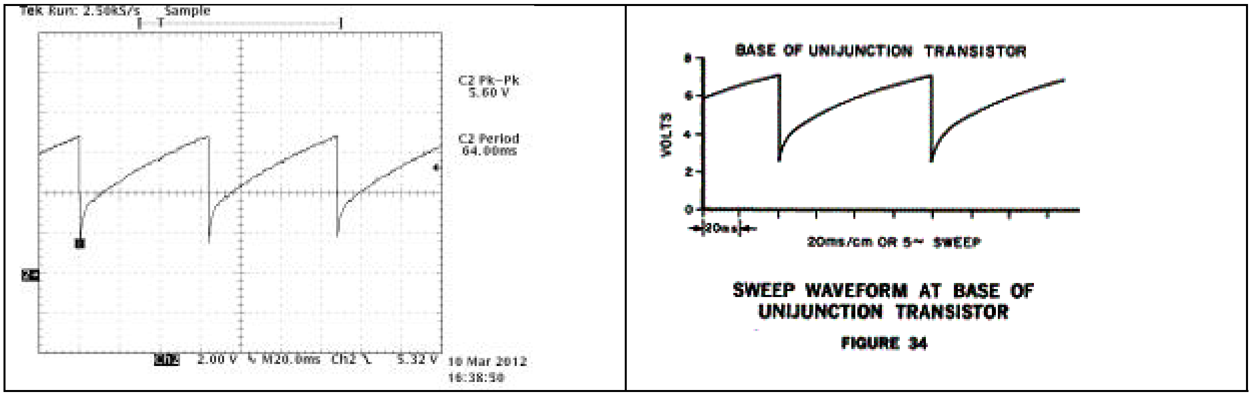


Figure 14 Waveform on the left is at the base of Q311 when the synthesizer is not locked. The sweep period illustrated is 80ms.

The illustrate sweep waveform has period of 80ms but the measured sweep period on my receiver was originally less than half that at about 30ms. I increased the sweep period from 30ms to 60ms by doubling C374 from 1uf to 2uf. Slowing down the sweep rate should allow the synthesizer a bit more time to lock.

Lock Detector Circuit

The lock detect circuit is pretty simple and mine functioned well. The circuit simply detects if the unijunction ramp generator is sweeping the tune voltage. It does this by detecting the ac signal and turning on the lock detect indictor lamp. When the synthesizer is locked, the tuning voltage will be at some steady state between 3V and 8V.

The lock detector circuit also provides a mute switch (Q16) which disables the last IF amplifier whenever an unlocked condition exists. I would like to recommend that you try removing Q16, which would disable the mute function. When the mute function is disabled, you will here a soft puttering sound if the synthesizer is unlocked. This can actually be a tuning aid and will assist you in finding the correct lock when adjusting the Synthesizer Tune control.

Up-converter Passband Alignment and Preselector Alignment

Band 1 and Band 2 use coupled inductors T6 and T7 to provide tuned bandpass filter for the up-converter. My receiver was fairly misaligned on Band 1 and required tuning of T6. The bottom alignment slug of T6 was frozen and could not be turned. This required removing the T6 can from the chassis, removing the coil form, and breaking out the ferrite slug. I was able to find a replacement slug from a similar part on eBay.

Band 2 passband alignment was okay and no adjustment was need. However, if adjustment was needed it may not have been possible since the top alignment slug of T7 was found to be stuck. Since the alignment wasn't really required, I did not bother to remove and replace the tuning slug.

Conclusions and thoughts

I believe a certain mystique has been developed around the HRO-500 as the ultimate receiver. The HRO-500 is an obvious first attempt to build a solid-state radio for the sake of saying it was all sold-state. The National engineers must have been under pressure to get an all transistor receiver into the market in order to shore up the company's flagging prestige as an innovator.

A Collins 51S-1 would have been available for around the same time and cost and would be a superior, albeit vacuum tube, general coverage radio. A Drake 2B receiver, also vacuum tube based, would also have been available at much less cost and offered better ham band only performance.

I also feel the accolades about the HRO-500 mechanical construction are a bit overrated. The chassis and sub-chassis modules are held together with self-tapping sheet metal screws. Cover assemblies are rather rough sheet metal parts also secured with large clearances and sheet metal screws. The below chassis wiring is point-to-point and components are suspended on phenolic terminal boards. These terminal boards are fragile and cannot tolerate much mechanical or thermal stress before the terminals break loose. The wiring and soldering workmanship is also below standards. The best practices would be to loop the component leads through the terminal lugs with at least a full turn. In this radio, the component leads were just placed in the terminal eyes without and mechanical restraint and relied on the solder joint for mechanical stability. Using short and direct component leads and connections for high frequency circuits was followed to well.

The synthesizer was the unique feature of the receiver in its day. The synthesizer could produce stable 1st local oscillator injection signals in 500kHz increments. However the receiver did still use a free-running VFO for the second local oscillator and still another crystal controlled BFO. The synthesizer generates a comb of harmonic frequencies from a 500kHz crystal, but requires a 4.75MHz offset crystal oscillator to phase lock the high frequency oscillator for the 1st local oscillator. As a result, the accuracy and stability of the receiver is dependent on the 500kHz harmonic generator, the 4.75MHz offset oscillator, the tunable VCO, and the 2nd IF center frequency/BFO frequency. The result is that holding 1kHz accuracy is difficult for any length of time.

The HRO didn't use any crystal filters or mechanical filters to provide the various selectivity choices. Instead, a 6-pole LC network that was gang-tuned with a 6-section air variable capacitor was implemented. This arrangement provided the selectivity a form of pass-band tuning. The problem with this technique is that it is difficult to align precisely and maintain over time.

The designers must have been exhausted by the time they got to the product detector. This is just a pair of diodes in very simple single balanced detector design and suffers from linearity and dynamic range problems. The AGC is also derived from the output of the last IF amplifier. A better approach would have been to use audio derived AGC, which would have improved the SSB audio quality.

It seems odd that they used sockets for the transistors and I suspect this was a holdover from a vacuum tube mindset. The resistors and capacitors used are not high quality components. Also the die-cast front panel bezel hides the rather cheaply contrasted chassis held together with sheet metal screws.

The radio uses many germanium, mostly PNP, transistors. There are a few silicon NPN transistor used in the RF amplifier, Spectrum Generator, and various other places. The designers can't be faulted for using germanium PNP transistors since, at the time, that's what was reasonably available. What I do take issue with is the transistor biasing. The radio has 37 transistors and with the pilot lights switched off and the audio gain at minimum, the total 12Vdc input current is only 150mA. Most of that is the quiescent current in the class-B audio amplifier. The RF and IF signal processing stages only draw about 1mA each. There is hardly any wonder that this radio has dynamic range problems when its mixers and amplifiers are so current starved. The noise figure of the 2nd mixer is very high and contributes to large degree to the noise floor of the receiver. This is probably due in part to the minimal LO injection from the VFO. A mod that may improve the receiver noise floor is to increase the coupling between the VFO and VFO buffer from the current 1/50th to something a bit larger in order to provide more 2nd mixer injections signal.

This radio may give some clues as to why the American amateur radio manufacturing disappeared. Perhaps American manufacturers were putting so much effort into developing these early solid-state designs they were unable to put resources on more advanced digital development. The foreign competitors could take advantage of these early designs to develop lower cost and more efficient radios, which were released in the early seventies thereby leap-frogging the Americans in the marketplace.

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