Notes on converting an AM radio to FM

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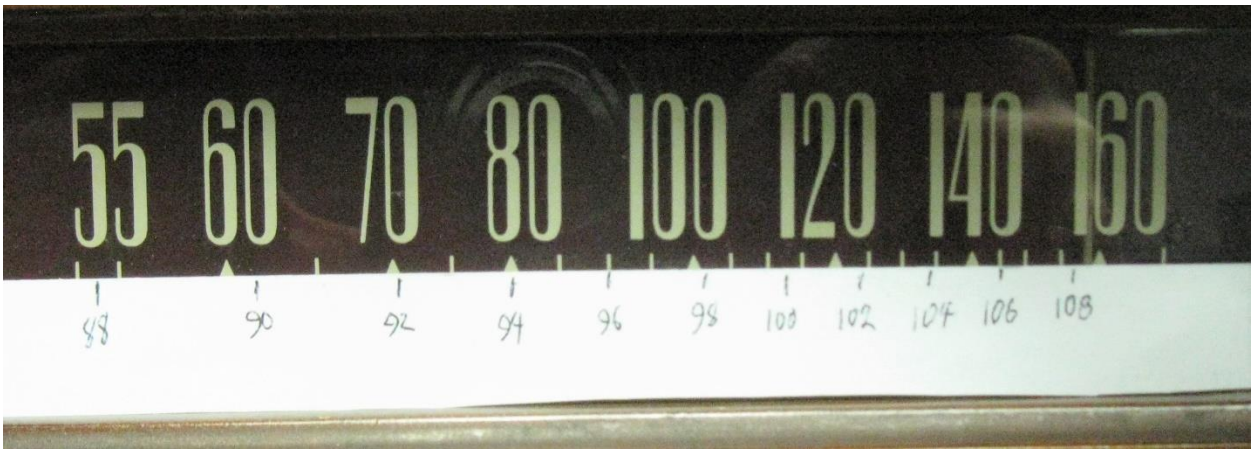
The goal here it to convert a standard 5-tube superheterodyne (like an All American 5) to FM without modifying the radio (except for plugging adaptors into the tube sockets), and have the radio operate and behave as usual. That is, you tune the radio with its tuning mechanism, knowing that the scale will be all wrong.



This is my 4th version!

The first one used a HC4046 PLL as a frequency to voltage converter (it follows the radio's LO), followed by an op amp (to get the tuning direction right), followed by a TDA7088 (sometimes marked 9088) FM receiver, followed by a NE602 modulator. It plugged into the converter (6SA7) socket of an AM radio to convert it to FM. The audio was modulated onto the 455kHz IF carrier and injected into the IF amplifier.

The second one was more complex. It used a digital/analog frequency to voltage converter rather than a PLL. It used a proper superhet FM tuner that I had converted to voltage tuning with varactor diodes. The output was fed in after the detector. It was designed for an AM/Shortwave receiver, such that AM remained, but the receiver switched to FM when on the SW band. It was unreasonably complicated, and it's not well documented, but it works well!

The third version reverted back to the PLL, the opamp and the TDA 7088, but the audio was fed into the 6SQ7 at the detector. Avoiding the modulator makes it simpler and gives it better fidelity.

This 4th version started as a challenge to myself. Earlier versions all had socket adaptors connected to a small box that held most of the electronics. Can I instead squeeze all of these parts onto small circuit boards that would fit under the 6SA7 and 6SQ7 tubes? Under the 6SA7, we would have the HC4046 PLL circuit. Under the 6SQ7, we would have the power supply and the TDA7088 tuner. (By changing the configuration around the TDA7088, it was possible to eliminate the op amp)

The answer is yes, but I have not had the circuit boards professionally made. The HC4046 under the 6SA7 circuit is a slam dunk; it would be quite easy to get it all onto a circuit board that would fit nicely

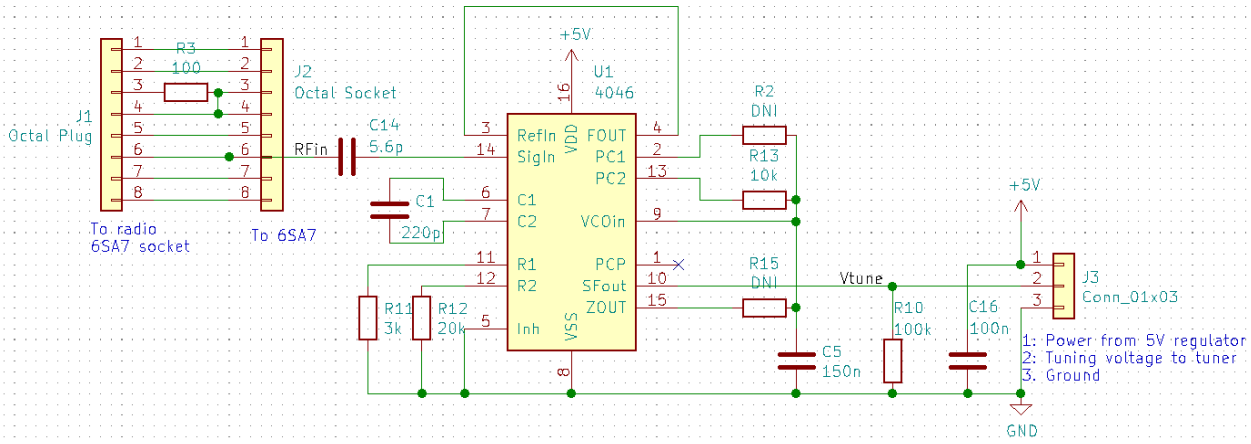
under an octal socket. In fact, I did it using a DIP version of the PLL chip, hand wired. The other side is much tighter. The TDA7088 needs quite a few components, but if you stick with 0402's it should fit. I discovered that I need some voltage gain and one more audio stage after the tuner to get adequate volume, and this squeezed it more. The power supply, though, probably needs its own board as there are some large components in there. (an interesting option I did not try was using the cathode voltage of the 50L6 to power everything. I would use a 4.7V Zener, and another 50 ohms or so to replace the 150-180ohm cathode resistor. Big capacitor to prevent feedback…)

The PLL side

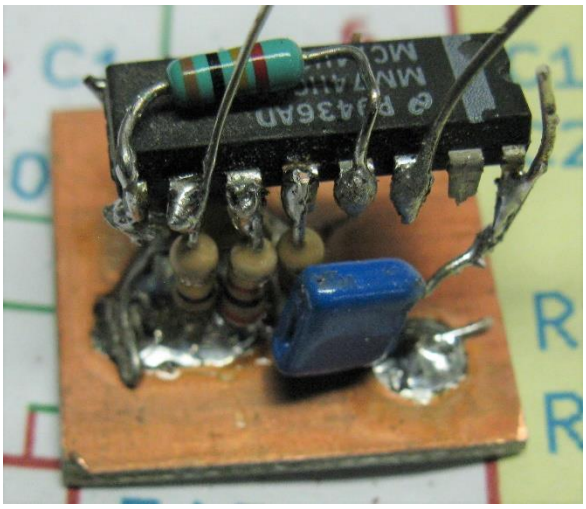
The PLL turns the 1MHz to 2.1MHz AM local oscillator frequency to a voltage of 0.6 to 2.0V (see below) to tune the FM tuner. I decided to couple from the 6SA7 (note that this can be many different tubes: 6A7, 6A8, 12A8, 6SA7, 12SA7, 6BE6, 12BE6, 7A8, 14A8, and others) cathode. I used a 74HC4046 PLL (the non-HC version is not fast enough).

Not all HC4046 are the same. The one I happen to be using is National Semiconductor, and there is an offset of about a half a volt between the VCO input and the buffered demod output. The difference is that the part I have does not have the suffix "A" or "B". The TI, Nexperia, and ON semi data sheets (with a suffix A or B) say that the offset is less than 30mv. I found an old Fairchild data sheet without the "A", and it has an offset. The non-A part's output goes almost low enough that it could drive the varactor diode without any offset. It can get tantalizing close to 0V at the low end, especially with a stronger load resistor. It is specified for a 10K load. I would have preferred the more modern part without the offset, but I used what I had. I think you would be hard pressed to find a non-A part these days. If you make this circuit with a non-A part, you will change the reference voltage divider on the TDA7088 pin 16 (R1, R2). I had it set for about 0.45V (33K and 390K). For a HC4046A or B, you will want more like 1V (say 33K and 150K).

The LO swing is much larger than it needs to be! I only needed 5.6pF coupling into pin 14 of the PLL. Excess coupling caused the PLL to come unlocked and fall to the bottom of the band. I used the type II phase detector, and being lazy, used the simplest 1st order loop filter. The requirements are so very easy to meet.



I disconnected the 6SA7 plate from the IF transformer (tied it to the screen) so no AM would be injected to the IF. I shunted the IF transformer with 100 ohms to “de-Q” it, and avoid a potential oscillation.



The FM tuner side

The tuner connects into the 6SQ7 (also could be 6Q7, 12Q7, 12SQ7, 12AT6, 12AV6, 6AV6, 6AT6, 7B6, 7C6, 14B6, 14C6, 6B6, 6H6, and others) in your radio. The TDA7088 (also seen as CD9088) is a single-chip FM tuner found in inexpensive pocket “autotune” radios. It seems to be rated at 5V max, but I swept several samples to at least 7V and there was no sign of breakdown. There should be no device-level reason that it cannot work at 7V, it is not a very sophisticated process. Perhaps a circuit level reason, but I have not found it. So, I have been running them directly off of 5V.

TDA7088 does not have enough output to fully drive at least one AA5 radio I tried. (Though, I thought Ted’s radio was OK without an extra amplifier). So, with the transistor on the radio board, I cobbled together a simple buffer amplifier. Not proud of it, but it uses few parts.

TDA7088 has poor high frequency response.

All of the radios I have seen with the TD7088 have the “seek” and “reset” tuning buttons. You can drive the varactor directly by injecting a voltage into the varactor where it connects to pin 16, the “reset” button. Unfortunately, the sense of that voltage is wrong: high voltage is at the low end of the band. It needs to be the other way around for use with the PLL. An op-amp inverter does the trick (the first version I made used this), but to reduce the parts count, I elected to redo the tuning circuit as shown below. Now, the tuning voltage comes to the other side of the varactor, so has the correct sense for the PLL. The pin 16 side is tied to a fixed voltage (divider) that works as an offset to the tuning voltage, and this is adjusted to make it match up with the PLL output voltage range. This divider must be different depending on the version of the PLL chip used, as described above. The impedance of this divider determines how much AFC action there is (charge pumps coming from pin 16); higher impedance means more AFC. I found that about 3K was good, though it is not at all critical.

Note that the voltage divider on the varactor anode effectively determines the AFC power. I used 100k/400k originally (the 100k mostly defining the degree of AFC action. Larger = more AFC), but I think that gave too much AGC pulling. 50K or 25K might be better. Make the 390K to positive variable? For the

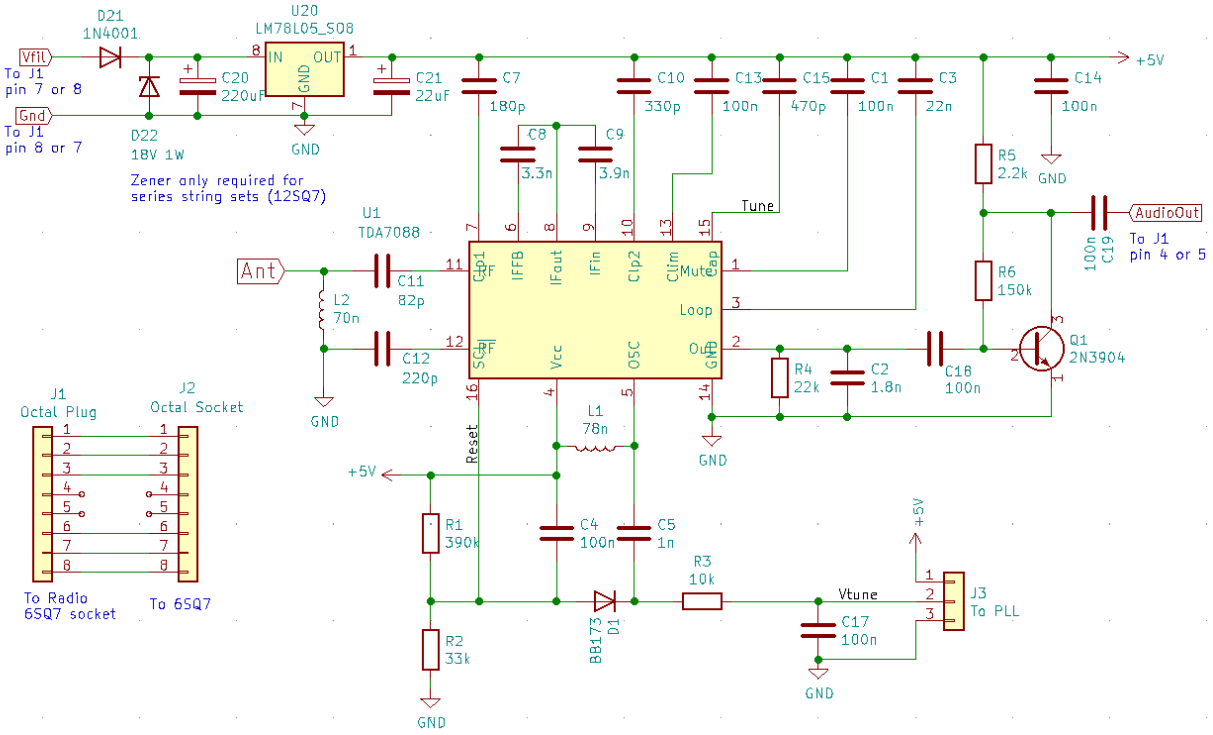
non-A version, we only need maybe 0.5V max, so 50K + a 500K pot would be about right. I ended up with 33K and 390K.

So, there are three mechanisms tuning the VCO on the 7088. 1) is the internal mechanism that narrows the FM bandwidth and is performed by the internal chip electronics. 2) is the AFC from pin 16 which acts on the external varactor. If allowed to go unchecked, it can tune the radio across the band, but we restrict it with the voltage divider. It is essentially a charge pump like used in a PLL. Note that there is a 100nF capacitor to ground on this node (from 7088 schematic), so we need not be shy about the capacitance we use in the C-L-C tank network. 3) is the external tuning voltage that we apply to the other side of the varactor diode in order to get the tuning running in the right direction.

I believe this could fit on a small custom SMT socket under the 6SQ7, but I have not tried. I started with a radio (they are widely available), and modified it. The radio has almost everything you need, it's the easiest way to proceed. It will have U1, L1, C1-C15 (except C5, you'll need to add that), R4, and maybe even C21, al wired up where you need them. It will probably have C18, C19, Q1, R5 and R6, but you'll need to rewire them.

The connection to the 6SQ7 is to the diode plate. The 6SQ7 has 2 diode plates and you cannot be certain which one it uses until you check your radio to see which one is connected directly to the IF transformer. The power also comes from the 6SQ7 filament, pin 7 and 8. Again, you cannot be sure which pin is connected to the filament and which is ground unless you check. The 18V (or so, I actually used a 22V because I had one) is required only for series filaments (like 12SQ7), usually 12V. If the filament burns out, or the tube is removed with the power on, the full line voltage would be applied to our circuit which would certainly damage it. The Zener diode would take the assault, dissipate about 2W, and survive, at

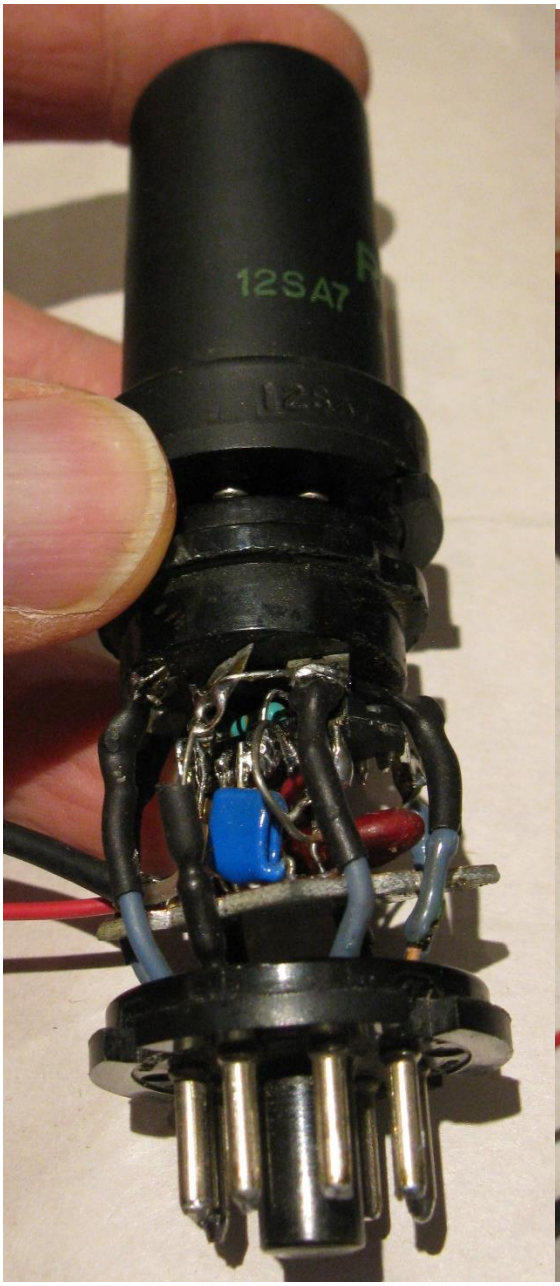
least for a while.



Alignment

You want the radio to tune from about 88 to 108MHz as it is tuned across the band. Here's the procedure I recommend to make this happen. Build the PLL with the values in the schematic. Aside from the difference between the HC4046 and the HC4046A/B (which imparts a fixed offset in the output voltage), I expect that the output swing across the band (for a radio with 455kHz IF) will be consistent part-to-part. Select the voltage divider on the tuner to produce a voltage equal to the voltage produced by the PLL when tuned to about 540kHz. The final adjustment will be the inductor, L1, on the radio. Make it smaller (stretch it out or remove a turn) if you can not get all the way up to 108MHz on the high end of the band, make it larger (squeeze it together, making the turns closer, or add a turn) if you can not get all the way down to 88MHz at the low end of the band.

Below: the completed tube adaptors, on the left with the PLL, on the right with the power supply.


12SA7