902MHz TX for the IC-901

By Joseph Haas, KEØFF
9/02/2016
joeh-*at*-rollanet-*dot*-org

Introduction

I have always been interested in microwave circuits but have not pursued very many designs in the world above UHF. Time has been the common culprit with motivation and resources not far behind. My recent acquisition of a spectrum analyzer with profound coverage in the microwave region and subsequent design of a microwave PLL source using the ADF-4531 (Figure 1) have made a big dent in the "resources" and "motivation" aspects of this problem. Time, of course, is always short, so sometimes you just have to make time to have it.

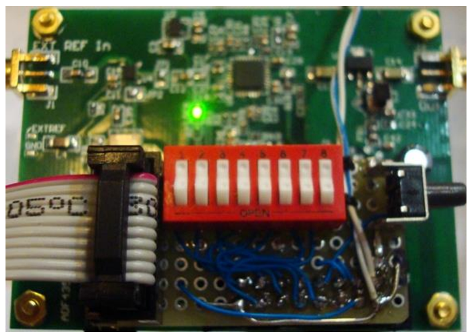


Figure 1. Orion PLL, with coverage from 35 to 4400 MHz

I have known about the amateur privileges on 902 MHz for some time, and have been interested in getting active there. I was recently introduced to one of the local 902 MHz repeater gurus and the fire to get on the band was re-ignited.

Yet Another Project

While commercial gear is readily available for the band, this is not an attractive alternative considering that I am generally not an appliance operator and am looking to fire up projects in the microwave region. Admittedly, by most definitions, 902 MHz is not technically microwave, but instead, is more properly designated as the high-end UHF. Still, it is painfully close, and thus seems to represent a good place to get on to the microwave bandwagon.

At first, I considered a transverter. This is the typical entry pathway for someone who has a decent radio, but which lacks coverage on the new band. 902 MHz represents a particular challenge in that, at around 2.6 KHz, the FM deviation is roughly half what other amateur bands utilize. For a transverter, this means that the deviation control on the base-band radio would have to be changed to match the NNBFM (Narrow-Narrow Band FM) requirements. If that radio is to be used on other amateur bands along with the 902 MHz band, provision would have to be made to accommodate dual deviation controls that can be selected by the operator. This starts to become rather complicated and increases the integration risk.

Since I already have an ICOM IC-901, my goal was to make a transverter using an ICOM UX module, placing this module on the IC-901 module address for the 1200 MHz, UX-129 module. In this way, the module could have its own deviation control, and be easily switched into or out-of the radio stack by simply selecting the 1200 MHz band on the IC-901. A microcontroller could read the UX-129 PLL data and morph this into a 902 MHz frequency. It seemed an interesting approach. However, morphing the frequencies would not be easy. Firstly, a microcontroller application to read and interpret the PLL data would have to be designed (not difficult, but time-consuming). Then there was the problem of frequency step: the F-step on 1200 MHz is 10 KHz (at least for the IC-901) while the band-plan for 902 MHz generally calls for an F-step of 12.5 KHz. Trying to get 12.5 KHz from a 10 KHz system that would be easily human-readable would be a serious challenge.

Then, I remembered that the UX-R91, the wide-band receive module for the IC-901, covered the 902 MHz band. My IC-901 had that module in the stack, so I tuned in the “local” repeater and was surprised to find that I could receive it, in spite of the fact that I was using a dipole tuned for 100MHz. This development was intriguing as it now changed what was possible. Instead of a transverter, I could now simply build a transmitter, and use the receive module to accomplish the transceiver functions (this approach would also allow the possibility of full-duplex operation).

Having just built the first article of my Orion-I microwave PLL source, this was the front-runner for the exciter. Although not necessarily the best, it had the advantage that it covered the band of interest and it was readily available. All that would be needed to produce a transmitter was a modulator, some filtering, and a PA. By using the faux UX-129 idea from the transverter straw-man, I could easily produce a module that would interface with the IC-901, if only on a single channel (for the moment, this is not a serious limitation since only one repeater is in range of my home).

The Block Diagram

Figure 2 illustrates the block diagram. I decided to morph the ICOM module naming convention and christened the new 902 MHz module as the “UX-902”. A Front Unit board from one of my idle UX modules will perform the interface to the IC-901 stack. A simple solder jumper change sets the unit address to the UX-129 setting. This then provides PTT, High/Low power select, unit power-on, and modulation audio to the transmitter. Since the IC-901 handles audio shaping and CTCSS injection in the base unit, the modulator for the PLL is simplified.

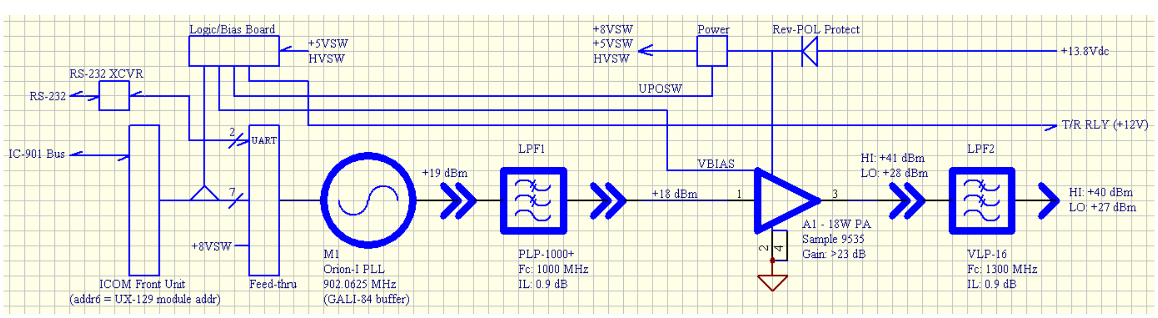


Figure 2. “UX-902” block diagram

A Cu-clad, FR-4 box was constructed to house the transmitter. It has the same width and approximate length as a UX module, but is somewhat thicker to accommodate the 2" heat spreader I decided to use for the PA. The box was designed with internal separators to isolate the PLL, PA, and non-RF circuits. In the end, this would have been much easier to accomplish with separate enclosures joined together. Electroless Ag plate was applied to contact surfaces and to the PA grounding flange. This was primarily due to the fact that these were to be wiping contact surfaces, but the silver plate also reduces the RF resistance.

A diode-less reverse polarity circuit was employed to protect against reverse polarity power while providing a minimum voltage drop. A P-FET switch with the drain and source reversed accomplishes this task. If one neglects the gate for a moment and assumes that the FET is biased in the OFF state, it can be seen that the FET body diode will be forward biased for normally applied power and will allow current to flow. For reverse polarity power, the body diode will block current flow. Thus, with the gate biased off, the FET behaves as a standard diode.

However, for this circuit, the gate is grounded (the Vgs zener simply provides a voltage limit to protect the gate from over-voltage) which biases the FET ON when the polarity is normal. With the transistor turned on, the Id and Rds(on) of the transistor set the voltage Vds voltage drop. By choosing a low Rds(on) transistor, the Vds drop can be made to be lower than that afforded by a low-loss Schottky diode. With reverse polarity power, the gate is biased beyond cut-off, and the body diode blocks current flow, so only the off leakage current of the FET will flow through the load (typically, this will be only a few μA or less). For a FET with an Rds(on) of 0.007Ω, the break-even current is about 10A, assuming a 0.7V diode for comparison (most good Schottky diodes will drop more than 0.7V at 10A). For this project, 5A is well above the maximum expected current.

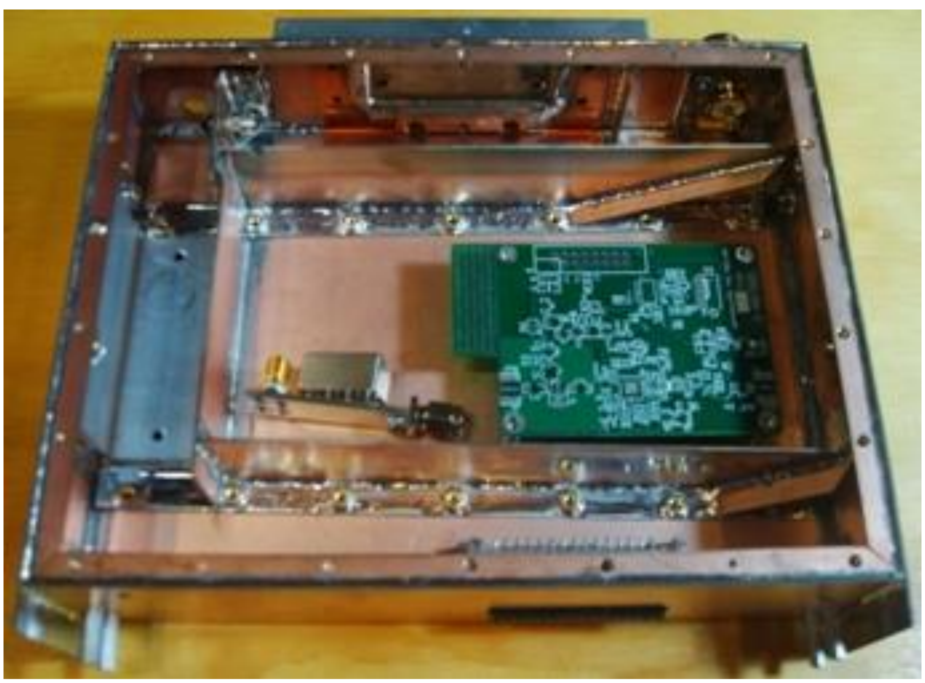


Figure 3. 902 TX chassis mock-up

Figure 3 illustrates the Cu-clad box with some of the internal artifacts assembled as a mock-up. Ag-plated brass shield lids will be used to cover the PLL (center-right) and PA (rear-right) sections at final assembly.

The ~~Problems~~ Solutions

The Antenna and Receiver

To improve reception, and eventually increase ERP, an 11 element beam was constructed. The beam construction proceeded well, but the tuning was hampered by the large shorting bar that was fabricated for the gamma match. A much smaller strap would be a better solution and will be attempted in the future. The antenna was mounted on the same shelf as the IC-901 (the IC-901 base is installed on an upper shelf in an upstairs closet, while the operating point in a room on the lower floor) with a Sinclair duplexer between the RX and the antenna. This would hopefully allow full duplex operation once the TX was completed.

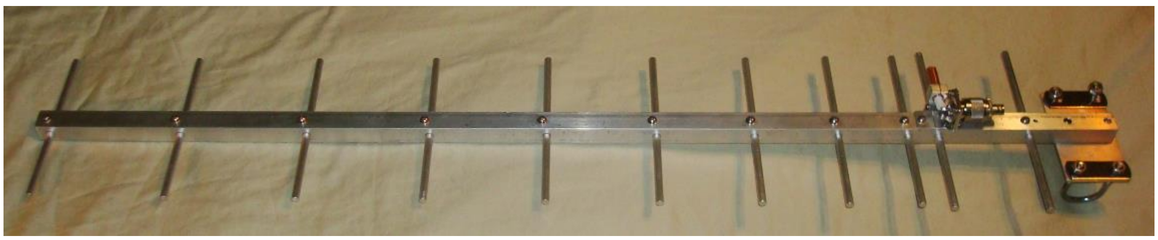


Figure 4. 11 element, home-brew beam for 902 MHz

However, the performance with the beam was not significantly better than with the 100 MHz dipole. After listening to the remote repeater for a time, I decided that the receiver was off-frequency (low-deviation audio, like courtesy tones, was perfectly readable, but operator speech was garbled). After performing an alignment, this diagnosis seemed to be supported as the LO was found to be about 2.5 KHz off frequency. Performance improved greatly, but later declined again. I either need to replace the LOs with a TCXO (small, SMD modules are readily available on virtually any frequency) or replace the variable reactance components.

I actually have two RX-91A modules, and later re-tuned the second unit and swapped it for the recalcitrant one. This made a big improvement in reception so long as it does not later degrade like the first module (so far, so good).

The Software

The Orion software was modified for this project. The modification allows the software to quickly transfer the serial data to the ADF4351 to enable or disable the PLL when the PTT changes state. In addition, a KEY signal is produced to allow some delay to be added to the transition between PTT states. This allows the T/R switch to stabilize (/PTT going low, or TX mode) before activating the PLL, or to have the T/R relay wait for the PLL and PA to de-activate (/PTT going high, or RX mode).

The Modulator

The modulator posed some problems as well. The typical PLL modulation scheme is to mix the modulation signal with the loop-filter output and apply this combination to the VCO. Furthermore, the loop filter generally needs to be set below the lowest frequency range of the modulation spectrum. This tends to slow the PLL lock, but is necessary to prevent the loop-filter/VCO combination from filtering out the modulation signal.

For the ADF-4351, a relatively wide-bandwidth loop filter is typical and this helps improve lock time and reduce noise in the synthesizer output. Thus, applying a modulation signal to the VCO's VTUNE input causes the modulation to be high-pass filtered. This must be countered by applying a low-pass filter in the modulation circuit.

One of my Ham colleagues (Ben, NO5K) spent some degree of effort designing a modulation test bed for the Orion-I board. This was basically to accomplish what I was trying to do, but without using a radio. Thus, all of the circuits needed to condition the microphone audio (biasing, buffering, and shaping) as well as CTCSS and DPL capability were placed onto a prototype board so that the modulation characteristics of the system could be measured. While much of this was unnecessary for my project, his work proved that the Orion board could be FM modulated, and confirmed the high-pass characteristic of the PLL's wide-band loop filter.

In the panel for the Orion PLL boards, I placed a SMD prototype area adjacent to two of the Orion boards. I had not yet cut out all of the Orion boards, so I was able to remove one with a portion of the prototype area still attached to the Orion board (this can be observed in Figure 3). This would allow for a small space in which to place the modulation buffer and filter. I used two, dual op-amps: one as a differential amplifier to buffer the modulation signal from the ICOM front-unit and also provide a Vcc/2 buffered bias voltage. The second dual op-amp was to be used as a possible 2nd LPF pole, and VTUNE driver buffer. This worked well and resulted in reasonably good modulation audio.

The RF Filters

I was able to obtain some MiniCircuits PLP-1000 LPF modules with the intention to use them to filter the Orion-I output. The ADF-4351 harmonic content is notoriously high when used in the low-noise mode, so filtering at its output is important. After a couple of tries, an in-line module was constructed that exhibited very good attenuation over the range covered by the first few harmonics of 902 MHz. A home-brew discrete-element LPF for the PA was planned, but I found and obtained a pair of MiniCircuits VLP-16 in-line filters just in case I had problems. As it turned out, I ended up using the VLP-16 to filter the PA output. This resulted in better than -58 dBc for all harmonics below 4.6 GHz.

The Heat

The PA I used was a Motorola prototype module that was very similar to the NHW913. It was designed for +20dBm input, but I was only supplying it with a scant +10 dBm. To get 5W out with this drive, I had to run the bias up to nearly 5V. This drives the DC power dissipation of the module up. In fact, at 5W out, the DC power input is about 27W. This gives an efficiency of about 17%. Not good even for a poor class-C amplifier.

To combat this, I had to increase the drive level so that I could then reduce the bias. I considered another out-board module, but it would be simpler to find a different buffer amplifier for the Orion-I. The Mini Circuits GALI-84+ has about 23 dB of gain, with an IP1 output level of +20 dBm, and it uses the same package as the GVA-62 which is used as the buffer amp on the Orion PLL. This would allow the Orion to produce about +19 dBm of Po, or about 80 mW at the input to the PA.

This represents an input level that is more consistent with the design point of the PA and allows the bias to be reduced, with a corresponding reduction in the DC input power to the PA. Ultimately, this should improve the efficiency to better than 40% and will also allow higher power levels to be reached.

Again, with the Antenna

With the UX-902 installed and operational, the problems with the Yagi came to a head. The basic problem with the match is that it was very narrow-band. A match at the RX frequency would not be a suitable match for the TX, and vis-à-vis. This, coupled with the fact that I was unable to get sufficient rejection in the duplexers (the UX-R91A is not well shielded and this serves to defeat the efficacy of the duplexers) has forced me to a split antenna solution.

A 77ft run of ½" heliax that was collecting dust was deployed to locate the TX antenna up and away from the Yagi near-field. This improves the duplex function and allows a resonant TX antenna to be used without impacting the RX antenna.

Conclusion

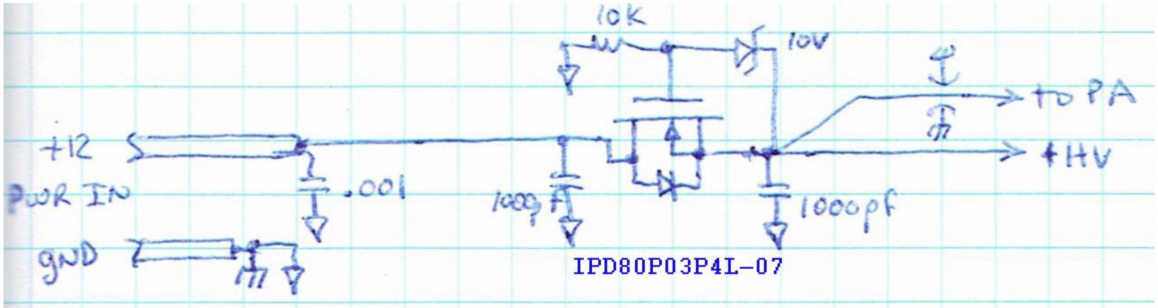
While this project did not involve much actual RF design (the PA filter was to be the bulk of such activity and that was abandoned, at least for the moment, in favor of an off-the-shelf solution) it has at least gotten me started on the road to higher frequencies. I still need to produce a 902 MHz mobile installation, and will be pressuring myself to build a discrete PA for that application (likely, with a re-use of the UX-R91/Orion topology).

Overall, the project was reasonably close to the desired target and seems to work well considering the obstacles.

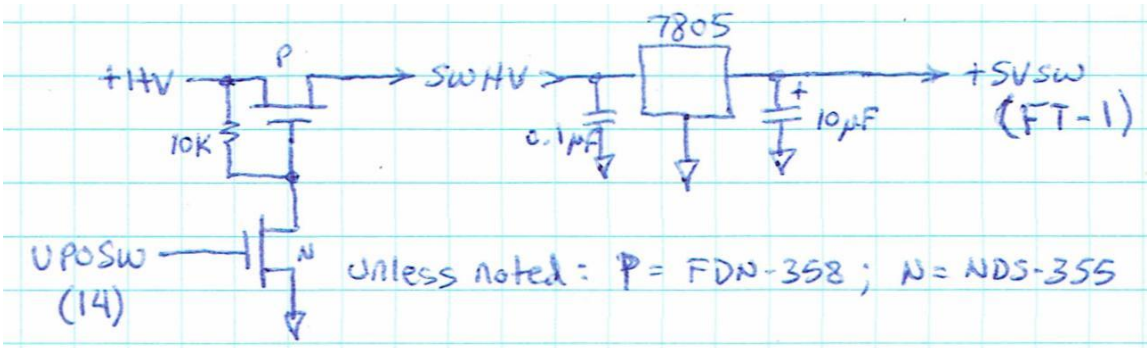
Bibliography:

1) "ICOM UX Module Design Guide", 12/08/2012, Joseph Haas, KEØFF, http://www.rollanet.org/~joeh/projects/ICOM_Design_Guide.pdf
2) "Orion Operating Manual", 8/17/2012, Joseph Haas, KEØFF, http://www.rollanet.org/~joeh/projects/Orion/
3) Yagi Calculator Spreadsheet: "DL6WU.xls", as downloaded July, 2016, http://www.df2ck.de/tech/23cm_yagi/DL6WU.XLS
4) Datasheet: "MHW913/D", Motorola, Inc. (now NXP), Rev 3, 1997
5) Datasheet: "PLP-1000+", Mini Circuits, http://www.minicircuits.com/
6) Datasheet: "VLP-16", Mini Circuits, http://www.minicircuits.com/

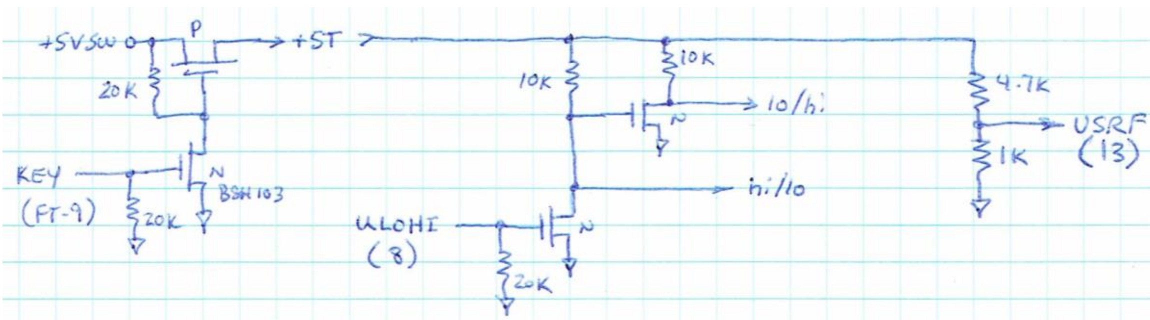
Image Gallery



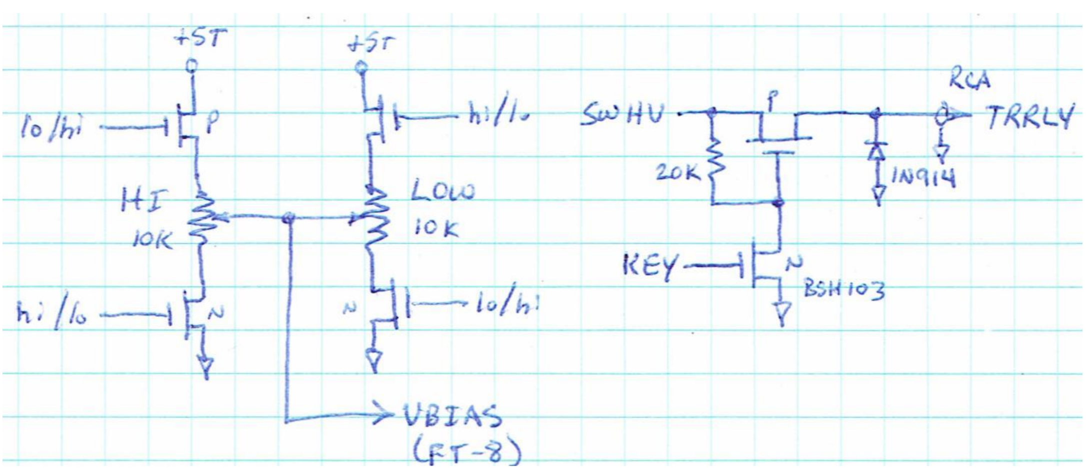
Power input and reverse polarity circuit.



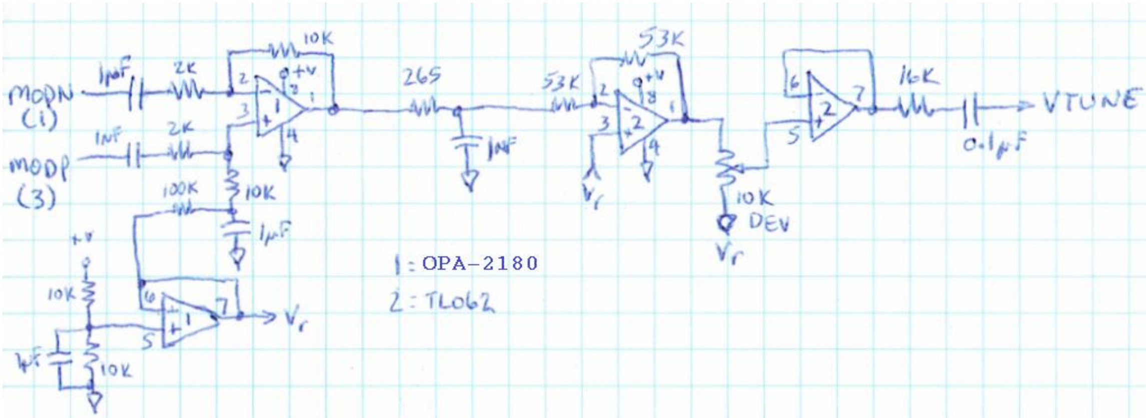
Module power control & 5V regulator.



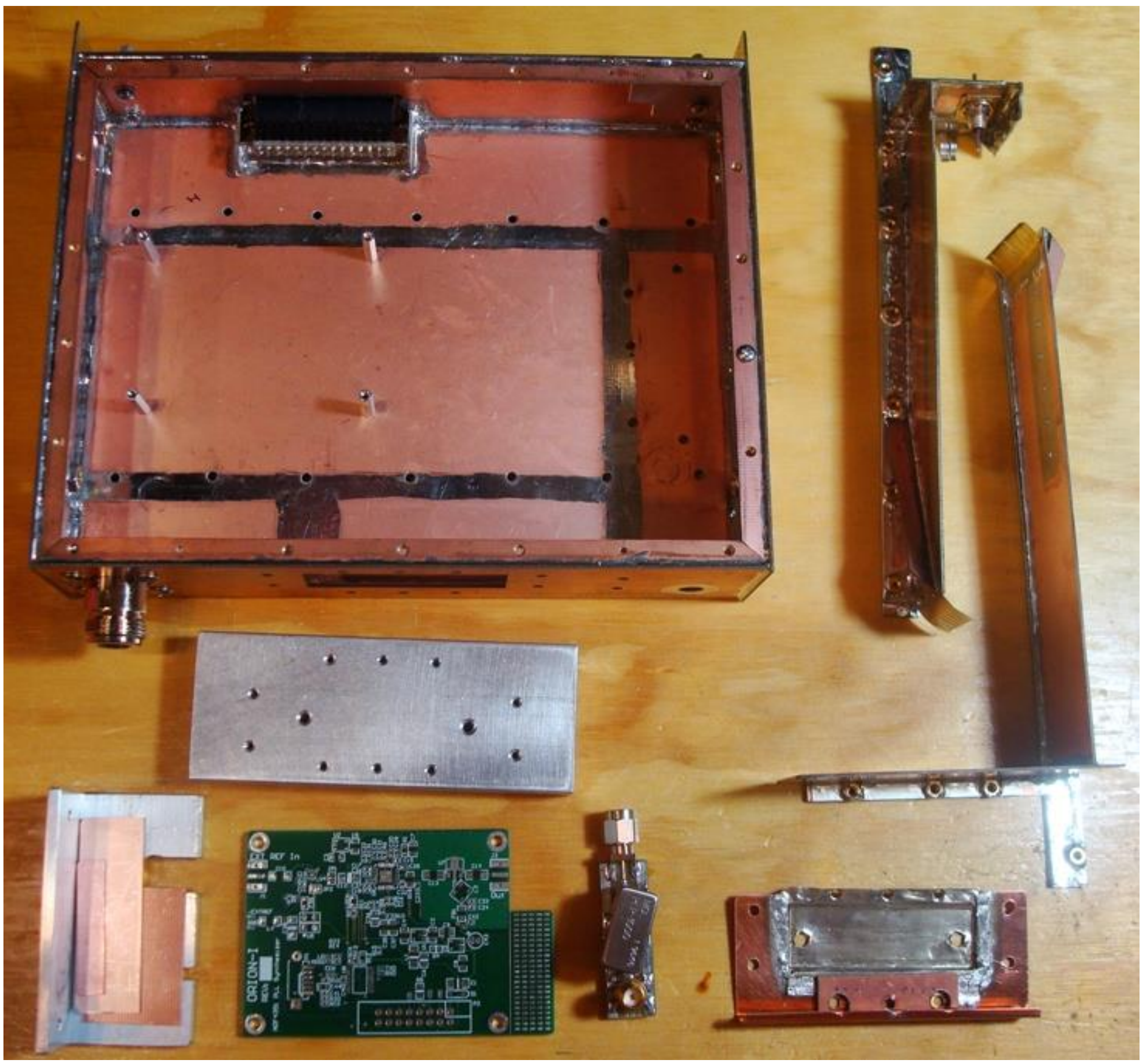
KEY and High/Low power logic: USRF presents a small voltage in TX and 0V in RX so that the IC-901 RF/SMET indication is correct.



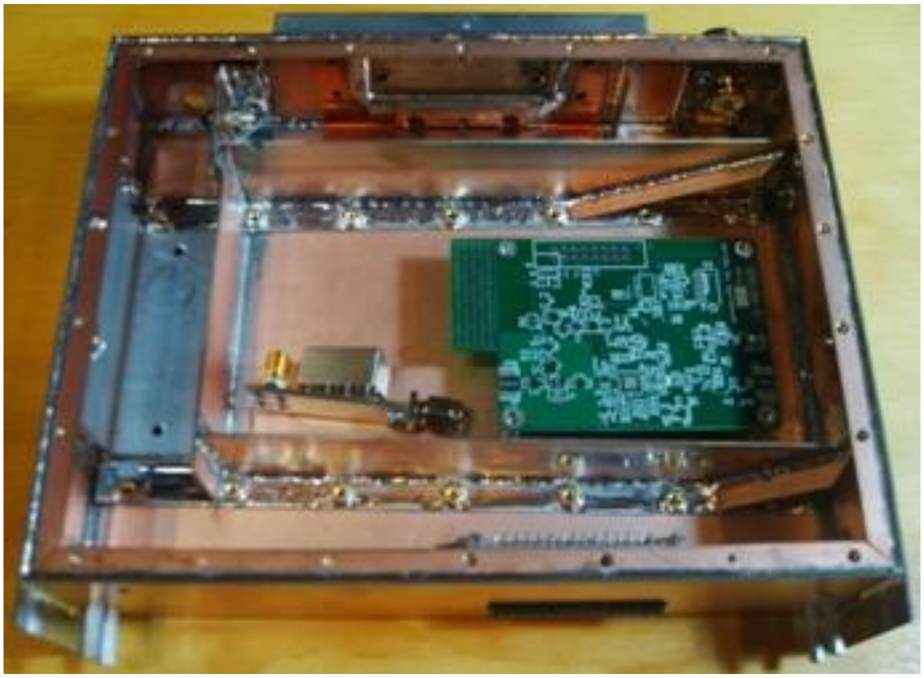
High/Low VBIAS selection and T/R relay drive.



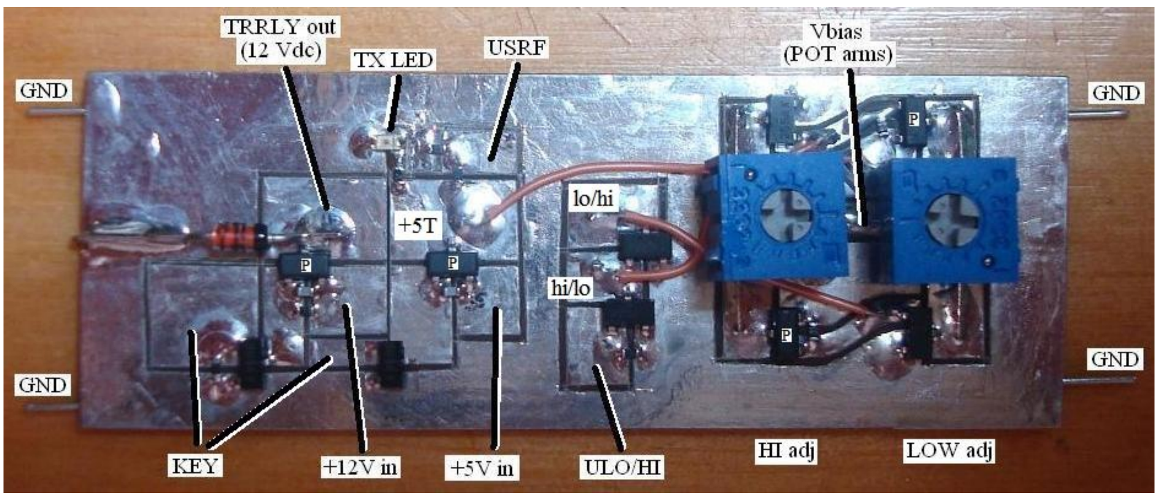
Modulator buffer and conditioning circuit: The 265Ω and 1uF capacitor (a film type) form a 600 Hz LPF to counter-act the HP effect of the PLL loop filter.



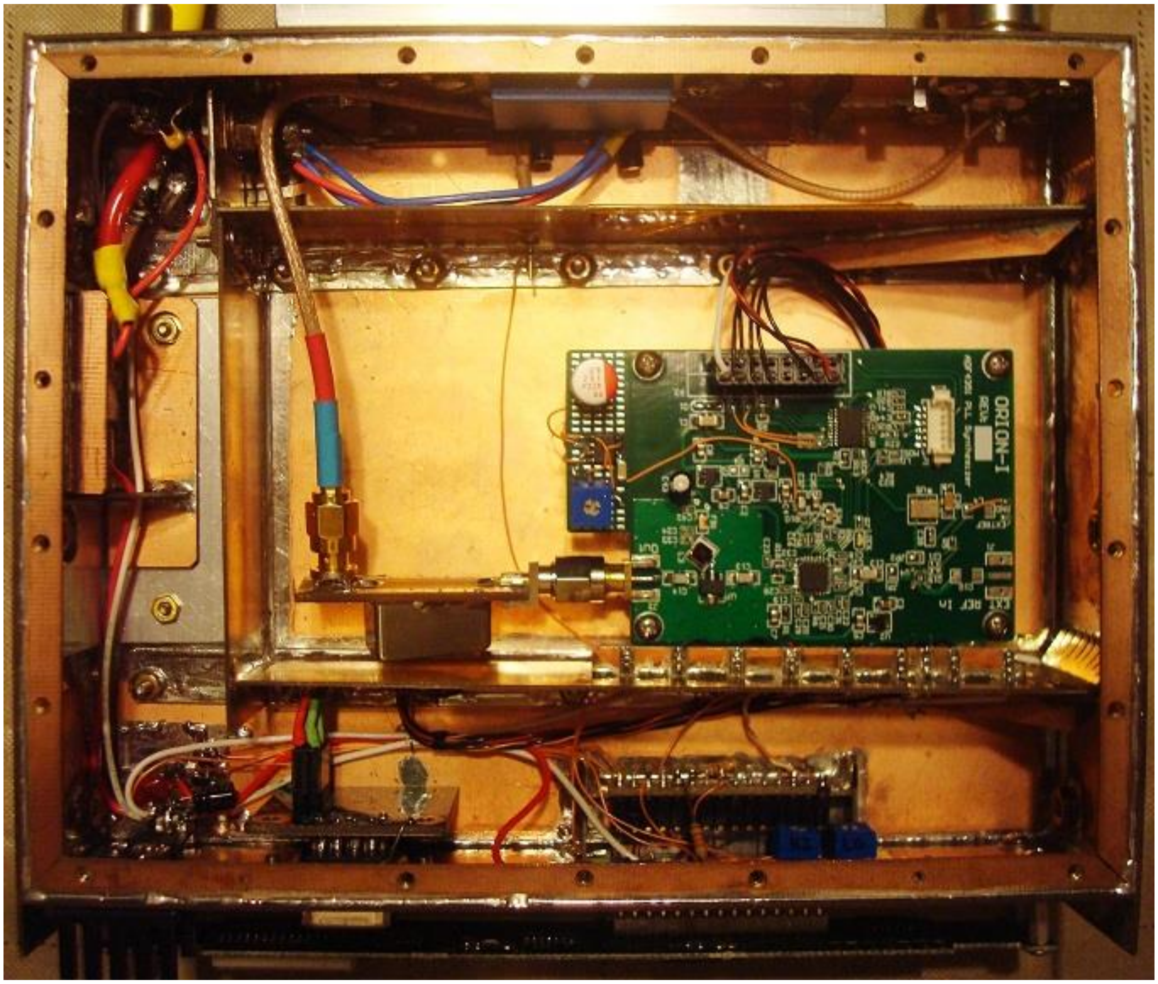
Major mechanical components early in the fabrication phase.



Early mock-up of component placement.



Main logic board: Contains the T/R relay driver, S/RF level, and VBIAS (HIGH and LOW) adjust. The TX LED is for debug use and is not placed for viewing in normal operation.



Finished UX-902: The power switch and regulator are in the lower-left corner. The RS-232 transceiver, logic board, and Front-Unit connector are along the bottom side with the feedthrus located on the divider just above the logic board. The reverse-polarity protection circuit is mid-way up on the left side and the Orion exciter and PLP-1000+ is mid-way up on the right side. DC power and T/R relay connection is at the upper-left, with the PA at the upper-mid and the RF out at the upper-right corner. The VLP-16 is an SMA-SMA barrel filter and is attached to the module N-connector with an N<->SMA adapter (not shown).

