

**mcHF Hardware modifications as of April 29, 2015
as compiled by KA7OEI for
Version 0.3/4 UI and Version 0.4 RF boards**

Comment to new builders – PLEASE READ:

It is *strongly recommended* that new builders do not make these board modifications, other than those involving simple *substituting/changing of component values*, before verifying that their transceiver is fully operational.

ONLY after you have verified that the transceiver operates normally and have worked out other problems should you proceed to perform the actual circuit modifications and changes, *one at a time!*

Note: *Most, if not all, of these modifications may be applicable to board versions other than the Version 0.3 UI board or Version 0.4 RF board, provided that care be taken to accommodate board/circuitry differences. Note that most of the modifications to the Version 0.3 UI boards (and earlier) have been incorporated in some way into the 0.4 UI board and need not be done!*

- Use 47uH inductors instead of 4.7 in a few locations (RFC5, RFC6 and RFC7) - one possible symptom being low TX power on lower bands (mostly due to RFC5 and RFC6.) The updated BOM reflects this. (Not really a mod, though as the diagram was correct, but the original BOM had a typo.)
- **Do NOT install Q2.** (Not really a mod, either!) The updated firmware (versions newer 185 or newer) make this obsolete: *Its installation will degrade sensitivity.* There is no need to install resistor R40 (1k) either. At the time of assembly, capacitor C64 may be optionally replaced with a jumper (*e.g. a zero-ohm resistor, piece of wire or “blob” of solder*) as the DC-blocking function C23 performs this function with Q2 removed. *There is no need to remove C64 on already-built boards as its presence does not degrade performance.*
- If, for RF board Q1, you use a BFR93R or BFR93AR, it will be required that its leads be bent backwards over the body of the device before soldering. If the **more-common** BFR93 or BR93A is used, the footprint is correct. **Note:** *The Bill-of-Materials dated prior to 20141116 called out a Mouser part number that referenced a BFR93AR, requiring that the leads be bent before soldering. As of 20141116 this has been corrected. The Farnell part number is believed to have been correct for all versions.*
- The use of a low-dropout regulator for U5. Not really a mod, just a different part from the "original" BOM.
- Tantalum capacitors C5 and C6 are shown backwards on the footprint of boards **prior** to the version 0.3 UI board. The silkscreen is correct on the Version 0.3 UI board.

The importance of placing a metal shield between the UI and RF boards:

- Some of the RFI/noises that can reduce sensitivity – particularly those that remain *after* all of the modifications below are completed (*e.g. the “Helicopter” noise from the LCD's update*) can be significantly reduced **by placing a metal shield** between the UI and RF boards – even if

it is ***not*** grounded to anything. This shield should be covered with an insulating material to prevent it from shorting against any components/connections.

More recent modifications:

Low Frequency oscillation prevention of the Final Amplifier stage:

It has been observed that at higher PA bias settings that the final amplifier stage can oscillate at relatively low frequencies, specifically in the range of 100 to 1000 kHz. This occurs due to the fact that inductor RFC8 and C106 can form a low-Q “tank” circuit and when the finals are heavily biased, oscillate at very low frequencies due to very high DC gain.

The symptoms of this may be a bit difficult for the average user to notice, but these can include:

- RF power when keyed down in SSB mode, but no audio present – particularly power that goes up suddenly with higher PA Bias settings.
- A noticed higher SWR reading on a frequency that you ***KNOW*** to have a good match. This is due to spurious oscillations at frequencies ***other*** than your operating frequency being reflected.
- Higher than expected DC operating current and/or hotter finals.
- Reports of “oddly” distorted audio – particularly if it seems to clear up if you reduce the PA bias.
- Sudden and unexpected loss of RF power at times, but proper RF power at other times.
- With an oscilloscope attached to the junction of RFC8 and C106, this oscillation will be seen when the transmitter is keyed, with the output terminated into a 50 ohm load, with no RF drive, at high RF levels.

The fix:

- Placing another capacitor in parallel with C106. A 10uF, 16 volt ***tantalum*** capacitor is suitable for this. The value isn't critical and anything from 4.7uF to 22uF should work just fine.
- If this turns out to be insufficient (*I'd be surprised...*) parallel a 10 ohm resistor across RFC8 as a “Q” spoiler.

This is a **highly-recommended** modification!

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Increase of conduction current through PIN Diode D3 on RF board:

With the value of R54 set to 22k it had been observed that the current through PIN diode 22k was on the order of 200uA which, according to the data sheet for this device, would set its series resistance to approximately 30 ohms.

In testing, I found the insertion through D3 to be on the order of 4-6dB, which represents about 1 S-unit. Practically speaking, this was difficult to detect when test equipment was used to analyze the

receiver sensitivity – probably because of the fact that the receiver is noise-limited elsewhere in the signal chain.

Nevertheless, the modifications to reduce this loss are quite simple:

- R53 = 220 Ohms
- R54 = 3.9k

This combination yields a (measured!) current of 1.03 mA through D3 (do not forget that there is a 0.6 volt drop across D3 and some resistive losses in RFC2 and RFC3) which, according to the specifications should set the series resistance of D3 approximately 6 ohms. The voltage across D4 is only 0.26 volts, which is very comfortably below its "ON" threshold - especially considering the fact that these are PIN diodes and will not react to incidental RF waveforms in the way "normal" diodes would.

In transmit the current through D4 would be approximately 19 mA, well within the safe drive capability of RF board's U7's outputs.

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Improvement in receiver low-frequency response:

***Note:** This modification is unnecessary if you use the “Frequency Translate” function available in more recent firmware.*

Capacitors C71 and C73 on the RF board, near U16, cause excessive low-frequency rolloff. These capacitors should be replaced with zero-ohm resistors (e.g. jumpers.)

The DC blocking function that these capacitors provide is actually redundant in that C26 and C31 on the UI board perform the same function.

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The addition of sink current and improved stability for the PA bias regulator:

In certain cases it may be observed that there is a “squeal” on transmitted audio, particularly in the TUNE mode when listening to the signal on another receiver. The problem turns out to be related to insufficient output capacitance on the LM2931 to maintain unconditional stability.

The data sheet for the LM2931 recommends a minimum load capacitance of at least 100uF to maintain stability and failure to observe this specification can cause this “squealing” and an unstable transmitter.

It was noted, both from testing and on the LM2931 data sheet that a 22uF tantalum unit such as that used elsewhere on the mcHF is seemingly enough to make it stable: Always be careful of polarity, noting which side of C96 is ground using an ohmmeter. **Comment:** The side of C96 closest to RF output transistors Q5/Q6 is ground.

If an electrolytic is all that is available, the **MINIMUM** recommended value is 100 uF and for this one may use any of the surface-mount 100uF capacitors (or 220uF units) used elsewhere in the mcHF, connecting it with short, flying leads, or one may use a standard through-hole capacitor. The voltage rating is unimportant as long as the capacitor that is chosen has a rating of 6.3 volts or higher.

When using a capacitor with leads, it is absolutely imperative that the leads be cut as short as possible to maximize the capacitor's effectiveness: Even a few centimeters will negate the capacitor's usefulness!

It was also observed that the voltage at C96/RFC7 was not properly following the setting of the **PA Bias** adjustment. This turned out to be due to the fact that U18, an LM2931, like many regulators, has a **minimum** load current requirement for regulation.

If you look at the diagram you will note that there is **NO** DC loading on the DC output from this regulator as the gates of the PA transistors are purely capacitive. If leakage currents from U18 exceed those of C96, C101, Q5 and/or Q6, the voltage on this line can exceed the regulated output. Similarly, if there **are** leakage currents through C99 and/or C100 due to the components, board contaminants, moisture or other sources, this can also cause the voltage to rise.

What this means is that the bias voltage can not only exceed the setting for **PA Bias**, but it may not turn off when in receive mode which could mean that the PA transistors may conduct current and generate heat **EVEN IN RECEIVE MODE!**

The fix is simple:

Install a resistor in parallel with C96. The value of this resistor may be anything from 470 ohms to 10k: I used 2.2k since I had plenty of them left over from construction, but I'd recommend 470 ohms or 1k to more-quickly discharge the 100uF capacitor installed above.

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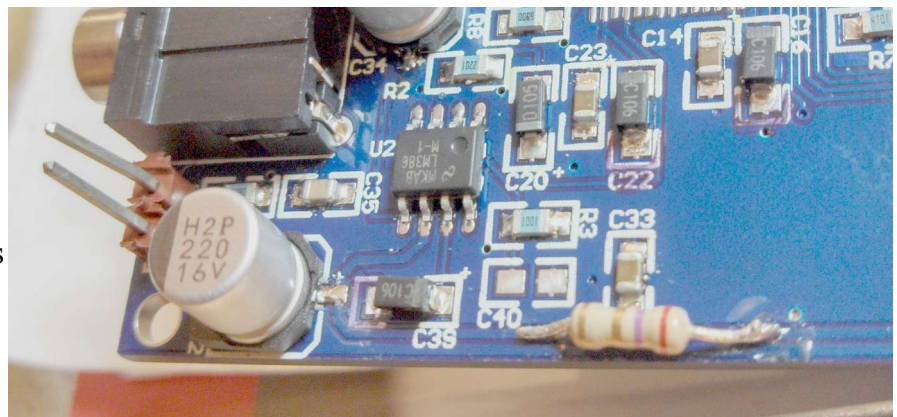
Reduction of conducted audio on the 8 volt line to prevent audio feedback (Version 0.3 and older UI boards only):

The insertion of a 4.7 ohm, 1/2 watt resistor in series (or two 10 ohm 1/8 watt resistors in parallel) with the +8 volt line, near the LM386 audio amplifier.

This is an important modification that fixes one source of oscillation at high volume levels.

I'd originally suggested a 2.7 ohm resistor, but I later found 4.7 ohms to be better, as Chris pointed out.

This modification prevents audio



The 4.7 ohm resistor added to the UI_8V line feeding U2, the audio amplifier.

from appearing on the 8 volt line which, in turn, causes audio to appear on the ground busses and other power supplies in the radio which can cause feedback, particularly at high volume levels with wider audio filters.

If you have done the other modifications, and you still get feedback when using a speaker, at high volume levels:

It has been noted that even with this modification having been done, if all of the other noise reduction modifications described in this are also done the receiver sensitivity is increased enough that the addition of just the 4.7 ohm resistor may not be enough to prevent feedback at high volume levels. This can sound like a howl, or just a “hollow” sound at high volume levels, with worsened feedback in the 300 Hz setting.

If this describes what is happening to you, this fix is also quite simple: Increase the capacitance at C32. It has been found that adding another 1000 uF of capacitance across C32 seems to prevent audio feedback, having done all of the other modifications.

You may also prevent this feedback by increasing the value of the 4.7 ohm resistor even more at the expense of a reduction of audio output power.

Additional comments about this modification – how it is done in the newer board:

The newer version of the UI board (version 0.4) has *additional* filtering beyond that mentioned above in that it uses **two** resistors and **two** capacitors for filtering. In addition to the existing capacitor at C32 and the added resistor mentioned above, there is yet another capacitor to ground and series resistor: Both of these series resistors are 2.2-2.7 ohms and the capacitors are at least 220uF in capacitance.

These two capacitors and resistor together provide somewhat better filtering than a single capacitor/resistor.

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Modification to improve performance and usability of the forward and reverse power detectors:

This modification is appropriate for firmware versions 0.0.219.3 and later.

It has been observed that with the original component values of R59/R60 and R58/R62 in the power detector, a static voltage of approximately 200 millivolts was present on the “PWR_FWD” and “PWR_RET” lines. Inspection with an oscilloscope revealed the presence of a very narrow pulse emanating from the MCU's A/D input lines of significant voltage, charging the capacitors (C82/C83) and this “bias” voltage was the result. Because the full-scale A/D voltage is just 3.3 volts, this 210 millivolt “bias” (approximately) represented a significant portion of the A/D range (approx. 6-7%).

Whatever the reason for this spurious signal, the easiest solution was to lower the source impedance of the voltage from the power detectors which was done by changing the values of the aforementioned resistors. With the change of the resistors, the capacitors were changed as well to minimize the

possibility of “aliasing” occurring due to the fact that the forward and reverse power readings are not taken simultaneously, but via sequential readings: Slowing the rate-of-change minimizes this potential source of error.

Another potential problem that was observed was that the voltage being output by the power sensor exceeded 3.3 volts, a voltage above the A/D input range, at power levels below 10 watts – a power level attained on some bands by some users.

The modifications described below resolve these problems and are simple to perform and are as follows:

- Remove R59 and R60 and replace with zero-ohm resistors or jumpers.
- Change R58 and R62 to 2.2k resistors.
- Change C82 and C83 to 2.2uF resistors.
- Replace R55 and R56 with 47uH inductors. If you do not have these, 4.7 uH inductors will work adequately.
- Additionally, it is recommended that one capacitor each of 1nF to 100nF be connected between pins 9 and 10 of the 30 pin edge connector on the RF board and ground (pin 6).

Important comments:

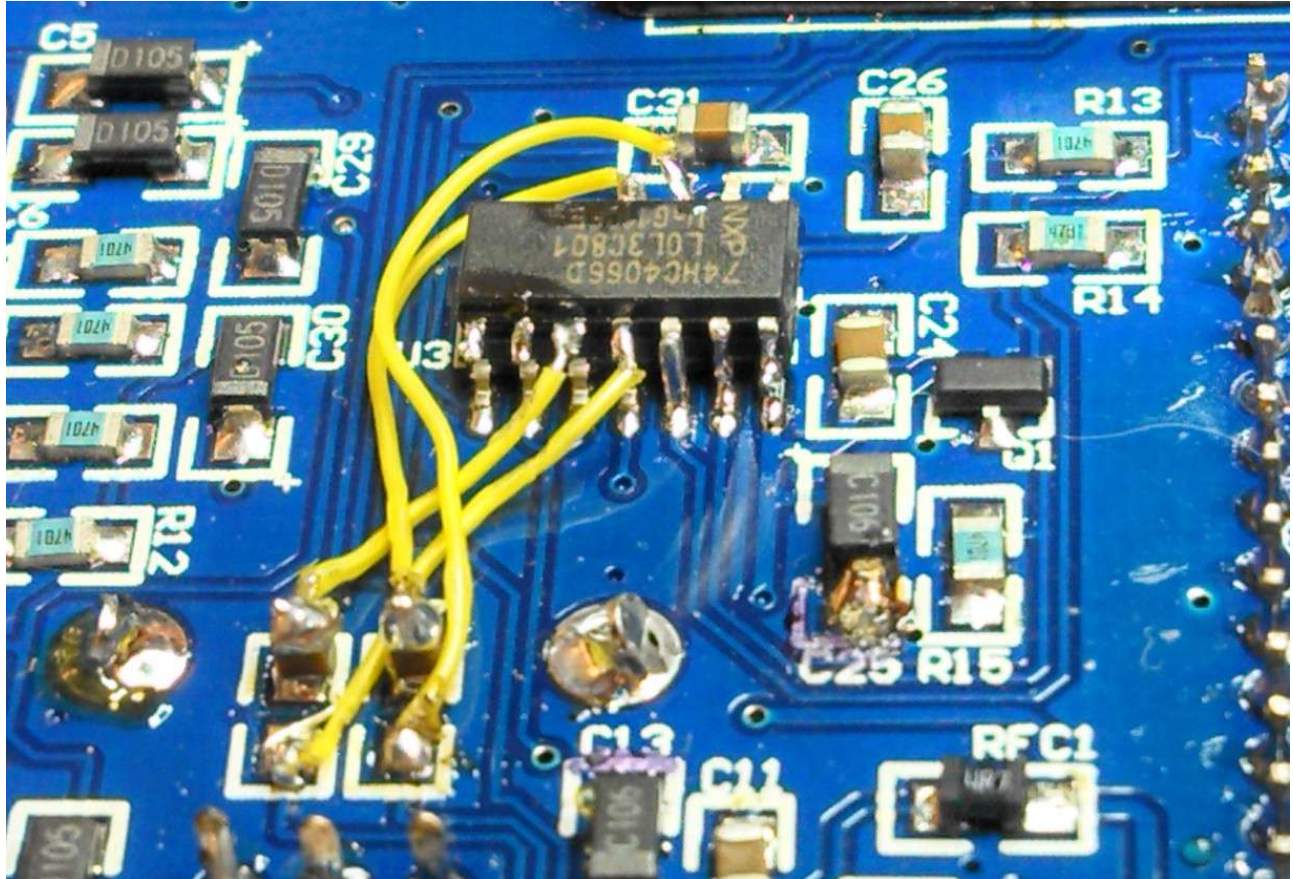
- *If firmware version 0.0.219.3 or newer is used **without** the above modifications the power metering will incorrectly read power, even when there is no RF output power present, and it will read very high RF power during transmit. It will not correctly calculate VSWR.*
- *If the above modifications are done and a version of firmware **older** than 0.0.219.3 is used, the RF power metering will read very low. There was no VSWR metering on these earlier versions.*

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Prevention of RX audio “breakthrough” on the TX mixer (Version 0.3 and older UI boards only):

The installation of a which, which we call "U3a", is a 74HC4066 switch, piggybacked atop U3, and is a pretty easy mod if you have soldered the rest of the board!

This fixes a source of distortion/oscillation in the receiver, particularly at high volume levels and on high bands: **This is a very important modification that all users of this transceiver should perform.**



The "U3a" modification, piggybacking another 74HC4066 atop U3 to prevent feedback into the receiver.

Take a 74HC4066 chip, of the same type and package as U3 and piggyback it atop U3 (on the UI board) and use its power supply and control signals. This chip will now be able to turn on/off the TX I and Q signals with a bit of fairly simple rewiring. Let us call this new chip "U3a"

This modification is relatively simple and it seems to be effective in solving this particular feedback problem: This 'mod', in addition to the installation of a 4.7 ohm resistor in the 8 volt supply line for U2, the audio amplifier (see message #144) has caused my receiver (board revision 0.3) to be (almost) completely stable on all bands at all volume levels.

The procedure is approximately thus:

- On the new 74HC4066, U3a, bend pins 5, 6, 7, 12, 13 and 14 straight down using a VERY FINE pair of needle nose pliers or tweezers. Bending these leads down will cause them to be just long enough to allow them to be overlaid atop U3 and connected to it.
- Bend pins 1, 2, 3, 4, 8, 9, 10 and 11 of U3a straight out using a the same pair of very fine needle nose pliers or tweezers.
- Set this chip atop U3, making sure to align pin 1 with pin 1.
- Using a VERY FINE tip, solder pin 14 of U3a to pin 14 of U3.
- Align pin 7 of U3a to U3 and solder.
- Now solder pins 5, 6, 12 and 13 of U3a to U3.
- Remove capacitors C7 and C8 and stand them on end, attaching them to the pad closest to U3, the upper pad. This will leave the lower pads of C7 and C8 empty. *You may turn C7 and C8 around, the “open” end facing U3 rather than standing them on end, if you prefer.*
- Using fine-gauge wire such as #30 AWG wire-wrap wire, run leads to sections 1 and 4 of U3a. For example, the wires connecting across the connection of C8 would go to pins 1 and 2 of U3a and the connection of C7 would go to pins 10 and 11 of U3a. Which wire goes to which side of the switch does not matter, nor does which connection goes to which switch.

How this works:

U3 is used to switch the A/D input of the codec (U1) between the Line input and receive I/Q audio lines. This chip already has a complement of logic levels that follow the PTT (Push-to-Talk) lines.

When in receive mode, the TX I and Q lines (AUDIO_IN_I and AUDIO_IN_Q) are disconnected and left floating. Fortunately, U19 on the RF board, the lowpass filters, remain stable in this condition. Importantly, this method of muting the TX audio does not cause a DC shift which should prevent/minimized a broadband "click" or thump when going to transmit mode.

Note that the other two sections of "U3a" (2 and 3) are connected to the inversion logic (Q1 on the UI board) and are active when in receive mode and the corresponding I/O pins (pins 3, 4 and 8,9) are left floating (which will cause no problems on a '4066) - but these may be useful for something else...

This modification prevents “breakthrough” of the TX QSD mixer (U17) caused by the fact that the Codec's DA is shared both for RX audio and TX modulation. Because the audio drivers for the TX modulator (U20-U23) are powered from 8 volts it is possible for high RX level audio to violate logic levels at U17, turning it “on” on voltage peaks: The result of this is highly-distorted, on-frequency noise/feedback.

Reduction of standing current by the PA driver transistors:

It may be noticed by those studying the diagram – or having happened to make current measurements of the transceiver – that PA driver transistors Q3 and Q4 are *always* biased on. Because of this, an extra 30-60 mA is consumed at *all* times when the power is applied to the transceiver: During receive and even when it is turned off!

In studying the diagram you will note that bias resistors R73 and R75 are connected, via RFC5/RFC6, to the VCC_12 volt supply – which is always on. R73/R75 also provide a degree of RF degenerative feedback from the collector to the base of the transistors and reduce their impedance as well, possibly

causing an increased mismatch to the output of T5, further reducing RF output, particularly at higher frequencies.

It is possible to derive the bias from a regulated source that is switched on when the transceiver is in transmit mode and one such supply of bias is the source of Q1a which provides a +5 volts when the radio is keyed. Because the bias supply is now 5 volts rather than 12, the values of R74/R76 must be changed as well.

The modifications are as follows:

- Change R74, R76 to 2.2k
- Remove R73, R75
- Where R73, R75 would be, stand on end, in each location, a 2.2k resistor, the bottom end connecting to the base of transistors Q3, Q4.
- Solder, standing on end, 100nF capacitor(s) to the ground end of R74 and/or R76.
- Connect the "top" of these components (the two resistors and the capacitor(s)) together.
- Connect the tops of these components to the junction of R15 and Q1a (at R15) using a piece of very thin, insulated wire: I used #30 AWG wire-wrap wire, tacked down in several places with small dots of thermoset ("hot-melt") glue.

If the above modifications are done, the "Off" current of the mcHF is reduced to 3-4 mA – the “off” current of U3 and the current through R9/R10 and R13/R14 and the low-volume receive current with the LCD at full brightness reduces to 360 mA.

IMPORTANT NOTE:

A *PREVIOUS* recommendation had been to replace C94 and C95 with 4.7nF capacitors to reduce the gain at lower frequencies (<10 MHz).

Unfortunately, reports indicate that this can cause instability to some users so this recommendation is withdrawn: Continue using 47nF capacitors at these locations!

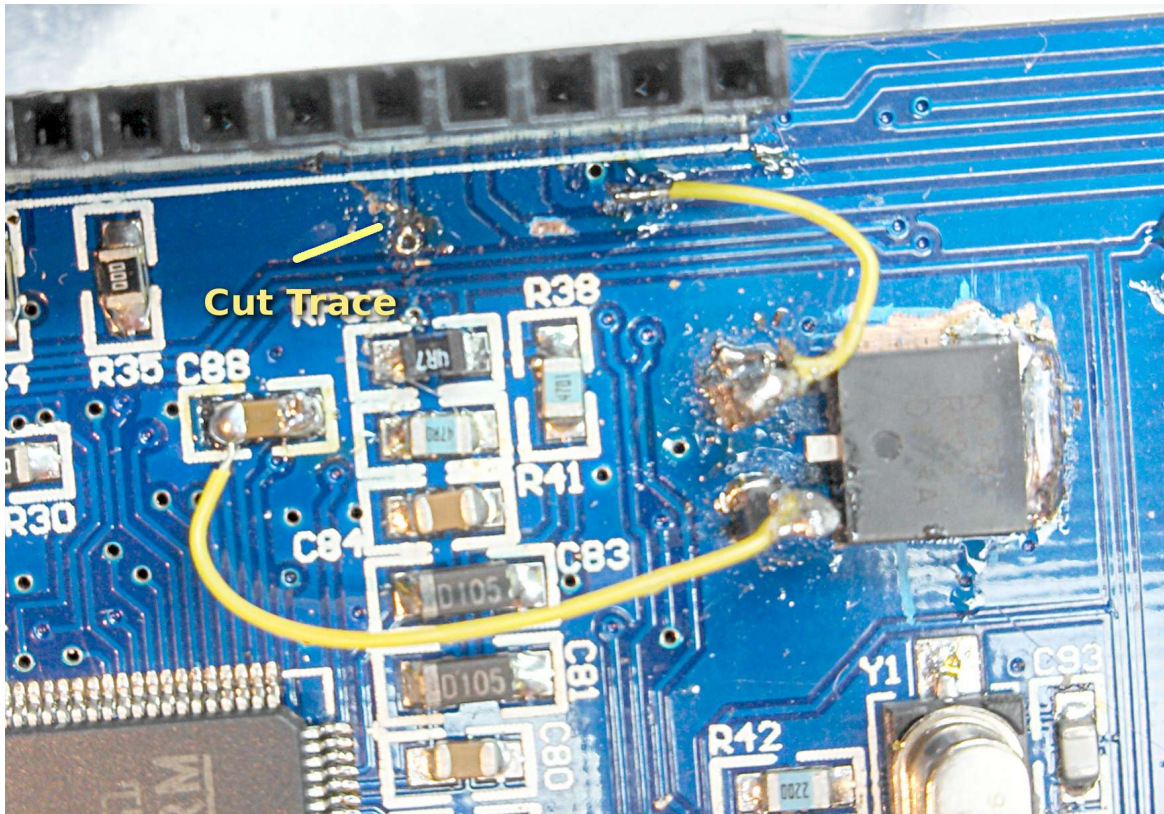
A separate 3.3 volt regulator for the MCU and additional LCD +5V filtering (Version 0.3 and older boards UI only):

It has been determined that the *most sensitive power supply is the main +5 volt supply*. This appears to be due to the fact that receive QSD mixer (*U15 and related components*) have minimal capability for power supply rejection. Because of this, even millivolt-level modulation of the +5 volt power supply with audio frequency signals will yield artifacts that are readily audible at low/no signal levels.

It is *not* even necessary that this source of audio modulation be due to a device that operates directly from the +5 volt supply: Modulation of *any* of the power supplies can cause this, most likely due to ground loops causing slight voltage changes throughout the system – including that on the +5 volt supply – an example of this being the aforementioned needed isolation of the +8 volt supply line feeding the audio amplifier.

This leads to the recommended installation of another 3.3 volt regulator on the UI board for the MCU: This mod is actually easier than the "U3a" mod and uses the same type of parts as those that you'd already have gotten (e.g. another 3.3 volt regulator and two more 10uF capacitors.) This reduces one source of low-level noise – much of it in the form of a 1.5 kHz “whine” – getting into the receiver due to the MCU's modulation of current on the 3.3 volt line shared with low-level audio circuitry. Taken together, these two modifications can improve the receiver sensitivity by 2-3 S-units, depending on band.

The trace to isolate the 3.3 volt supply feeding the MCU is indicated on the picture and it should be cut **just above the via** that goes through to the other side of the board. The 3.3 volt output from the added



The added 3.3 volt regulator to deliver an isolated power supply to U4a, the MCU. This reduces a noise source that can get into low-level RF and audio stages. The trace is cut just above the via. Note that this picture was taken before the addition of the 4.7 ohm resistors and additional capacitors described below and is included for clarity.

regulator is shown connected to the left-hand side of C88, below.

It was noted that when the above modification was completed that there was residual noise on the 5 volt line so further investigation was carried out. It turned out that the remainder of the noise was from two sources:

- The +5 volt supply for the LCD
- The transmission of noise **through** the 3.3 volt regulator.

When the “LCD Backlight Brightness” control function was added, the need for even better filtering of the LCD's power supply was made apparent as the modulation of the LCD's power supply current rippled (literally!) throughout the rest of the receiver!

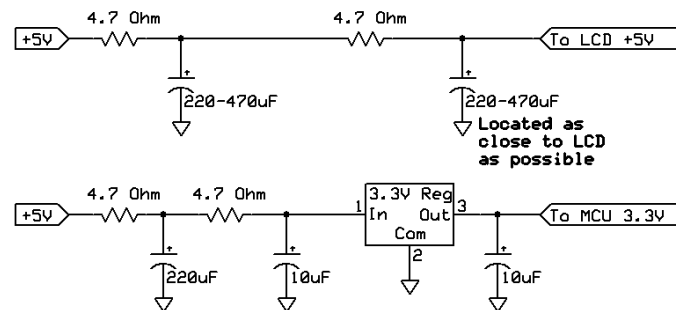
While the regulator's contribution directly to the 3.3 volt line was significant and moving it to the 5 volt line made a significant improvement, it still put noise on the 5 volt bus which powers devices many other low-level circuits, such as the QSD mixers and, to a lesser degree, the RF signal sources (e.g. local oscillators.)

The diagram shows the filtering in schematic form. There is a voltage drop associated with each resistor, but each is well within the range of the associated device.

- The LCD has an internal 3.3 volt regulator that has a (worst-case) dropout voltage of 600mV – and less than 1 volt is dropped across the two 4.7 ohm resistors.
- The MCU regulator drops less than 250 mV per 4.7 ohm resistor, leaving well over a volt of headroom for the low-dropout regulator.

For LCD filtering, place the noted capacitor as close to the LCD's pins as possible – preferably **at** the LCD itself! The 4.7 ohm resistors and the other capacitor may be placed farther away, but the second capacitor should be placed as close to the LCD's ground as well.

On the 3.3 volt MCU regulator, the 220uF capacitor on the input side of the 3.3 volt regulator, along with the 4.7 ohm resistors, form a low-pass filter that provides an impedance path between the noise source at the input of the regulator and the capacitor, greatly improving its ability to filter. The other 4.7 ohm resistor provides isolation between the noise that remains at the 220 uF capacitor and the rest of the 5 volt bus in the transceiver.



Note: Additional isolation will be obtained if the LCD, MCU and USB +5 volt supplies were derived from a separate 5 volt regulator on the UI board, powered from the +8 volt rail as depicted below.

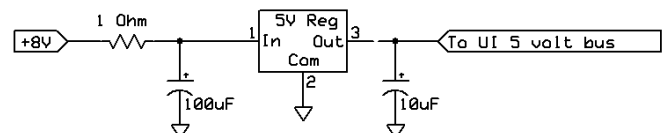


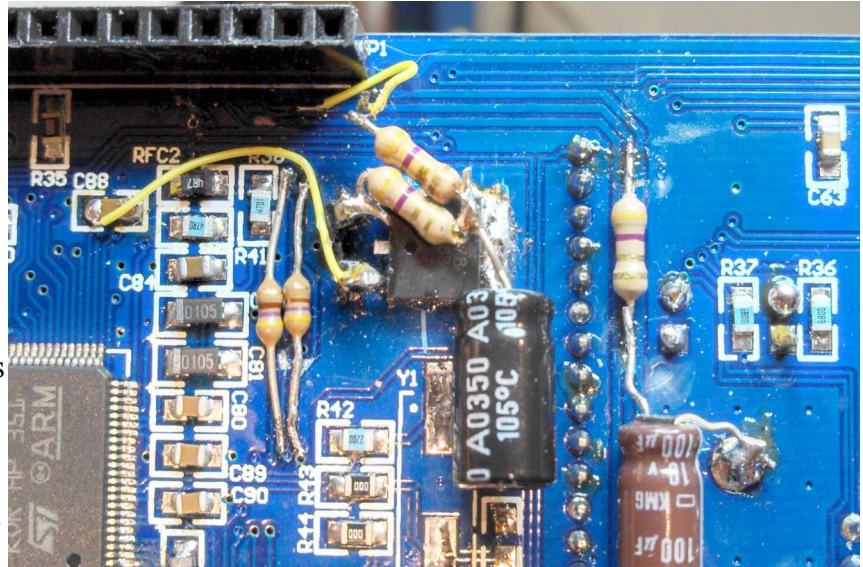
Diagram depicting the MCU's own, isolated 3.3 volt power supply. This also shows additional isolation of the LCD power supply as well as the suggested, separate 5 volt power supply for the UI board - see text.

Isolation of the USB power supply on the UI board:

In the future, it is expected that USB devices may be plugged into J10 and/or J11, powered from the mcHF. Because these, too, use the +5 volt supply that is known to be very sensitive to noise, it would be prudent to isolate this supply as well as noted in the diagram, above.

Discussion:

With the increase in sensitivity due to the reduced receiver background noise there may be the additional tendency for audio feedback to occur at high volume levels, particularly with no antenna connected *when using a speaker*. This is related to circulating currents on the UI board, some of which were addressed with the addition of the 4.7 ohm resistor in series with the 8 volt line on U2 noted earlier in this document.



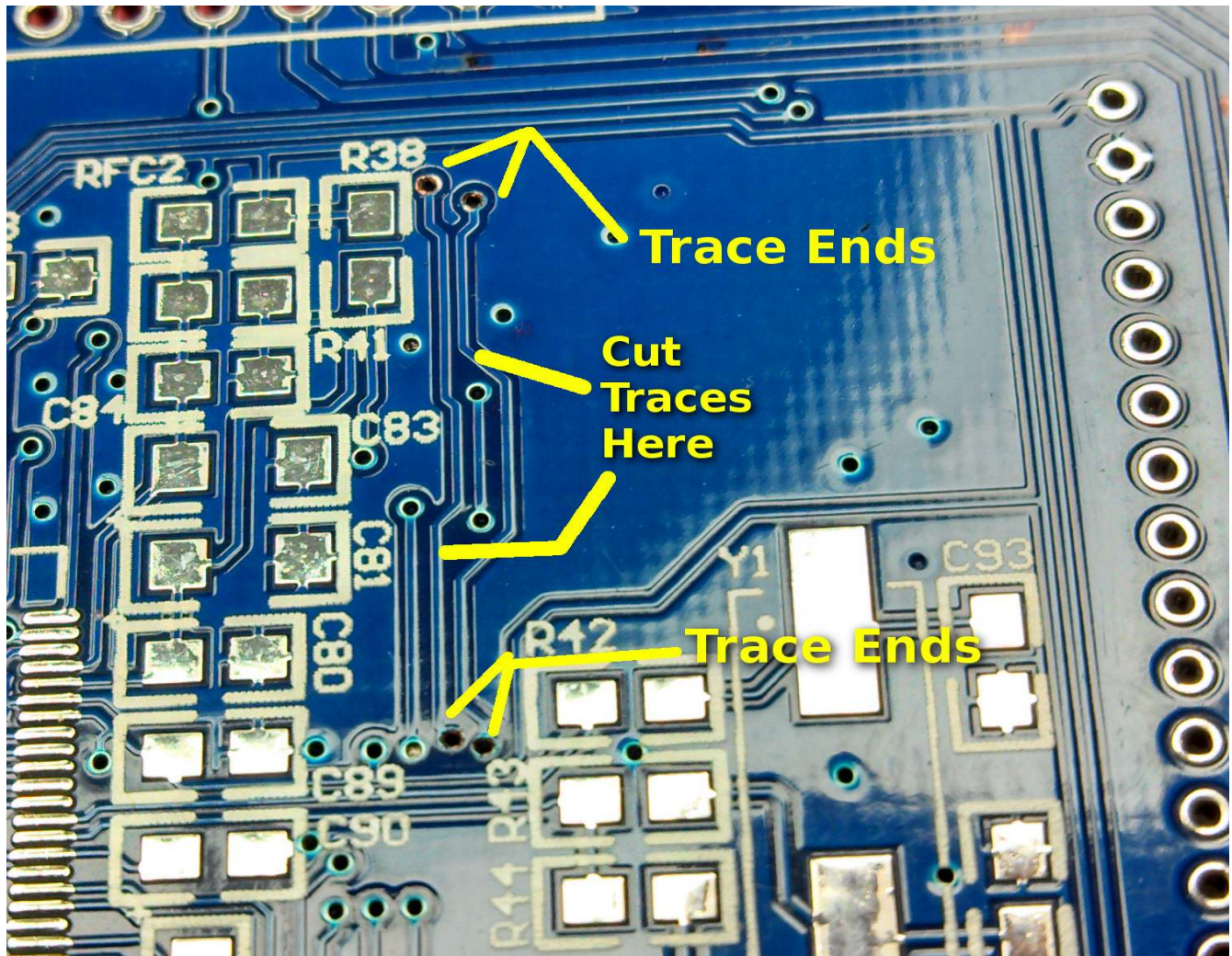
The modifications showing the 3.3 volt regulator (center) and increasing the capacitance of C32 to filtering and the additional filtering of the 5 volt LCD line (right). 1000uF can reduce this effect, as The resistor to filter the "tick" (see next section) are also visible. can the use of headphones or an external audio amplifier.

Further modifications to reduce this source of feedback are being investigated – but it's a good thing that the receiver's being improved to where this is a problem!

Elimination of the 1-second “tick” noise in the receiver – particularly on the higher bands (Version 0.3 and older UI boards only):

If the above modifications are made, with no antenna connected – or even with an antenna connected when listening on higher bands (especially 20 meters and above) a fairly strong “tick” may be heard every second. This is due to the polling of the onboard temperature sensor and the fact that the “fall” time of the on the I2C line from the MCU is extremely fast and rich with harmonic energy. This problem can be easily “fixed” with the addition of resistors on the UI board in series with the SCL and SDA lines which effectively reduce the slew rate of these lines, quashing the RF energy.

To identify the traces into which the resistors are to be installed, refer to the picture below:



This picture shows the location of the traces and where the cuts should be made. This is found to the right and above U4a, the MCU. A picture of a “bare” board is used for clarity.

A reasonable value of resistor to install is 470 ohms and the installed components may be seen in the picture.

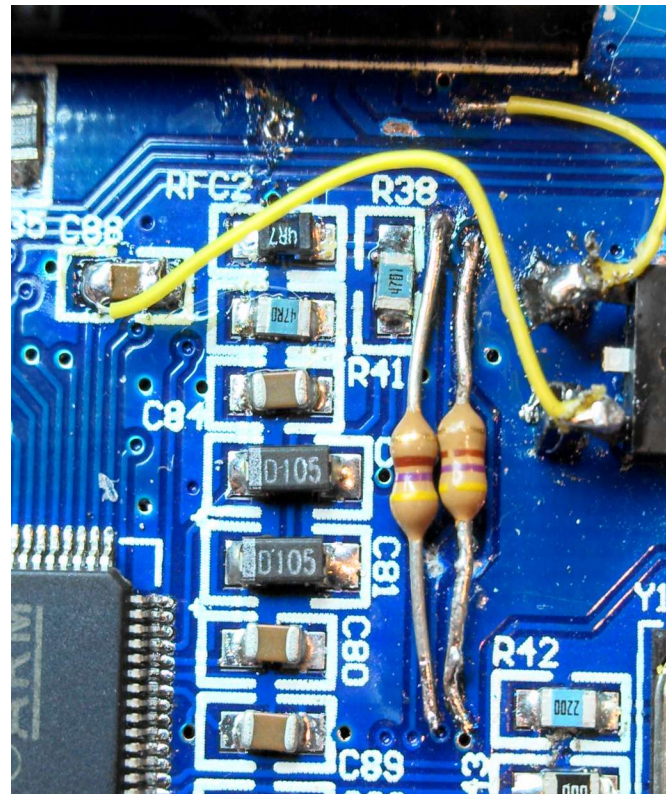
In the picture can be seen the two added 470 ohm resistors. As you can see, I used leaded 1/8 watt resistors, but surface mount resistors can be used, instead if that is your preference. (The 3.3 volt regulator used for the MCU – see the modification earlier in this document – can be partially seen.)

This modification appears to be **completely** effective in removing the “tick” noise from the higher bands and does not appear to compromise the operation of the I2C data stream in any way.

To verify the integrity of the I2C data stream – which is shared with the Si570 frequency synthesizer – I monitored the data stream with a digital storage oscilloscope and measured the worst-case slew rate – which was actually the risetime - the result being noted below.

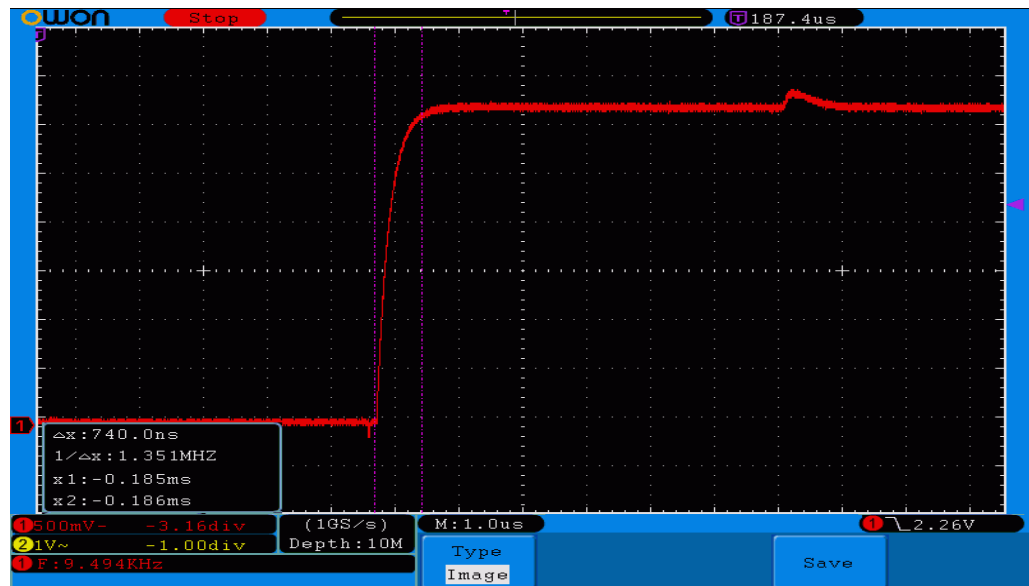
As can be seen, the risetime is less than 740 ns at the 10%-90% points which is a fraction of the I2C clocking rate, well within the time at which the edge of the clock into which the data is strobed in by the peripheral.

It should be noted that R16 and R17 are already present to moderate the slew rate of the data being sent **from** the Si570 and MCP9801 temperature sensor to prevent **those** devices from causing clicks!



The added 470 ohm resistors in series with the SCL and SDA lines. Note that this picture also shows the added 3.3 volt MCU regulator mentioned above. 1/8 watt, leaded resistors are used, but surface mount resistors could be used, if desired.

(END OF DOCUMENT)



*Of the rise and fall times on the I2C, the slowest slew rate was the **rise** time shown in this digital oscilloscope capture, which is well within the acceptable time for the clocking rate!*