FM Receiver ver. 1.0

A home built FM Receiver, ongoing project

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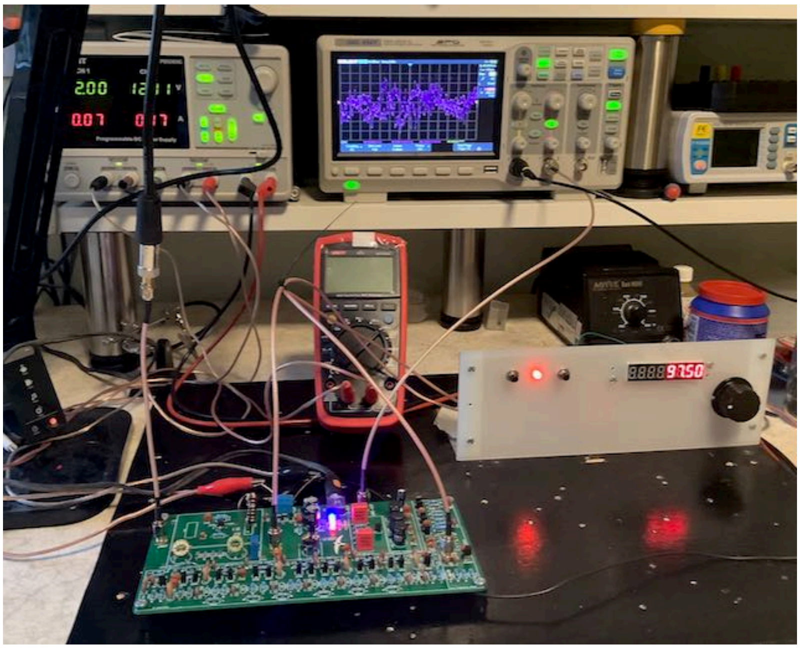
Introduction

A few years ago I started building some simple radio receivers. First these were AM receivers. Later my focus moved to FM receivers. Most of my knowledge of electronics and radio up to now has been gained from the internet. Very useful resources are the following

- Mateo Aboy videos on https://www.youtube.com/channel/UCfFq8r---cp2IBwoGcWWsvw, especially the videos by Dr. Christina Crespo.
- Electronics playlist of Caltech's Prof. Ali Hajimiri at https://www.youtube.com/playlist?list=PLc7Gz02Znph-c2-ssFpRrzYwbzplXfXUT
- RF Circuit Design - Bowick, 1982
- Experimental Methods in RF Design (Hayward, Campbell & Larkin)
- W2AEW's description of a pulse counting detector at https://www.youtube.com/watch?v=jQlN2fc7LJc

but also many more.

At this moment I have a very well functioning FM receiver designed and built by myself. It receives all the public FM stations in my country with great clarity. It is a mono receiver. Although it can still be improved on many points I feel it is a good moment to publish it at this moment so others can benefit from it as well.



Complete receiver, with the digital section right at the back

The current receiver is built on a PCB which I designed myself and was produced by JLCPCB. There is one major error in the design, but it is easy to solder your components around this design error. Also the current implementation is a bit different from the PCB because during PCB production at JLCPCB I discovered a very simple improvement which is also cheaper in components. The actual implementation can be built on the provided PCB.

The receiver has a large analog section and a small digital section. The digital section has the user interface with frequency/station selection, IF settings and some more features. The digital section is based on a Arduino Nano, with a Si5351 frequency synthesiser.

The project is an ongoing project. At this moment I am finishing performance measurements on the actual implementation. From the results of these, I will prepare for the next version of the receiver.

The analog section of the receiver runs on ±12 volts and consumes about 2.3 Watts. Sensitivity is about 50μV. The digital section burns 1.3 Watt when it is run from a 12V power source.

Things to improve

Things I want to improve, in no particular order

- selectivity
- stereo reception
- less stages in the IF section (smaller values for R308, R314, R326 and R337 for higher current so larger amplification)
- remove the follower in the last stage of the IF amplifier.
- replace the RF mixer with a design which does not have toroids
- replace the RM pre-amplifier with a design without toroid
- signal strength indicator
- to program the digital section it needs to be disconnected from power, and needs to be connected to USB only. This is too cumbersome and should be changed.

General architecture

The design is a commonly known heterodyne receiver, with two down-mixing stages:

1. RF Amplifier, one stage amplifier to boost the input signal, and isolate the antenna from the rest of the receiver.
2. RF Mixer, mixes RF down to the IF of 10.7 MHz (actually 10.66 MHz)
3. IF amplifier, for amplification and limiting of the signal at the intermediate frequency.
4. Low Frequency mixer, mixes the signal at 10.66 MHz down to the FM detection frequency of 450 MHz.
5. Pulse counting FM detector, converts the 450 kHz FM signal to audio
6. Audio section, filters out all frequencies higher than about 50kHz, and provides some amplification to line level audio.

Antenna

The antenna which I have currently in use is a vertical dipole, with two 75 centimeter branches. It is located on my attic, which is about 10 meters above ground level. The antenna is connected through a 300 ohms coax to the receiver.

RF Pre-amplifier

Dipole antenna

The RF pre-amplifier amplifies the input signal by about 10dB. Furthermore it tries to block signal coming in reverse direction from the receiver to the antenna based on its common base design.

Some time has been spent in trying to match the antenna impedance to the input impedance of the preamp. This did not result in much better reception however, so this has been abandoned for the moment. The antenna is directly connected to the emitter of the preamp's transistor Q201.

The current through Q201 (6mA) has been chosen such that its noise level is lowest.

The coil is chosen to perform in the RF domain. Number of windings are such that the coils impedance at 100MHz is reasonable (340Ω). The winding at which the signal is tapped has been found empirically [1].

C203 and C204 gave better performance in the receiver when it was still in the experimental stage. On the PCB however C203 and C204 do not seem necessary anymore. Their locations are not populated. Also the impedance matching circuit at the input (L201 and C201) are not populated on the PCB.

RF Mixer

The RF mixer is a double balanced diode ring mixer. The coils have been chosen to perform in the 100 MHz domain. They are trifilar wound.

The diodes are 1N6263 Schotky diodes. No effort has been made to match the diodes.

IF Amplifier

The IF amplifier amplifies the 10.66 MHz signal. It starts with a common base amplifier to prevent reverse signals feeding back into the RF mixer. The CB stage has an input impedance of about 10Ω. Next is a series of differential pair amplifiers, with inbetween 10.7MHz Murata crystal filters. The differential pairs provide amplification, but also limiting, which is essential in FM receivers.

See the document "IF Diffpair" in this directory for a more detailed description of the diffpairs functioning. The folder /IF Amplifier/Diffpair4 contains a Python project to model the workings of a differential pair amplifier. The section "RF and IF measurements" in this document contains some result of some measurements done in the RF and IF amplifiers.

Halfway the IF amplifier there is a coil which inverts the phase of the signal. This has been done to prevent positive feedback from the output signal of the IF amplifier onto its input.

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[1] Because there is much about toroids which I do not understand at this moment, there is a lot of guessing in this part. For this reason I'd like to replace this design with a resistor based design. Up to now I have not been able to reasonable performance with resistors however.

Finally there is a follower. This follower is a left-over from a previous version of the receiver, in which the IF amplifier was followed by a low impedance low-frequency mixer. To prevent loading of the last IF stage the follower was introduced. With the easy to drive JFET mixer which is in use at the moment, the follower should not be necessary however.

Low frequency mixer

The low frequency mixer is a very simple mixer which I have developed during the production of my video on JFET mixers https://www.youtube.com/watch?v=0p6FXlhfmts.

Pulse Counting FM Detector

See the document "Pulse Counting FM Detector" in this same directory for a detailed description of the detector.

Audio section

The audio section starts with a 100 kHz lowpass filter to filter out the 450 kHz remnants of the detector section. Then a simple common emitter amplifier to get signal level up to line level.

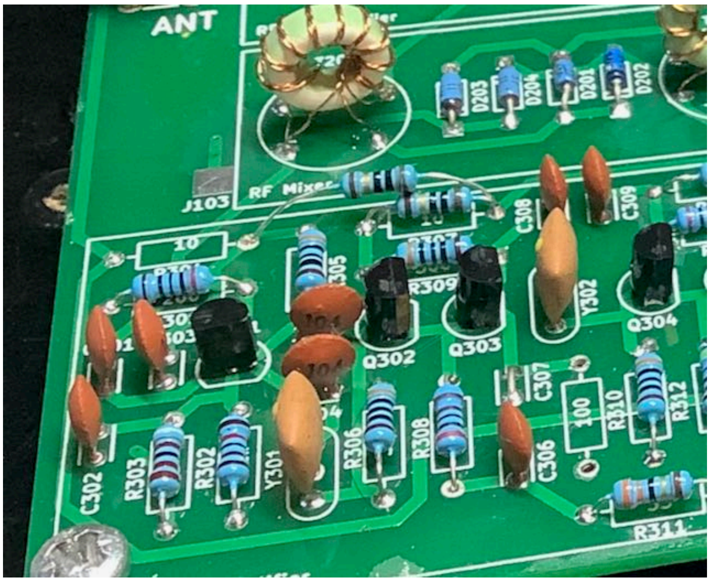
PCB Design

- There is a design error at R304. R304 should not be connected to V_{EE}, but to V_{CC}.
- The PCB has 20x10 centimeters dimensions.
- In the high frequency sections (RF amplifier, RF mixer, IF amplifier and FM detector) the ground plane has only been implemented on the bottom side, not on the top side of the PCB. This was done to minimise stray capacitance.

Differences between PCB design and current implementation

At the following points the current implementation differs from the schematic. In the next revision of the schematic and PCB this will be changed.

1. In the circuit diagram C505 is a 470pF capacitor, this is an error. It should be 220pF. In the actual implementation it is an 220pF capacitor.
2. In the circuit diagram one side of R304 is connected to VEE. This is an error. It should be connected to VCC. The PCB also has this error. In the actual implementation it is connected to VCC. On this photo the bodge is visible.
3. In the actual implementation L506 is 1mH instead of 1.2mH as is given in the circuit diagram. This is because I did not have a 1.2mH at the moment.
4. I used a 9.1kΩ value for R303 instead of 9.2kΩ.
5. I used a 1kΩ resistor for R308 instead of a 4.7kΩ.
6. The input impedance matching network on Q201 is not implemented at all. C201 is shorted, and L201 is left blank.



R304 bodge

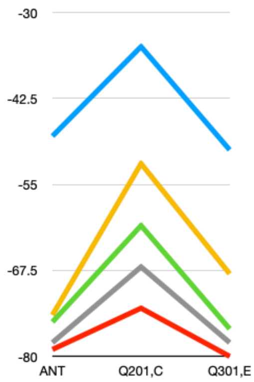
7. D103 is a red led, D104 is a blue led. To limit the current (and so brightness of D104) R104 is 5.1kΩ instead of 560Ω.
8. Resistors R310, R316, R322, R328, R334, R340 and R346 are not implemented. Also capacitors C307, C311, C315, C319, C323, C327 and C331 are not implemented, but shorted. The base of the righthand transistors of the differential pairs can be connected to ground directly.
9. The sixth order lowpass filter at the input of the detector has been replaced by a 4th order filter. C503 is left open, L503 has been shorted. L501, L502, C501 and C502 have the values as mentioned in the schematic.

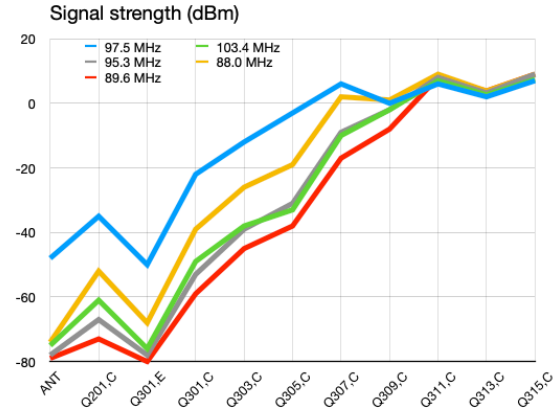
RF and IF measurements

In the following figure you can see measurement of the signal strength at various places in the RF and IF amplifier for different radio stations. The limiting action at about 10dBm is very obvious.

Signal Strength

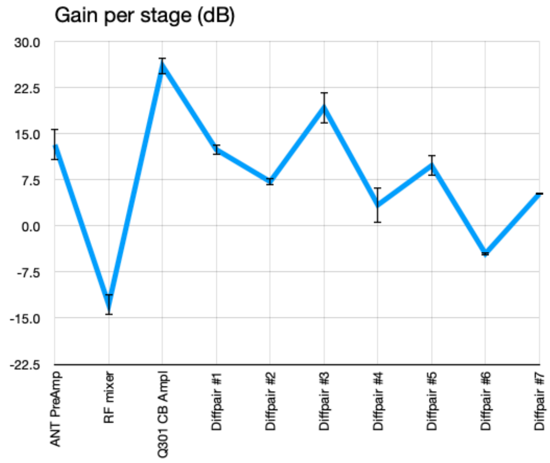
	97.5 MHz	103.4 MHz	95.3 MHz	88.0 MHz	89.6 MHz
ANT	-48	-75	-78	-74	-79
$Q_{201,C}$	-35	-61	-67	-52	-73
$Q_{301,E}$	-50	-76	-78	-68	-80
$Q_{301,C}$	-22	-49	-53	-39	-59
$Q_{303,C}$	-12	-38	-39	-26	-45
$Q_{305,C}$	-3	-33	-31	-19	-38
$Q_{307,C}$	6	-10	-9	2	-17
$Q_{309,C}$	0	-2	-2	1	-8
$Q_{311,C}$	6	7	8	9	8
$Q_{313,C}$	2	2.6	3.2	3.8	3.8
$Q_{315,C}$	7	7.4	9	9	9





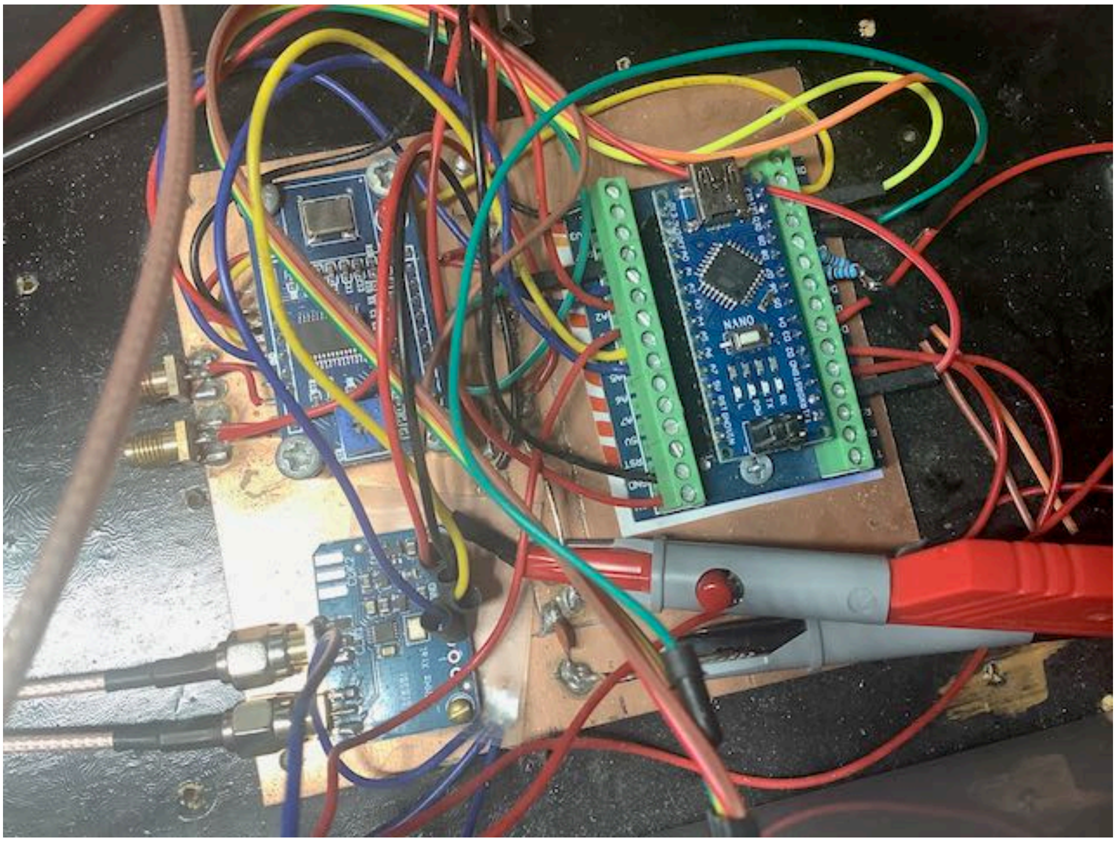
Gain

	97.5 MHz	103.4 MHz	95.3 MHz	88.0 MHz	89.6 MHz	mean	stdev	SEM
	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)	(dB)
ANT PreAmp	13	14	11	22	6	13.2	5.8	2.6
RF mixer	-15	-15	-11	-16	-7	-12.8	3.8	1.7
Q_{301} CB Ampl	28	27	25	29	21	26.0	3.2	1.4
Diffpair #1	10	11	14	13	14	12.4	1.8	0.8
Diffpair #2	9	5	8	7	7	7.2	1.5	0.7
Diffpair #3	9	23	22	21	21	19.2	5.8	2.6
Diffpair #4	-6	8	7	-1	9	3.4	6.6	2.9
Diffpair #5	6	9	10	8	16	9.8	3.8	1.7
Diffpair #6	-4	-4.4	-4.8	-5.2	-4.2	-4.5	0.5	0.2
Diffpair #7	5	4.8	5.8	5.2	5.2	5.2	0.4	0.2



Digital section

The digital section handles station selection, frequencies and signal level for the local oscillators and whether to have low-side or high-side injection for the RF section. The firmware runs on an Arduino Nano 328P. The Arduino instructs the Si5351 which generates the local oscillators for the RF and low frequency mixers. Source code for the firmware running on the Arduino is in the folder /firmware.



Digital section. In the topleft is a AD9851 which is not used in this project.