ICOM UX-R91A Modifications

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The ICOM UX-R91A module is a broad-band receive module designed specifically for the IC-901 Transceiver. The module covers six frequency bands: the AM broadcast band (WBAM, 0.5 to 1.6 MHz), the FM broadcast band (WBFM, 76 – 108 MHz), the aircraft band (AM, 108 – 137 MHz), the 2M band (NBFM, 137 – 200 MHz), the 220 band (NBFM, 200 – 236 MHz), the 440 band (NBFM, 300 – 500 MHz), and the 800 band (NBFM, 800 – 950 MHz). All of the NBFM bands are aimed at 5KHz deviation applications.

This document details several modifications to the UX-R91A to correct issues with the broadcast receive modes (both AM and FM broadcast bands are affected), improve the high-band receive sensitivity, and improve the frequency stability of the 1st LO PLL. These changes attempt to address some of the flaws of the basic design but are by no means a total fix. By and large, choosing to make these modifications requires that one proceed beyond the point of no return, as most of the steps are essentially impossible to completely undo (at least from a cosmetic perspective).

The AM/FM Situation…

The broadcast band AM/FM issue manifests as a low level, constant amplitude white noise superimposed on the broadcast audio. It has been determined that this noise is being coupled from the main band IC-901 receiver (including external modules) since it disappears when the main-band receiver is quieted with a strong, no-modulation signal.

During the check-out of a recently acquired IC-901, a noticeable degree of white noise was observed on one of the UX-R91A FM broadcast stations that was being monitored as a test signal. This was attributed it to the antenna, terrain, and distance to the transmitter since this station was usually difficult to receive in this area. However, the noise was observed to disappear when the main band was quieted. After checking the other UX-R91A bands, and other UX modules, the issue was determined to be limited to the broadcast AM and FM bands of the UX-R91A module.

The easiest way to examine this issue is to tune the UX-R91A to a broadcast station, and insert a pair of 1/8" audio plugs (with nothing connected to the plugs) into the UX-R91A speaker jacks (located at the rear of the module). Next, tune the main band (any FM frequency range) to an unused frequency with the squelch closed. In this configuration, there will be a noticeable white-noise output from the IC-901 speaker. This noise is not affected by any of the volume controls (except if the sub-band volume is turned all the way down). Turn the main band volume to zero and then quiet the main band by applying an un-modulated RF signal strong enough to fully quiet the receiver. The noise should disappear as long as the main band is quieted.

Since the IC-901 being tested was pre-owned, it was thoroughly investigated to make sure that there were no issues with any of its analog switch circuits. It was also determined that the noise was reduced by inserting 10K or less of resistance from DETB to GND. Of course, this also greatly reduced the receiver audio. It was further determined that the issue was not present at the stereo speaker outputs of the UX-R91A module.

The issue turns out to be a consequence of the circuit used by the UX-R91A to provide broadcast RX audio to the IC-901 DETB connection. The UX-R91A actually contains a couple of receiver circuits, one for the wide-band broadcast bands, and the other for narrow-band AM and FM bands. The broadcast AM and FM-stereo signals are combined at the UX-R91A speaker jacks using a pair of 470KΩ resistors that connect the stereo R and L audio signals to a common point. This common connection is terminated by a 12KΩ resistor to GND and becomes the IC-901 DETB signal after passing through a couple of 4066 analog switches. The relatively high impedance of this resistor network means that it is easy for the DETA signal to couple over into the DETB circuit at one or more locations in the IC-901. This is further exacerbated by the fact that the IC-901 runs its internal sub-band volume level to maximum when the UX-R91A is tuned to one of the broadcast bands (in these bands, the UX-R91A has an internal level control circuit that is used to adjust the audio volume).

Broadcast band Fix

There are two approaches to addressing this problem, both are geared towards reducing the driving impedance of the broadcast audio. The easiest is to simply install a pair of resistors across the 470KΩ resistors on the bottom of the UX-R91A main board (refer to Figure 1 – the resistors are located under the speaker jacks at the rear of the module) and another resistor across the 12KΩ terminating resistor. The resistors used were a 10KΩ, 0603, chip resistor across each of the 470K resistors (R75 and R77), and a 261Ω, 0603, chip resistor across the 12KΩ terminating resistor (R76). This gets rid of most of the offending noise and maintains the relative volume levels to be in balance with that of the other modules.

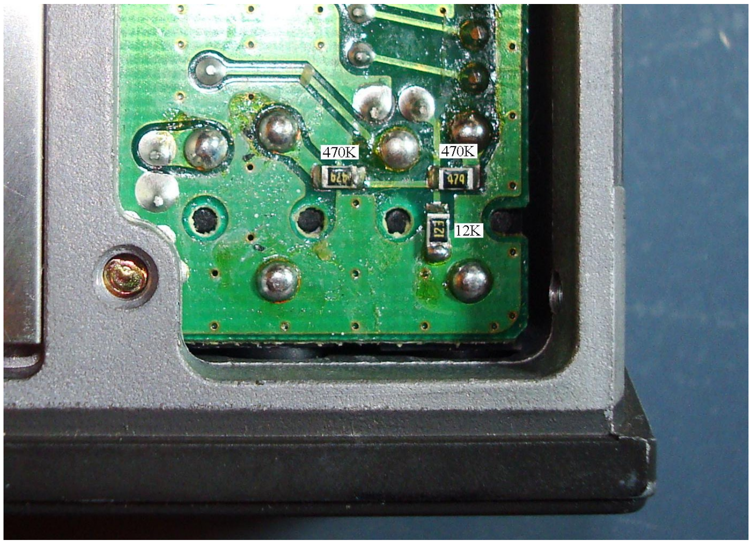

Figure 1. Resistor locations on bottom of UX-R91A circuit card

The other approach is a bit more involved and involves placing an op-amp buffer in series with the DETB signal feeding the UX-R91A Front Unit analog switch. A single-op-amp device in an SOT-23-5 package was used and provided very good results with only a modest effort.

The schematic of Figure 2 illustrates the added op-amp. This is simply a unity gain voltage follower that is inserted just before the CD4066 analog switch (IC1 A). C12 is removed and was re-used in the modification since it was deemed to be salvageable.

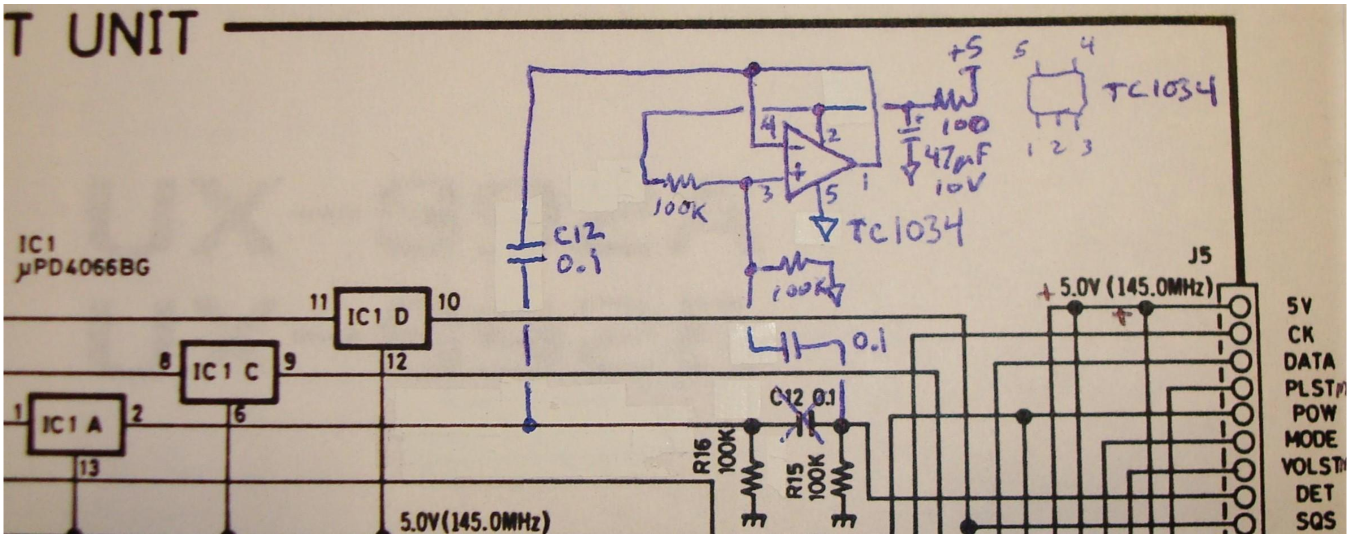

Figure 2. Op-amp buffer circuit for the UX-R91A DETB
signal superimposed on the UX-R91A Front Unit Schematic

The mod was accomplished by removing C12 and using epoxy to secure a small piece of SMD proto-board onto the Front Unit PCB (as shown in Figure 3, the proto-board was actually attached to a piece of Kapton tape so that the modification could be removed without great risk of damaging the Front Unit PCB). All resistors and capacitors are 0603 chip components with the exception of the electrolytic capacitor. The TC1034 op-amp is now obsolete, but any small, low-power op-amp can be used.

After the epoxy cured, the op-amp, two 100K resistors, a new 0.1uF capacitor, and the original C12 cap were then added to the protoboard. A 100Ω resistor was attached to the J5 pin at the end of the connector nearest C5 (the +5V pin). Jumpers were then added to connect the other end of the 100Ω resistor to the +5V pin of the op-amp, a couple of GND jumpers, a jumper to J5-8 (the DET audio from the Main Board), and a jumper from the open end of C12 to IC1-2 on the back side of the Front Unit. Lastly, the electrolytic capacitor is attached from the op-amp +5V pin to GND (the schematic shows a 47 µF cap, but a 39 µF substitute was handy as shown in Figure 3). The proto board secured most of the added components, with 30AWG wire-wrap wire to connect to the Front Unit circuits.

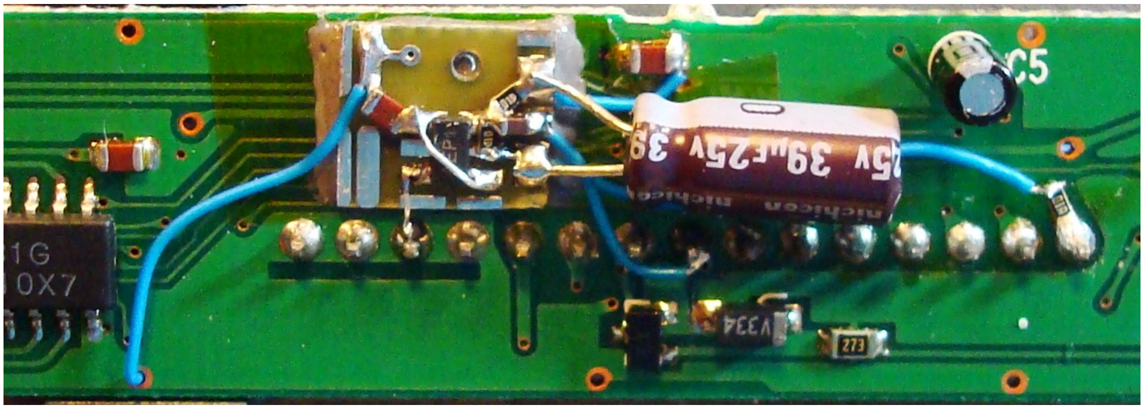

Figure 3. Photograph of the op-amp circuit mod.

"UX-R91A, why you gotta be so insensitive…"

The lower frequency ranges of the UX-R91A seem to do better at meeting the sensitivity specifications than do the upper ranges. No surprise, in general, but all of my modules seem to be off by nearly an order of magnitude at the upper end. Alignment doesn't seem to be the issue, so it is hard to dismiss this as anything other than a design issue. My interest of late is 902 MHz, so this "fix" centers on that band, but the 440 band can likewise be modified if improved sensitivity is desired there. A modest gain, low-noise amplifier should do the trick, but one must also band-limit the input to help reduce spurious responses to images and intermod distortion. In addition, I have chosen to bypass the RF switchgear for the 902 band so that any issues upstream can be eliminated. This also has the added benefit that one can use fewer di- or tri-plexer devices to connect multiple, band-specific antennae to the receiver. This extra effort is not required to reap the benefits of an LNA, but it does have other advantages.

Figure 4. Fit-check of the LNA PCB inside the custom machined enclosure.

To accomplish this end, I planned to use the PA cavity of the radio frame, which is largely empty for this RX only module. This provides ample room for a small preselctor, LNA, and easy access to the back-panel for a band-specific SMA connector. However, once I looked closely at the available space, I realized that I would only *just* fit a single band LNA, and it would be quite cramped. I then resigned myself to an external LNA. This actually has some potential benefit for installations with non-trivial feedline losses. By passing the LNA power via the connection feed, no extra wiring is needed. All that was required was to drill (and mill) mounting holes for a pair of SMA bulkhead connectors.

I chose a preselector and LNA from Mini Circuits. This choice virtually guarantees availability of quality parts with good support data but comes at a moderately steep cost. The LNA and preselector come in at about $35 for the 902 band. Not insurmountable, but well more than an average lunch bill.

The SMA connector is reasonably easy to install. I had hoped that only a drill press and adequate clamping tools would be needed, but because of the thickness of the rear edge of the chassis, a counter-bore was needed, which necessitates the use of an end-mill. I provided two holes to allow room for a second connector for UHF. Because of the difficulty of the next step, I decided to include modifications for the 440 band even though this is not a priority of mine at the moment.

Figure 5. SMA connector c-bores.

The next step is perhaps the most difficult, certainly the most nerve-wracking, which is to remove the RF shield above the switch components. I have removed other ICOM shield parts with results that are mostly good, but this one looks to be a decent challenge. There are multiple contact points, and a lot of bulk solder to remove. A vacuum-based (manual or mechanized) de-soldering tool is imperative, as well as plenty of solder wick. Use a high-temp, large mass tip (I have an 800F wedge tip for my Weller that works well for such tasks) and work quickly on each connection, allowing the board to cool before proceeding to the next connection.

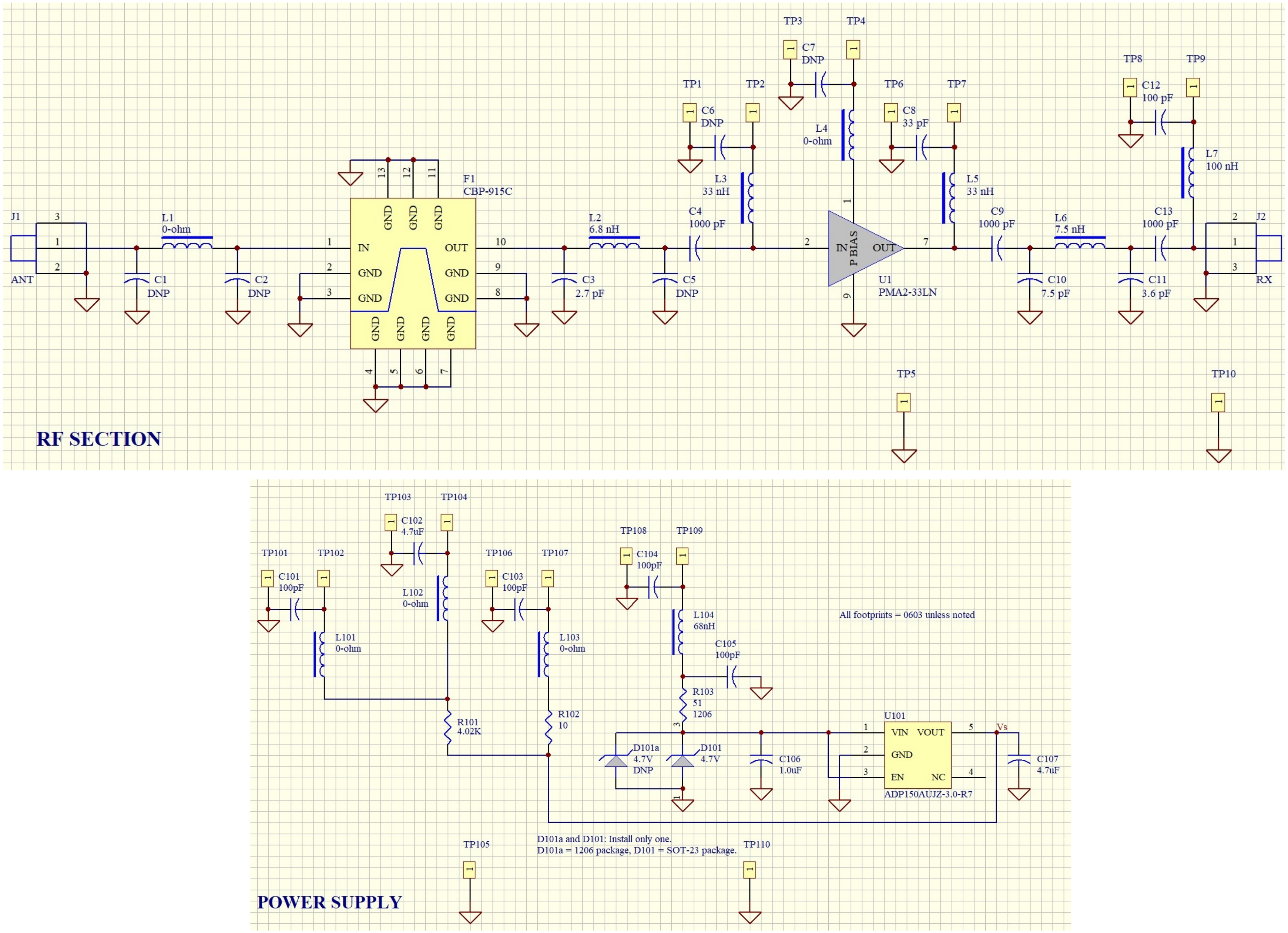

Figure 6. 902 MHz LNA schematic

Once the shield is removed, one simply need remove the RF switch diodes for the 440 and 902 bands, place DC injection components to power the LNAs, and then route coax feeds from the LNA board. I used 085 hand-formable coax (wrapped in PTFE plumber's tape to insulate the exposed shield) to get the best possible shield coverage, but double shielded RG-316 is a decent 2nd choice. 141 semi-rigid or hand formable is also an option, but the greater diameter of 141 will make it a challenge to fit into the narrow bottom cavity of the radio. Re-attaching the shield is a trivial task once the modification is complete and tested.

As shown in Figure 4, I fabricated a PCB to support the LNA and preselector. While the PMA2-33LN+ covers both 440 and 902, the noise figure is considerably degraded at 440, so I will have to find a different part for that band. I used AWR to model the match and calculated the target values. These were then verified on a VNA before installation.

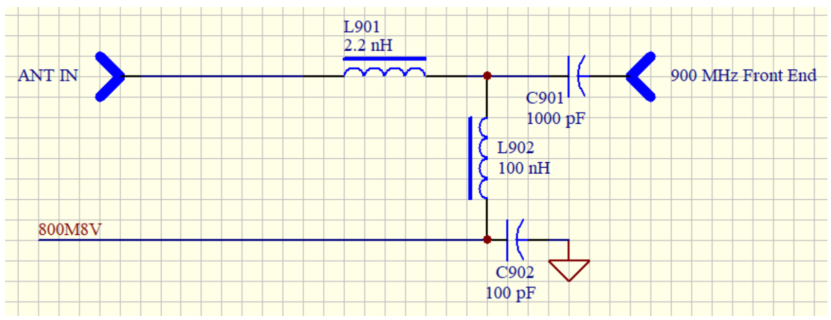

Figure 7. 902 band switch mods

The result at 902 MHz is very noticeable. About 3 S-units improvement on one of the repeaters that I can hear, and a noticeable reduction in the noise. A subjective data-point, perhaps, but hard to ignore and fully in support of the 1.6 dB noise figure and 15dB gain that the lab instruments measured.

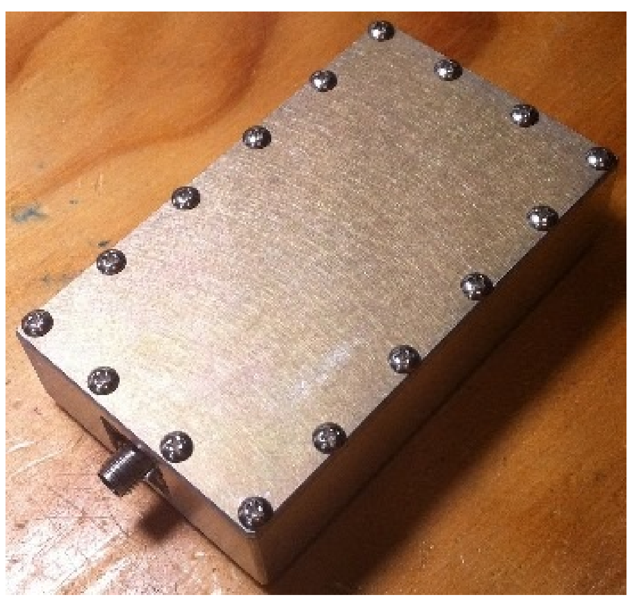

Figure 8. Finished 902 LNA

Steady as she goes…

My biggest complaint about the R91 is the reference oscillator's lack of stability. Two of the three modules I've owned weren't worth the trouble to net, as they would drift soon after (even though I was careful to first allow the unit to come to some measure of thermal equilibrium). For one of these units, I had tried replacing the netting cap with a quality Johanson piston type. An improvement, but there was still significant drift. Just 10ppm of variation in the reference, which is a pretty good frequency source, can result in about 9 KHz of LO variation at 902 MHz. For 5KHz NBFM, this is too much for comfort - even worse for the 2.6 KHz deviation used at 902. Clearly, something much better than "pretty good" is needed.

My solution was to completely replace the 12.8 MHz PLL reference with a temperature compensated, voltage-variable, crystal oscillator (TCVCXO). I then trim the control voltage with fixed resistors to net the frequency as close as I care to get. It seems hokey, but it has worked well for the two units I have modified thus far and the results are that I can now expect my UX-R91A to easily stay within a few hundred Hz of the target LO frequency for the upper reaches of the receive range. Fixed resistors mean some extra work during the netting process, but you don't have to worry about the aging effects of a pot. Also, a good, ULN supply for the VCXO and a very low-drive voltage reference for the voltage adjust are needed as well.

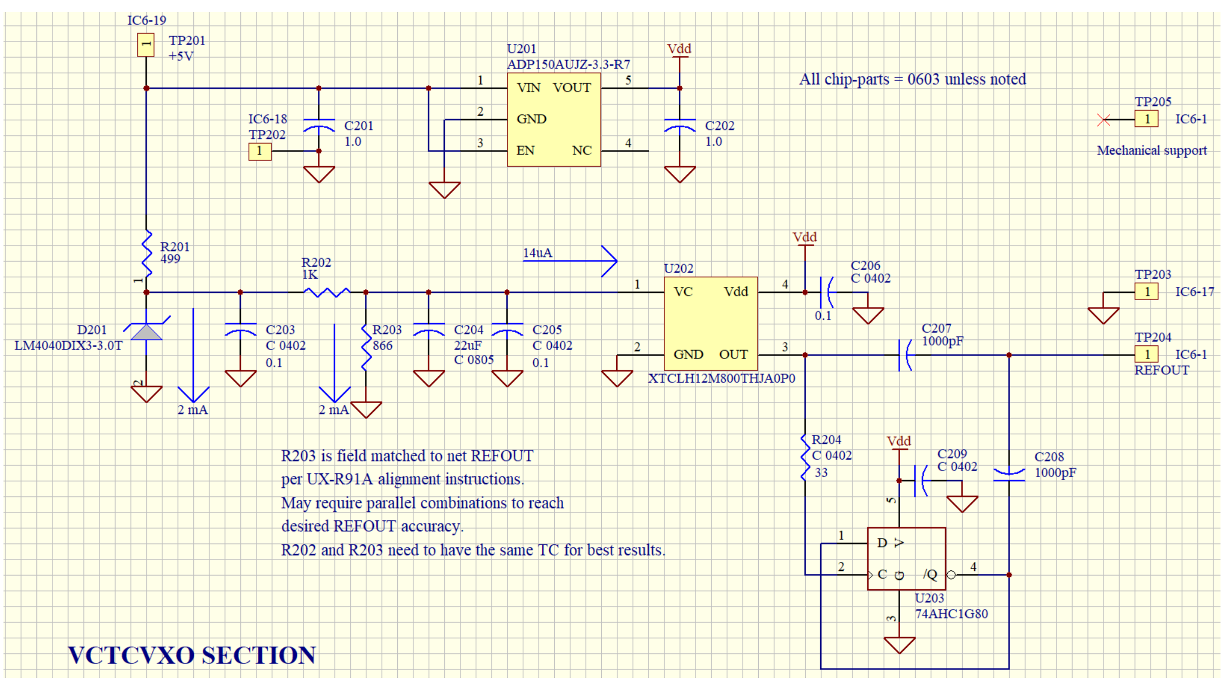

Figure 9. Schematic for the new PLL reference. U203 and associated components comprise a divide-by-2 option.

My first attempt at this was with a hand-carved FR-4 PCB (or more accurately, CCB, Carved Circuit Board). For the relatively few number of components, it was easy to carve the pattern and attach the parts. I trimmed several of the leads on the PLL chip, leaving three ground pins at their original length to which the bottom of the CCB was attached by soldering. A couple of short jumper wires to grab +5V and deliver the output complete the new component addition. Disabling the existing oscillator is simply a matter of removing the 100-ohm resistor that feeds power to the oscillator, and the coupling capacitor that connects the output to the PLL (I re-purposed this cap by using it to couple the new TCVCXO to the PLL). This disconnects the remaining oscillator components allowing them to be abandoned in-place.

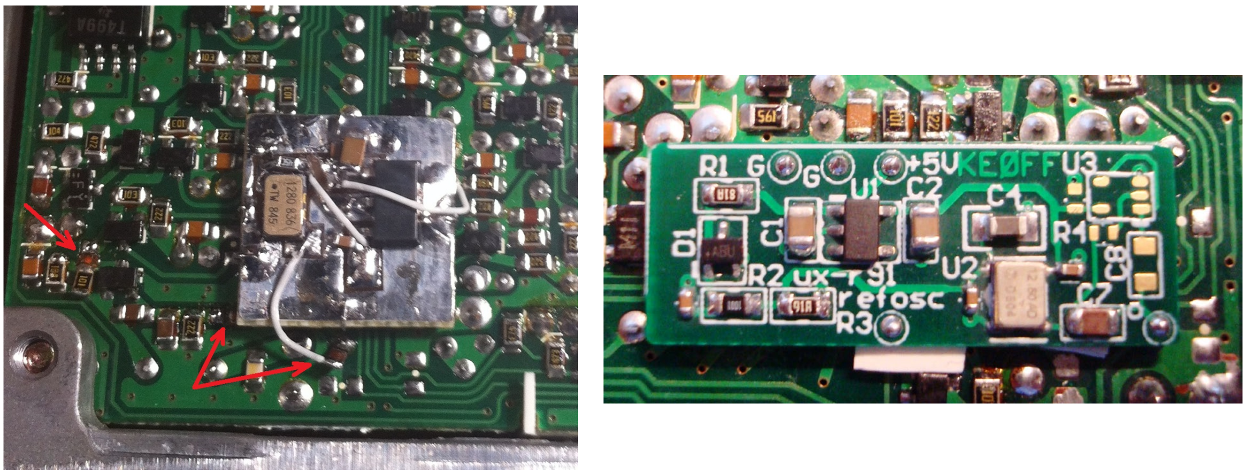

Figure 10. (left) A new PLL reference, Mark-I. Arrows indicate the affected component locations. (right) The final PCB version (R2 and R3 are the frequency netting components)

I also toyed with the notion of replacing the oscillator for the 2nd LO with an SiLabs programmable part (the 530CC59M0950DG oscillator module, 59.0950 MHz, 3.3V, 7ppm TC, -40 to +85C), going so far as to secure a sample. However, this LO has less influence on the frequency drift since it isn't multiplied by the effect of the PLL and seems to be more or less stable once adjusted. However, should one desire to pursue this, the 2nd LO should be replaced prior to netting the 1st LO. When netting the 1st LO, the error in the 2nd LO must be accounted for since the SiLabs oscillators are not trim-able. This suggests that a SINAD measurement may be the best option for netting. Barring that, one would need to measure the 2nd LO frequency, then calculate the optimum 1st LO and set per the service manual. A full RX alignment should also be performed after netting the LO.

Conclusion

The op-amp AM/FM mod was attempted first on one UX-R91A then the resistor mod was applied to a different UX-R91A. Swapping the modules for comparison yielded a reduced level of residual noise that was essentially the same for both modules. It is possible that an amplifier with very low (less than 50 ohms) output impedance might provide an improvement on the two methods discussed above, but this was not attempted. Based on the effectiveness of the result, the resistor method is very easy to implement and is recommended for anyone who experiences this issue.

It is arguable that this issue is not often encountered since, for most mobile installations, there is already a broadcast receiver present in the vehicle. Even if an operator chose to use the broadcast receive feature of the UX-R91A, it is likely that this particular issue might still go un-noticed given conditions of road noise typically encountered in mobile installations. However, for fixed installations, this issue is quite noticeable (especially when external speakers are connected to the UX-R91A) and the mod discussed herein can be used to reduce the level of noise that is present when receiving broadcast band stations to the point that it is no longer objectionable.

As for the other mods, I was reluctant to employ alternate frequency references for far too long. After finally taking the plunge, and with the help of improved front-end gain and NF, I am finding that my UX-R91A is now usable for more than just receiving broadcast radio stations. While the overall cost was rather high, the result has turned a useless trinket into a credible receiver that can be used with some degree of confidence. The combination of LNA and stabilized 1st LO has made an incredible difference to the receiver performance.

References

ICOM Service Manual, IC-901A/E

Datasheet: TC1034/TC1035, Microchip Doc# DS21343B, Dated 2002

Datasheet: PMA2-33LN+, Mini-Circuits, https://www.minicircuits.com/pdfs/PMA2-33LN+.pdf

Datasheet: CBP-915C+, Mini-Circuits, https://www.minicircuits.com/pdfs/CBP-915C+.pdf

