Shraddha Dangi, Courtney Howell
ECEN 5013

Project Report:
Ham Radio Receiver

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Abstract :

The purpose of this project was to design a HAM radio receiver for operation in the HF band. The frequency of operation is 28-28.5 MHz which is allowed for amateur technician licensee by ARRL. 28-28.3MHz allows for CW, RTTY and data whereas 28.3-28.5MHz is for SSB and CW. The radio receiver was designed to be tunable over these range of frequencies. The signals were downconverted to the audio range and the output fed into a speaker.

Block diagram :

The receiver works by using the superheterodyne principle of converting the incoming signal to a fixed intermediate frequency(IF). For this implementation, down conversion is used, which means that the IF frequency is lower than the incoming signal frequency. Refer Figure 1 for a complete block diagram of the receiver system. The input is fed through 2 sources, an antenna and a function generator and an RF switch enables to toggle between the 2. Source 1 is an antenna input with an RF filter (bandpass) filter which filters out the unwanted spectrum and passes only the frequencies of interest. This is followed by a low noise amplifier(RF amp) which would compensate for the loss in signal strength before it reaches the receiver. The second input is connected directly to the function generator and the bandpass RF filter. Both the function generator and antenna RF filter outputs were fed into an RF switch before the first mixer stage.

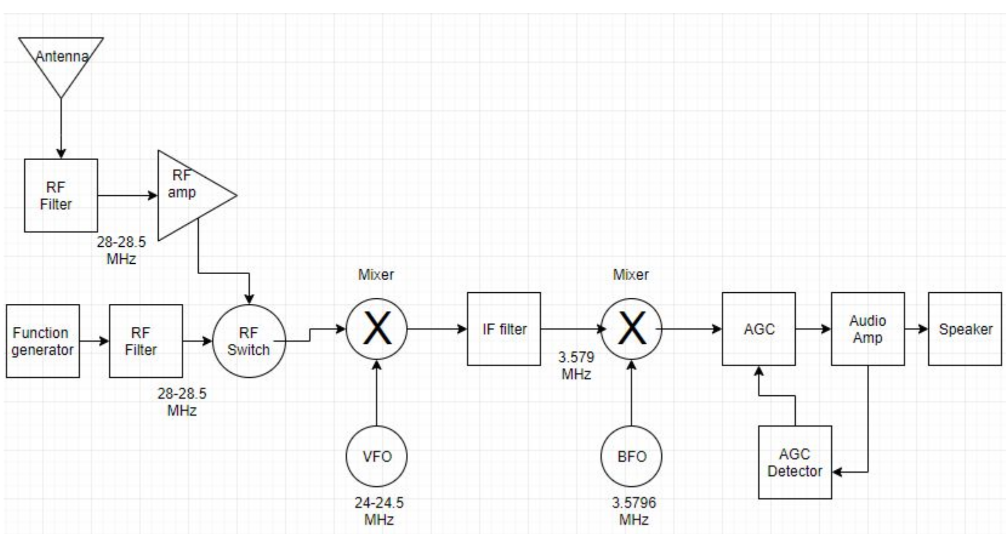

Figure 1 : Block Diagram of radio receiver

A voltage controlled oscillator is used to mix the input frequency using the SA602A mixer IC. The output is an IF frequency of 3.579 MHz. While mixing products including various harmonics, the narrowband IF filter made from crystal oscillators, allows only the desired down converted output into the second mixer. This is finally mixed with a beat frequency oscillator which is at roughly 600 Hz offset from the IF filter output, giving us a signal in the audible range. Finally, this is fed into an audio amplifier with an output power of 2.9W at 5V into 4 Ω speaker.

Circuit Design :

The design of each individual stage is given below, followed by the complete schematic and PCB layout in the next section. The design of the filters and matching network is done using ADS software.

1. Power supply

Since our IC's used 12V, 5V, or 3V, we decided to feed only 12V into the board and include two voltage regulator circuits to get 5V and 3V. We used the MIC5205 in the following arrangement to achieve the voltage down-conversion.

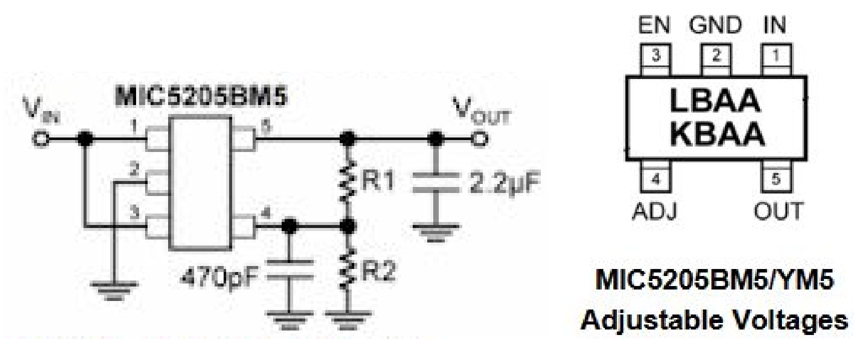

Figure 2: MIC5205 pinout and adjustable output voltage circuit.[1]

To find the resistor values to produce our desired output voltages, we did the calculations below. The ratio 30k ohm and 22k ohm is used for a voltage out of 3V and the ratio of 1k and 3k ohm is used for an output of 5V.

$$V_{out} = 1.242 \cdot \left(\frac{R_2}{R_1} + 1\right)$$

$$\frac{R_2}{R_1} = \frac{V_{out}}{1.242} - 1$$

$$\frac{R_{13}}{R_{12}} = \frac{3}{1.242} - 1 = 1.415459 \cong \frac{30k}{22k}$$

$$\frac{R_5}{R_4} = \frac{V_{out}}{1.242} - 1 = 3.025765 \cong \frac{3k}{1k}$$

2. Bandpass Filter

The input to the filters was provided with through hole SMA connectors on the board. The bandpass filter was a lumped element N=2 butterworth filter with simulated fractional bandwidth = 27.5% for an input match> 10dB. The filter schematic and |S11| and |S21| in dB are shown in Figures 3 and 4 respectively. Lumped element values were L=6.48 uH, 28 nH and C=5pF an 1.16nF. A blocking capacitor used at the output for the input of the RF switch for function generator input and to LNA for antenna input. Initially we only had one of the outputs to the mixer but decided that 2 inputs would be better for testing as the 28 MHz spectrum is highly affected by the solar cycle and it was unlikely we could pick up direct antenna inputs.

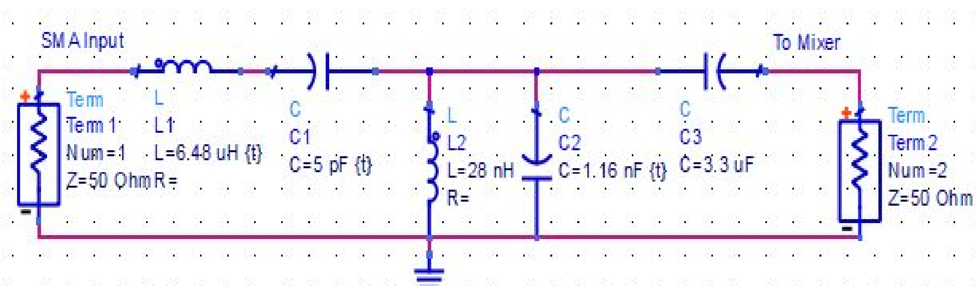

Figure 3: Simulated bandpass filter schematic in ADS

The 6.48H inductor was ferrite core FT-23-61 wound with 15 turns and the 28nH was an air core inductor. The inductor turns were calculated using the ferrite core specifications provided by the manufacturer : Amidon. Number of turns N is calculated using the equation below[2] where A_L is the inductance index. For FT-23-61, A_L =24.8. For 6.48uH, this gave around N = 15.

$$N = 1000\sqrt{\frac{\text{desired 'L' (mh)}}{A_L \text{ (mh/1000 turns)}}}$$

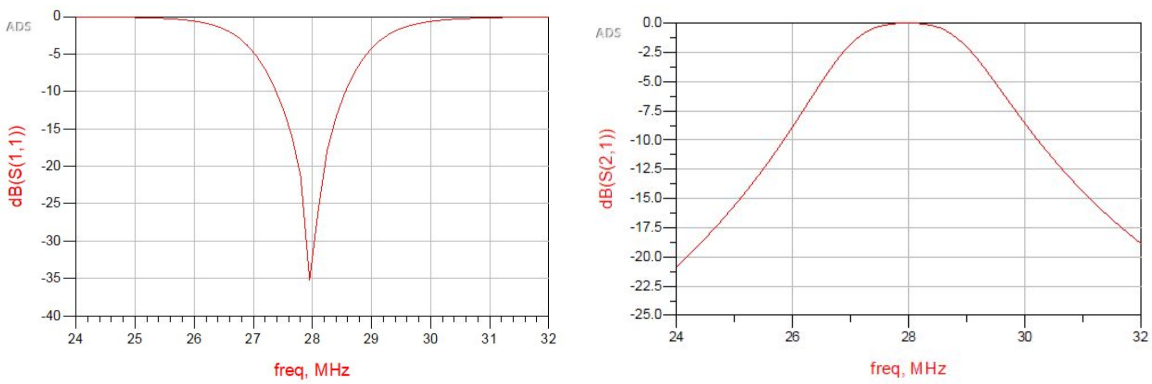

Figure 4 (left) : Simulated |S11| in dB for filter, match > 10dB for 27.5% fractional BW ; (right) |S21| in dB showing bandpass response.

In the ferrite inductor core selection it was important to make sure that we get an integer number of turns. While we got lesser number of turns with the FT-37-61 which had A_L =55.3, after winding and checking inductance on an LCR meter, the inductance value with the former core was closer to the desired value.

3. RF switch

The RF switch was controlled using a mechanical switch to input the correct voltage levels into two control pins on the RF switch. The RF switch uses the following truth table as its control inputs. Also, its outputs were pre-matched to 50 ohms, so it didn't need matching circuitry.

STATE	Control Input		RF Input / Output	
	Control 1	Control 2	RF1 to RF COMMON	RF2 to RF COMMON
1	Low	Low	OFF	OFF
2	Low	High	OFF	ON
3	High	Low	ON	OFF
4	High	High	N/A	N/A

Table 1: Truth table for the HSWA2-63DR+ RF switch[3]

We originally designed the circuit to switch between states 1-3. A 5V line was fed into the SPDT analog switch, which could switch between connecting to neither control pin or one of the two control pins. Pulldown resistors between the analog switch and RF switch ensured that our low voltage was very close to 0V and prevented floating voltages. Unfortunately, the on-off-on switch we ordered came with rectangular pins, rather than the round pins on the datasheet, so we had to use a simpler, two-state analog switch that could only switch between states 2 and 3 in the table above.

4. Low Noise Amplifier(LNA)

The low noise amplifier was added in the antenna chain to improve signal strength. We used MAX2611 DC-to-Microwave LNA with a low noise figure of about 3.5 dB and roughly 18dB gain at 28 MHz. The input and output of the LNA was pre-matched to 50 ohms so we didn't have to worry about matching. According to the datasheet[4], the minimum value of blocking capacitor at the output of the LNA was given as $C_{block} = 53000/f$ pF where f is in MHz. For our operating frequency of 28 MHz, this value was given as 1.8 nF. The blocking resistor value was determined by setting a drain current operating limit, which we set to 20mA. The nominal Vdd was given as 3.8V, Vcc= 5V so , $R_{bias} = (Vcc - Vd)/Id$ = 60 ohms.

Pin out	Function
1	Output to RF switch
2	Ground
3	Input from RF filter
4	Ground

Table 2: Pinout configuration for LNA[4]

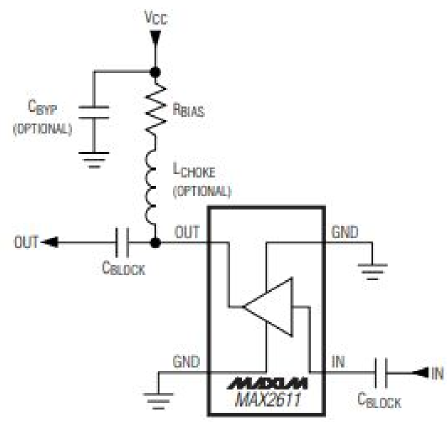

Figure 5: Circuit configuration of LNA[4]

The value of the blocking capacitor was chosen to be 3 uF with an added RF choke which would help reduce the loading effect from the bias resistor on the output of the amplifier[4]. The output of the LNA goes into the RF switch as one of the switched inputs.

5. Matching network to Mixer

The output from the RF switch is matched to 50 ohms whereas the input impedance of mixer chip is at 1.5k ohms. To minimize loss of signal due to mismatch, an LC matching network is designed as shown in Figure 6. The |S11| in dB is shown in Figure 7 which shows a good return loss for the frequency of interest. The output of mixer to the IF filter is similarly matched with the inductor placed in shunt before the series capacitor. Blocking capacitor of 0.1uF is taken into account in the simulation. Inductance of L =1.53uH was achieved with N=4 turns on ferrite core FT-37-61.

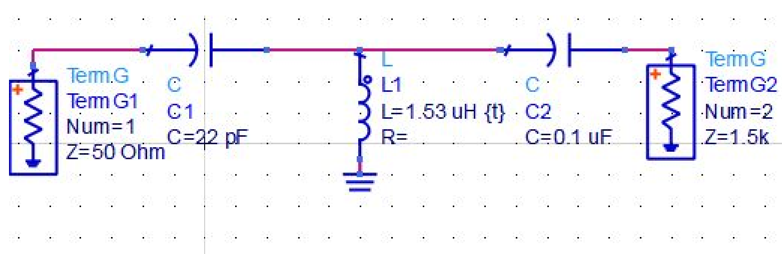

Figure 6: Matching network for input to mixer, designed in ADS

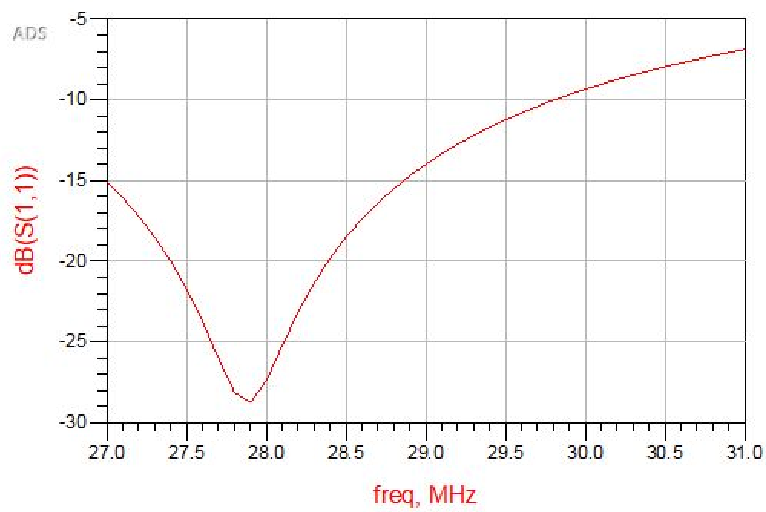

Figure 7: |S11| in dB of matching network, shows wideband match>10dB

6. Mixer

The mixer chip used was the SA602A doubly balanced mixer and oscillator chip from NXP. The advantage of using an IC for the mixer is that it had integrated gilbert cell mixer and pinout configuration for external oscillator as well. It had a low noise figure of < 4.7dB which is why it was a good choice for this design.

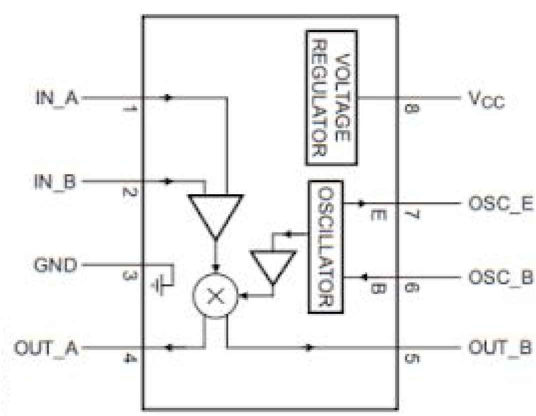

Figure 8: Pinout of the SA602A oscillator/mixer chip[5]

Pinout	Function
1	Input from matching network
3	Ground
6	Input from VCO or BFO
8	Vcc = 5V

Table 3: Relevant pin connections for SA602A

The chip also has an in-built oscillator/buffer that was used for the BFO, but since we wanted a tunable oscillator for the VCO, we chose to provide this externally. The VCO is described next.

7. VCO

For the VCO, we used the JTOS-50P+, which has an approximate tuning range of 19.8-31.5 MHz. To be able to tune the VCO to our desired range of 24.5-25 MHz (to drop down input 28-28.5 MHz to IF of 3.579 MHz), we designed a simple voltage divider with a 1k resistor and a 20k potentiometer to determine the voltage at the VCO's tuning input. Below in Figure 9 is the tuning sensitivity for the JTOS-50P+. Based on this chart, we would want a tuning voltage of about 1.5-2V.

V TUNE	TUNING SENS. (MHz/V)	FREQUENCY (MHz)			POWER OUTPUT (dBm)		
		-55°C	+25°C	+85°C	-55°C	+25°C	+85°C
0.00	3.64	21.03	19.87	19.00	6.92	6.99	6.38
0.50	3.59	22.51	21.68	21.07	7.58	8.01	7.68
1.00	2.74	23.72	23.17	22.73	8.30	9.01	8.94
1.50	2.57	25.14	24.38	23.94	8.99	9.68	9.70
2.00	2.33	26.34	25.60	25.16	9.27	10.03	9.80
2.50	2.03	27.42	26.65	26.25	9.29	10.03	9.80
3.00	1.99	28.43	27.66	27.24	9.29	10.01	9.77
3.50	1.87	29.40	28.61	28.20	9.27	9.97	9.72
4.00	1.92	30.37	29.58	29.14	9.23	9.91	9.65
4.50	1.85	31.34	30.52	30.08	9.16	9.85	9.58
5.00	1.97	32.32	31.49	31.03	9.10	9.78	9.50

Figure 9: Tuning sensitivity for the JTOS-50P+ from the datasheet[6]

8. IF Filter

The intermediate frequency (IF) filter is a 4-stage Cohn crystal ladder filter, which is a very narrowband filter. The frequency we finally used for our IF filter was 3.5792 MHz. The crystals we purchased for our filter were at 3.579545 MHz but after testing (described in a later section), we realized they resonated closer to 3.5792 MHz. Figure 10 shows the IF filter circuit with added parasitics determined through the tests. The simulated |S11| in dB shown in Figure 11 is very low, but it shows the resonant frequency to be close to the desired resonance. Through testing however, we received a better response from the filter.

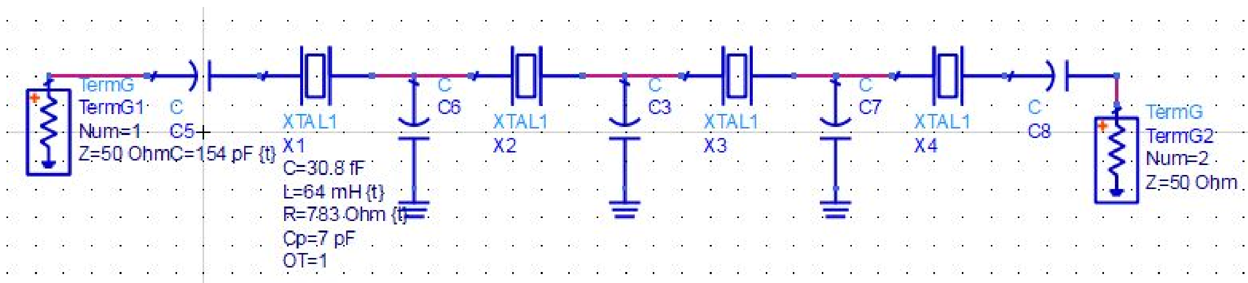

Figure 10: IF Cohn crystal filter circuit designed using ADS

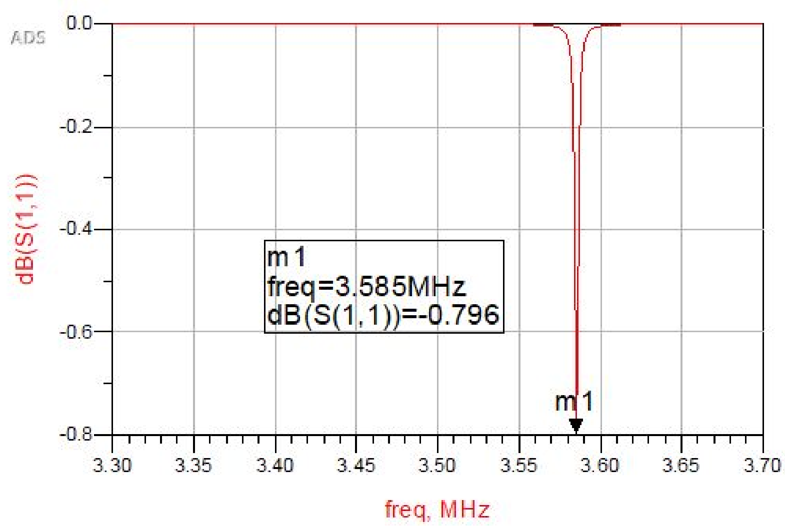

Figure 11: |S11| in dB for IF filter

9. Beat Frequency Oscillator (BFO)

The BFO was initially designed to have a center frequency of 3.579 MHz. but due to the tested IF filter output and BFO crystal resonance(resonated at 3.572 MHz) being very close to each other(difference would give a very low audio range), we loaded the crystal in series with a 16pF capacitor to increase the frequency to 3.579485 MHz, in parallel with capacitor of 30pF. The BFO outputs into the mixer/oscillator chip and is thus a very simple circuit.

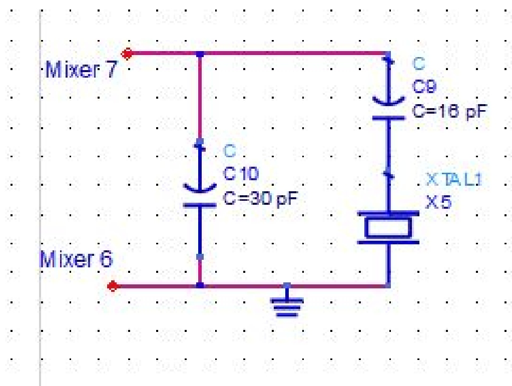

Figure 12: BFO circuit(ADS)

10. Audio Amplifier

Since audio amplifier and AGC circuit design is quite complex and involved, we used an off-the-shelf audio amp with AGC IC, specifically the IS31AP2145A. This chip is a class D amplifier that outputs 2.9W at 5V. We used the suggested circuit layout from the datasheet, which is shown below.

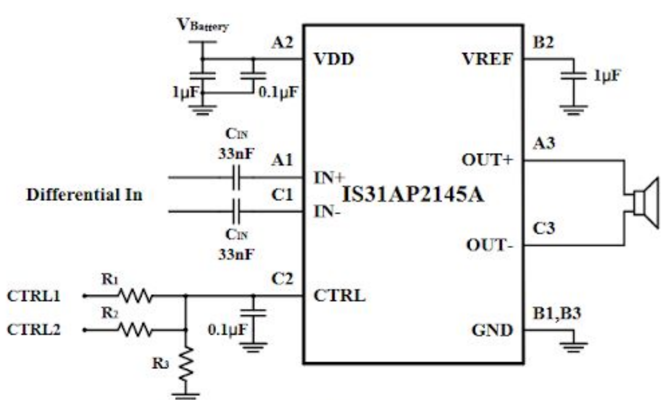

Figure 13: Typical application circuit of the IS31AP2145A[7]

Completed Schematic:

Our final schematic is laid out on 2 different sheets due to the complexity of the circuit. They're shown in Figures 14 and 15 below. The schematic we used to design the board and send to fab are shown in the Appendix. They have slight variations from the circuit configurations and values we got through testing. For example, in the initial IF filter we had some extra coupling capacitors which were not needed. Also, we realized later that in the schematic in Figure 15, we forgot the matching network from the IF filter to the mixer in our final design.

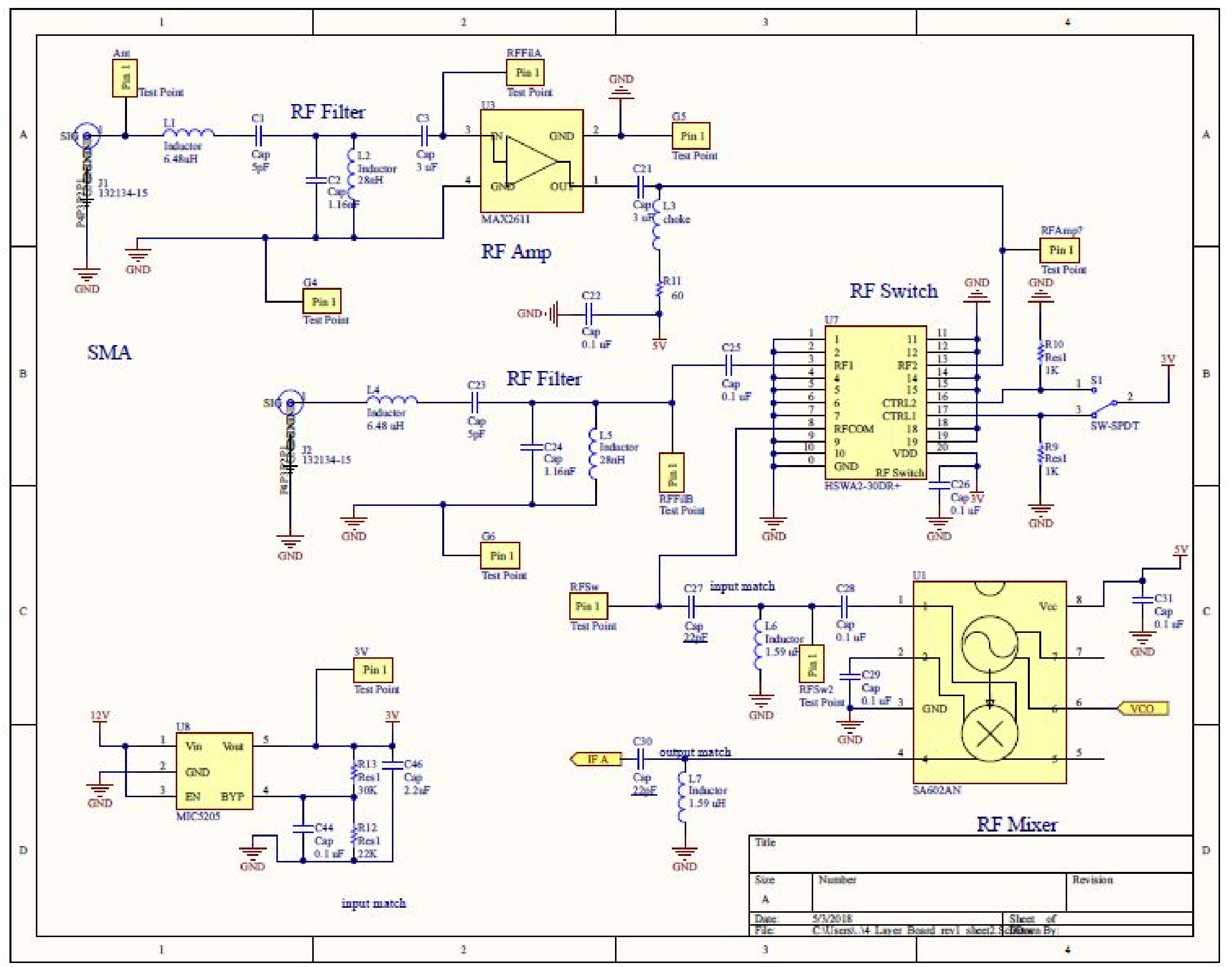

Figure 14: Schematic 1 containing SMA input points, RF filters, RF switch, First mixer stage and 3 V supply voltage regulator

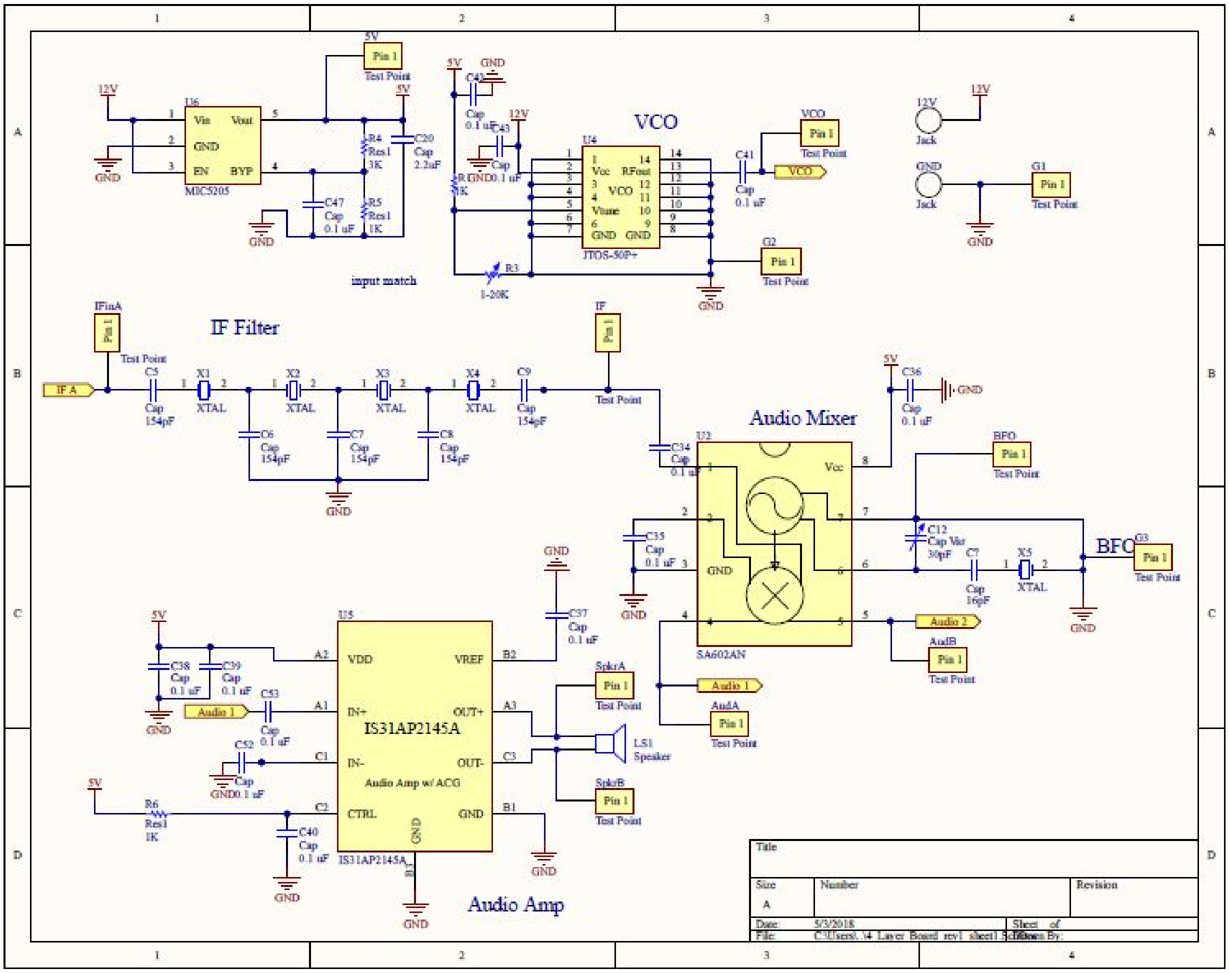

Figure 15: Schematic 2 containing 5V voltage regulator, VCO, IF filter, second mixer stage, audio amplifier and speaker

PCB Layout:

For our 4-layer PCB, we used the following stackup: signal || ground || ground/power || signal. On the ground/power plane, we had top half of the board with a 5V power plane and bottom half with a ground plane, and we positioned all ICs that required 5V on the half with the power plane.

The trace widths used were 8mils for signal lines and 20 mils for power lines. Vias were 10mils in diameter with a 20mil pad. Signal trace widths and via size were selected based on our PCB manufacturer's specifications to avoid additional charges. Power trace width was chosen to allow increased current flow. Since we used LC matching to match impedances, we did not have to do any calculations of trace width to match impedance. Test points were placed and connected throughout the circuit for ease of testing and debugging. A picture of our final PCB layout is below in Figure 16. and in Figure 17 is picture of the board back from fab and fully assembled.

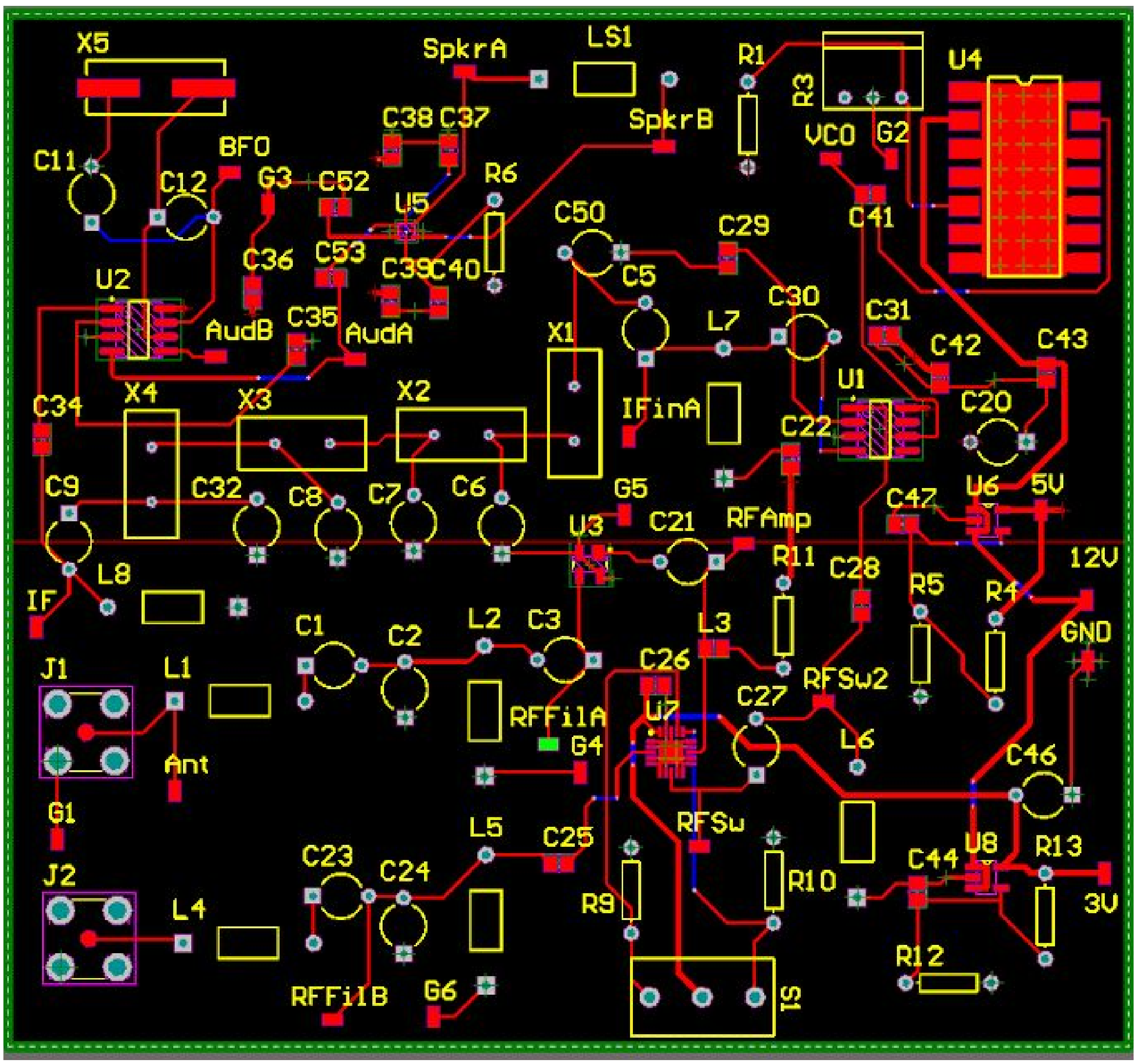

Figure 16: PCB layout of radio receiver.

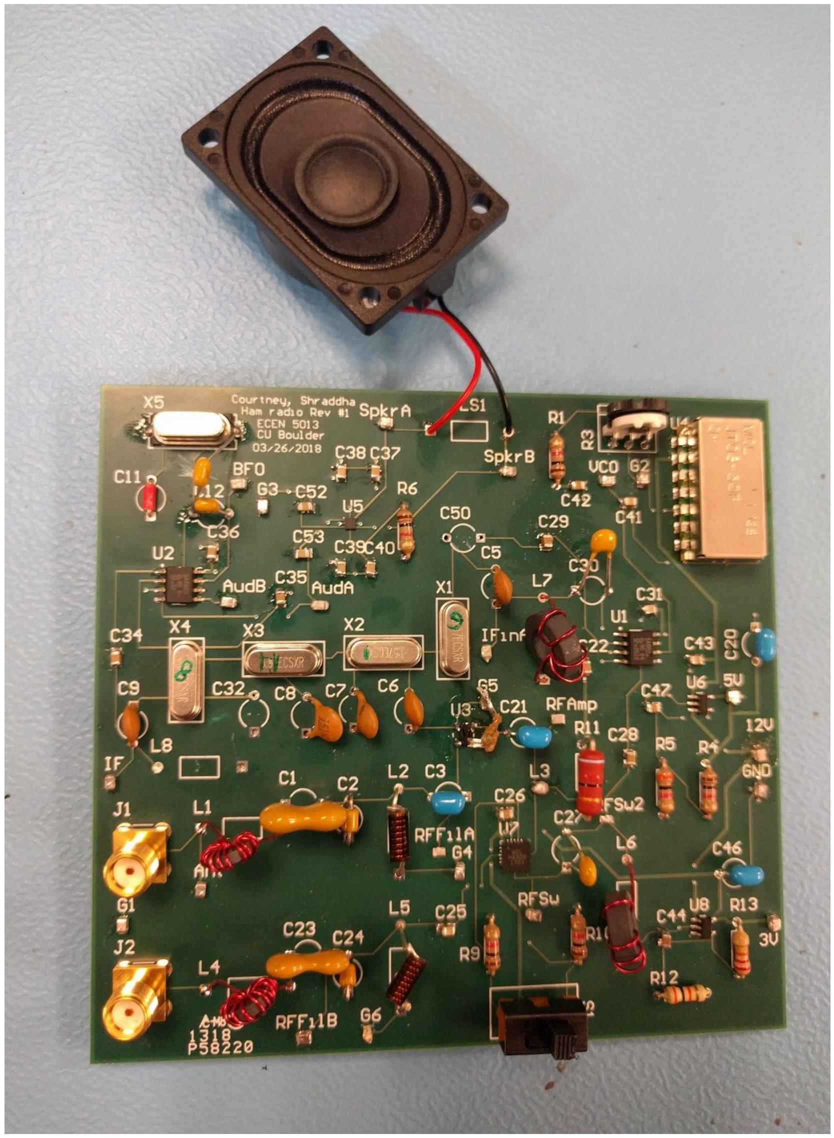

Figure 17: PCB back from fab and radio assembled.

We decided to have the speaker be off the board because most speakers specified for 4 ohms had positive and negative lead connections instead of a direct connection to the board. Table 4 shows the bill of materials for the design.

Comment	Description	Designator	Footprint	LibRef	Quantity
Test Point		3V, 5V, Ant, AudA, AudB, BFO, G1, G2, G3, G4, G5, G6, IF, IFinA, RFAmp?, RFFilA, RFFilB, RFSw, RFSw2, SpkrA, SpkrB, VCO	TP2	Test Point	22
Jack		12V, GND	TP2	Jack	2
Cap	Capacitor	C1, C2, C3, C5, C6, C7, C8, C9, C20, C21, C23, C24, C27, C30, C46, C?	CAPR5-4X5	Cap	16
Cap Var	Variable or Adjustable Capacitor	C12	CAPR5-4X5	Cap Var	1
Cap	Capacitor	C22, C25, C26, C28, C29, C31, C34, C35, C36, C37, C38, C39, C40, C41, C42, C43, C44, C47, C52, C53	C0805	Cap	20
132134-15	RF Connector SMA Straight PCB Jack Surface Mount 50 Ohm	J1, J2	AMPHENOL_132134-15_132134-15(Primary)	132134-15	2
Inductor	Inductor	L1, L2, L4, L5, L6, L7	PIN-W2/E2.8	Inductor	6
choke	Inductor	L3	C0805	Inductor	1
Speaker	Loudspeaker	LS1	PIN-W2/E2.8	Speaker	1
Res1	Resistor	R1, R4, R5, R6, R9, R10, R11, R12, R13	AXIAL-0.3	Res1	9
Res Adj1	Variable Resistor	R3	3352W	Res Adj1	1
SW-SPDT	SPDT Subminiature Toggle Switch, Right Angle Mounting, Vertical Actuation	S1	100SP3T1B1M2QEH	SW-SPDT	1
SA602AN		U1, U2	SO8_N	SA602AN	2
MAX2611		U3	SOT-143_N	MAX2611	1
JTOS-50P+		U4	BK377	JTOS-50P+	1
IS31AP2145A		U5	UTQFN-9	IS31AP2145A	1
MIC5205		U6, U8	SOT95P280X130-5N	MIC5205	2
HSWA2-30DR+		U7	DG983-1	HSWA2-30DR+	1
XTAL	Crystal Oscillator	X1, X2, X3, X4	XTAL1	XTAL	4
XTAL	Crystal Oscillator	X5	XTAL2	XTAL	1

Table 4 : Bill of materials

Testing:

The results of our testing each functional block are explained in detail below.

1. Power Supply

The output voltages of the voltage regulators was measured as 4.98V on the 5V line and 3.03V on the 3V line.

2. RF Filter

Our design had two identical RF filter circuits for the antenna and the function generator inputs. We found the center frequency to be about 23.4 MHz on the antenna side and about 22.2 MHz on the function generator side. These are both unfortunately very far away from our desired range of about 28-28.5 MHz. Below are two oscilloscope captures of the filter output with an input of 100mV, one at the desired center frequency of 28.2 MHz and the second, at the shifted frequency of 23.4 MHz. As seen in the graphs, the output at the desired frequency is highly attenuated(16mV) and the one at the center goes through with a magnitude of 93 mV.

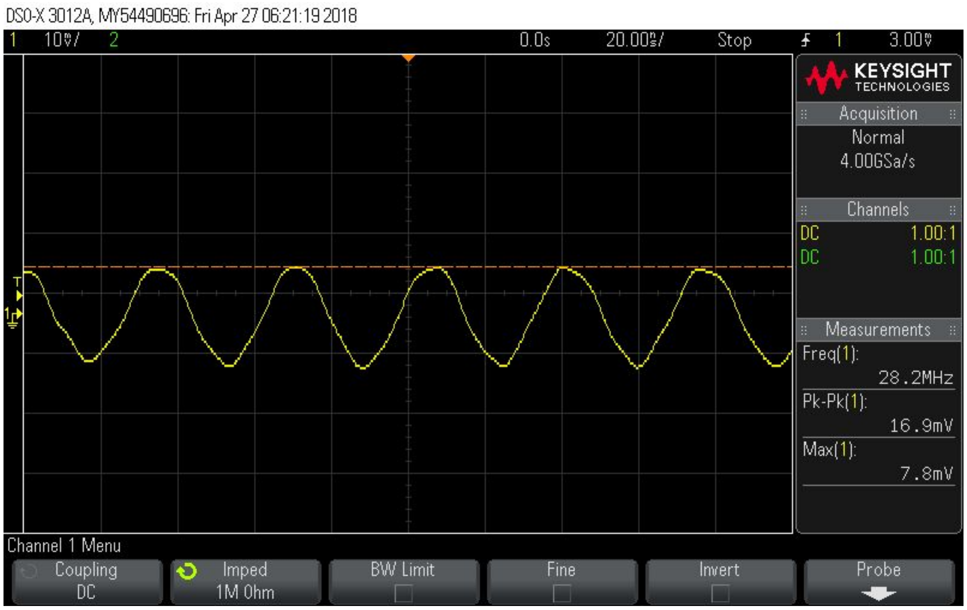

Figure 18: Output of RF bandpass filter at desired 28.2 MHz

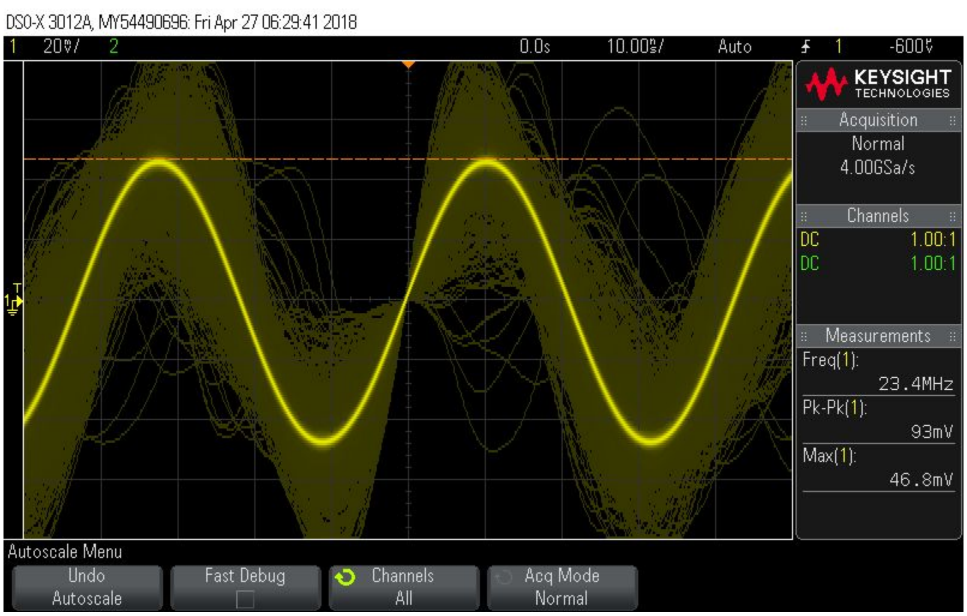

Figure 19: Output of RF bandpass filter at resonant frequency.

3. VCO

We measured the VCO with the potentiometer at its minimum and maximum. We found that the VCO produced an approximately 20 MHz wave when the potentiometer was tuned to its maximum 20kΩ and an approximately 29.4 MHZ wave when tuned to its minimum 1kΩ resistance.

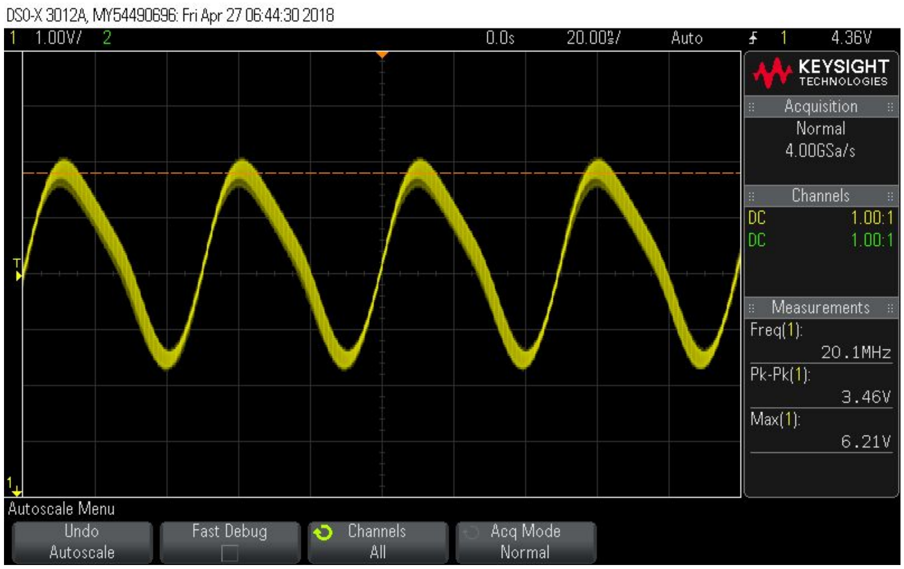

Figure 20: VCO output with potentiometer at its maximum.

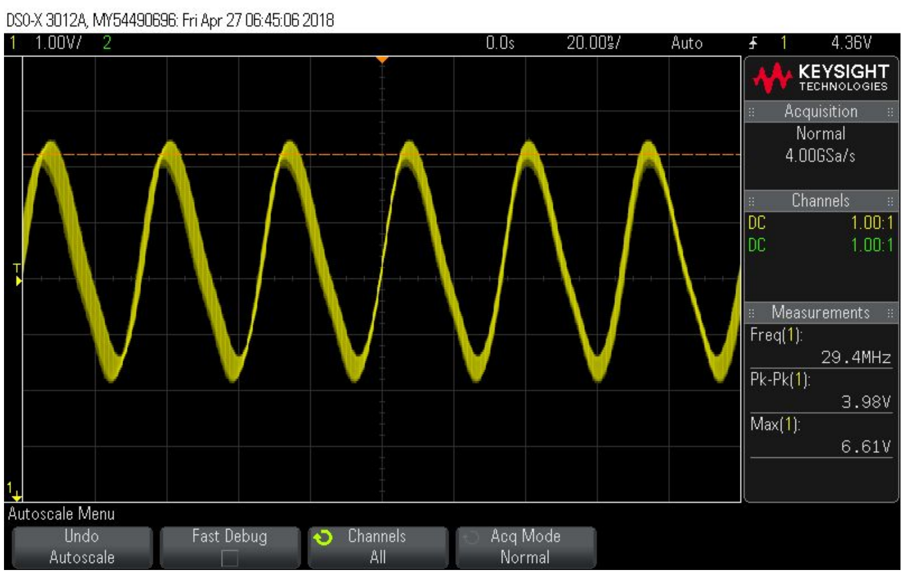

Figure 21: VCO output with potentiometer at its minimum.

We were able to tune the VCO to output a wave within the desired range. The output waveform is shown in Figure 22.

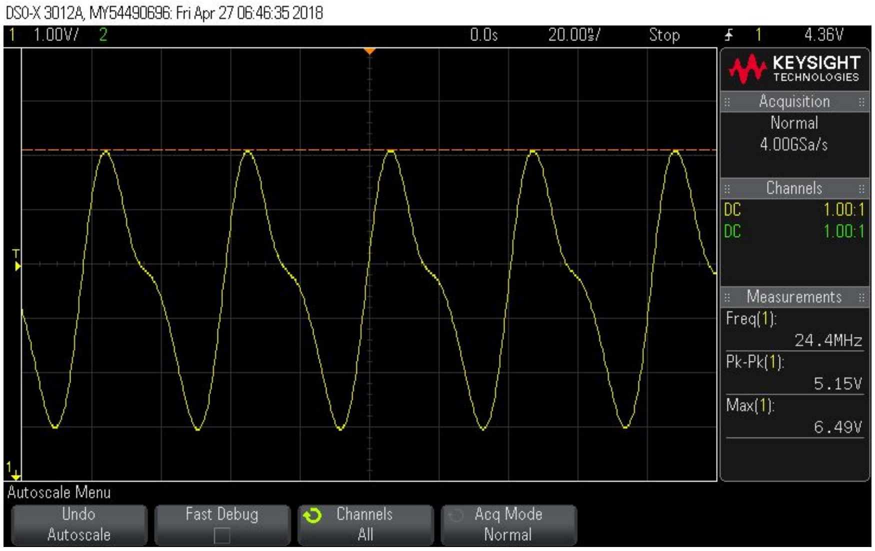

Figure 22: VCO output tuned to 24.4 MHz.

4. BFO

Characterizing the crystals was definitely a challenge. To determine the frequency of resonance, the following test was carried out[8]. Since a crystal has an LCR equivalent circuit, the setup in Figure 23 was used with a 1Vpp input from the function generator with the frequency close to the presumed crystal resonance and the output waveform measured across the crystal on a scope. At the frequency of resonance, 1/jwC=jwL and the reactance cancels out. The voltage waveform seen at the output would be the lowest at resonance. After sweeping through frequencies on the function generator, the lowest voltage on the scope was seen at 3.5792 MHz of the crystal(datasheet value 3.579 MHz) with shunt C=30pF. This was close to the IF filter frequency (described next). A 16pF series C was used to increase this resonance to f_r=3.579485 MHz. The resonant output of the BFO is shown in Figure 24. At an input of 1Vpp and frequency f_r, the voltage output was minimal at 580 mVpp.

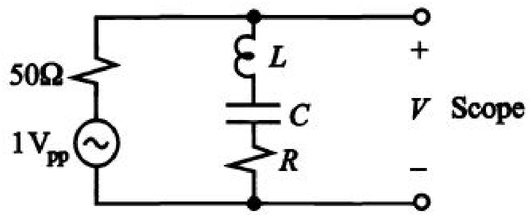

Figure 23 : Setup for characterizing crystal[8]

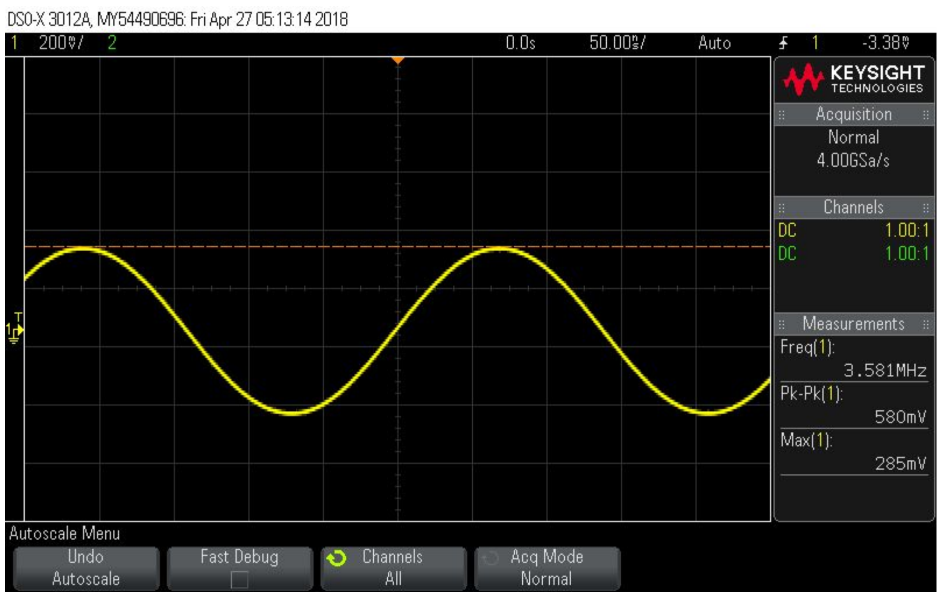

Figure 24: BFO output at resonant frequency (note: the significant digit setting on scope setting is probably the reason why it shows the resonance at 3.581 MHz. While recording the output however, the function generator was set to 3.579485 MHz)

5. IF Filter

The IF filter design using 4 crystals in a Cohn-crystal configuration. For this circuit to work, 4 crystals with close enough frequencies needed to be chosen. Using the setup in Figure 23, we chose crystals with resonant frequencies within about 20 Hz. The minimum voltage for a single crystal was found to be around 9.2-9.4V(for an input of 10Vpp form the function generator) and is shown in Figure 25. Since the reactance cancels at resonance, the voltage across the scope is through a voltage divider. Using this, we can find the internal R of the crystal. Vscope=10 R/(R+50) and so equivalent Resistance R= 783 ohms.

The crystal unloaded Q factor Qu can be found by finding the 3dB bandwidth of the crystal. This is achieved when the reactance value also equals R, with total impedance =R+jR. Vscope=10(R+jR)/(R+jR+50) ~ 9.7V. The frequency at the generator was controlled until this voltage value was seen at the scope around the center frequency. From this method, f_upper=3.579309 MHz and f_lower=3.579172 Mhz. Qu=fr/(f_upper-f_lower)=28820.

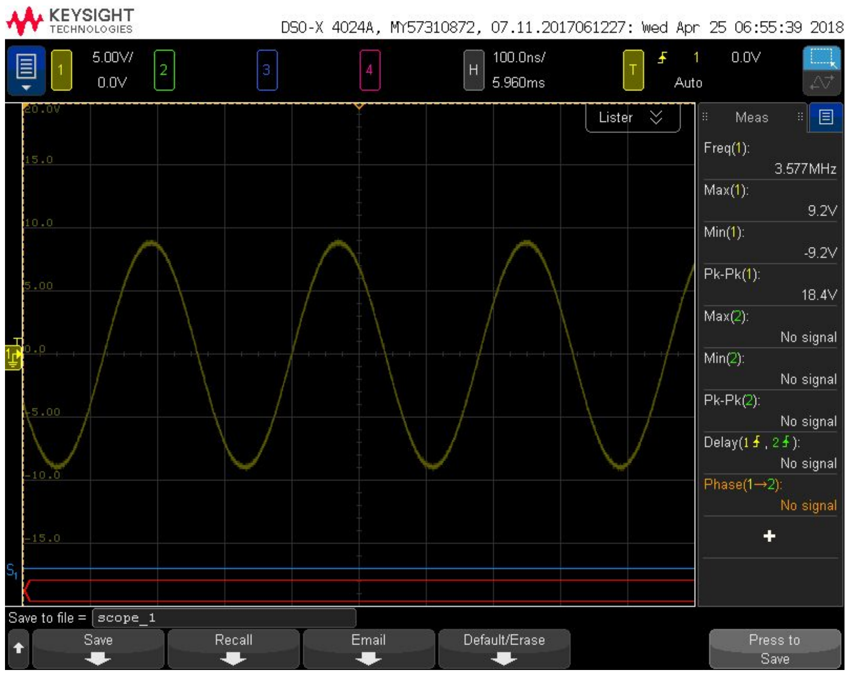

Figure 25: Measured voltage for a single crystal at resonance for 10Vpp input

To calculate the motional inductance and capacitance, we first set the end resistance of the topology to be 50 ohms. This would eliminate the need for additional matching. The coupling coefficient for N=4 crystal topology is given as kjk=(1/2)exp(Ln(2)/N) = 0.595 [9]. Normalized Q factor q=Qu B/F =9.66, where B is the bandwidth(1200 Hz, 600 Hz on both ends) and F is the center frequency =3.579247 MHz. R_end = 50 =2 pi B Lm/q . This sets the motional inductance Lm=0.064H. Since at resonance, Lm=Cm, F=1/(2 pi sqrt(Lm*Cm)). Cm=30.8 fF. External coupling caps C can the be calculated as C= Cm F/(kjk B) = 154 pF.

With a function generator input of 1Vpp sinusoid, 3.5792-4 MHz, and high Z load, there is attenuation seen around center frequency =3.579280 MHz. Figure 26 shows the 1 Mohm oscilloscope output of 900mV. The output waveform is 90% of the input voltage, which is well matched for a center frequency. Attenuation is seen to be 50 mV at frequencies 3.579190 MHz and 3.579400 MHz, which shows an operation bandwidth of around 200 Hz. These are shown in Figures 27 and 28 respectively.

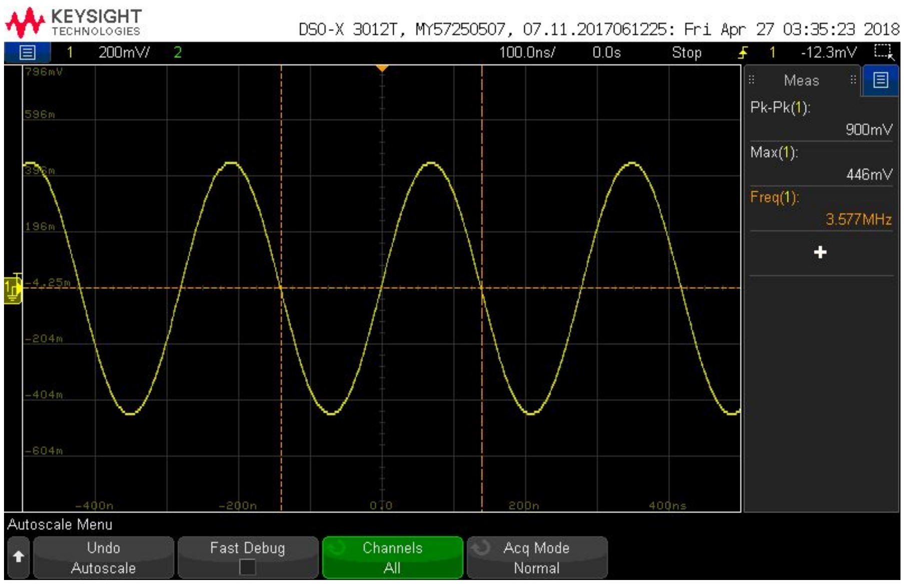

Figure 26: IF Filter output for 3.579280 MHz

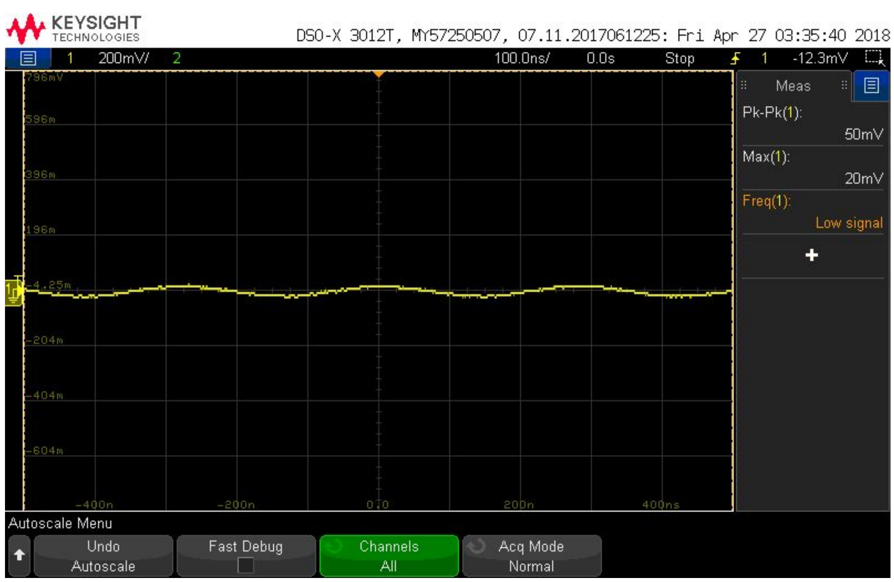

Figure 27: IF Filter output for 3.579190 MHz, Output attenuated to 50 mV

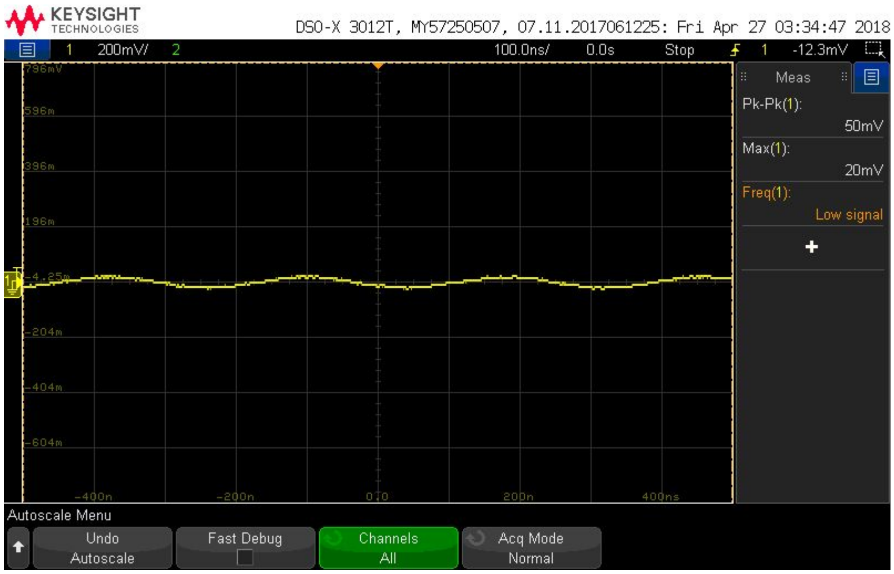

Figure 28: Oscilloscope output for 3.579400 MHz, Output attenuated to 50 mV

Lessons Learned :

Over the course of this project, we learned a lot about both PCB design and circuit design. When it comes to PCB design, we learned that it is extremely important to double check every footprint against the IC datasheet. We had to make our own footprints for almost all of our ICs, but two footprints were on snapEDA, so we downloaded and used those footprints rather than make new ones. For the voltage regulator chip, this worked great and saved us some time, but for the LNA chip, the footprint ended up being mirrored of what it should have been. This meant we had to messily solder the LNA chip upside-down on the board. This luckily wasn't too hard of a chip to do that for, but it could have been avoided if we had taken a closer look at the footprint we downloaded.

Because our project was a radio, we also learned about the extra considerations needed when dealing with RF signals on PCBs. We had to make sure to impedance match everything, which we did using LC matching, but could have been done by changing the trace width. We had to make sure to design good bias lines. The biggest consideration was dealing with noise, which our board did not perform as well as expected with. When designing, we had to be very careful about return paths, which is why we tried to minimize routing on the bottom layer since this layer did not have a ground plane return path under the entire layer. However, the decision to split that third layer into half ground plane and half power plane may have significantly increased noise in parts of the circuit over the power plane. In the future, it might be best to make this entirely a ground plane. We also tried to minimize noise by keeping signal lines somewhat farther apart and as short as possible; no two signal lines ran closely parallel to each other and we laid out the components on the board in a way that kept signal trace lengths short.

We particularly learned a lot about component choice for a PCB. In the future, we would try to minimize the use of uncertain components, such as wound inductors, since it is much more difficult to change impedances or replace components on a PCB than when breadboarding a circuit. We learned that it is important to keep in mind the availability of components when choosing them for a PCB, since widely-available components are cheaper and often have more resources and documentation for ease of use. In our case, some of our components could only be purchased by Mini-Circuits (e.g. the VCO), which meant that these parts were the most expensive parts we bought. Unfortunately, RF ICs tend to be much more limited in manufacturing, so this cost may not have been avoidable.

Availability is also important in common components like resistors, capacitors, and inductors. Designing around commonly used values is preferred since then the components are readily available and you don't get stuck needing to wind inductors to get weird values or having to buy a pricey capacitor because it's the only one you could find that matches your value. This is precisely why towards the end, our RF filter did not resonate at the desired frequency. Since we couldn't find a 1.16nF cap, we bought 1000pF and 160 pF and the goal was to place them in parallel, which we later forgot to do. This caused the frequency shift. Also, in the initial RF filter design, the inductor was 20 nH, which we changed to 28nH as that was available online. This is turn changed the other values which we accounted for in the final design.

Another component choice that we learned about was test points. We used surface-mount metal loops that you could hook onto, but these ended up costing us because they kept breaking off, sometimes taking the PCB pad underneath with them. In the future, we would use large through-hole style test points, possibly ones that were sized to fit a pin (burgstick), since these are much sturdier.

Finally, we also learned about good testing and assembly practices. We learned it is important to test sensitive components, such as crystals, against external loading, and that measuring the actual values of a purchased component is extremely important. Especially when dealing with RF, the tolerances in off-the-shelf components can result in an impedance or reactance that is too far from the desired value, to the point where it can cause significant shifts in the operating frequency range. Added parasitics of the board and imprecise values due to manufacturing tolerances can also contribute to shift from desired performance. Another example is our crystals. Our IF filter would not have worked if we had just used any four crystals (bought with same resonant frequency) because the center frequencies for the ten crystals we received differed by up to a tenth of a kilohertz. We had to test and select four crystals with close enough center frequencies.

Another good testing practice is to breadboard circuits first, so that when you move to the PCB, you know that everything works. For RF, this is much more difficult, but the circuits we were able to breadboard and test, like the IF filter and BFO, worked great and had no unexpected problems once they were soldered into the board. In an ideal situation, we would have physically tested each section, but due to time constraints and component packaging, we were only able to breadboard and test a few circuits ahead of time. This would also enable us to make a final schematic with minimal changes. For example, since we were able to test our components only after sending the board to fab, we had to modify the circuit and cut traces to incorporate the working circuit components. Luckily the changes were not major and were easily carried out.

References:

[1] Datasheet, MIC5205 “150mA Low-Noise LDO Regulator,” Micrel, February 2006

[2] Ferrite core specifications, Amidon product website

[3] Datasheet, HSWA2-63DR+ “SP2T RF Switch,” Mini-Circuits, Rev. OR

[4] Datasheet, MAX2611 “DC-to-Microwave, Low-Noise Amplifier,” MAXIM, 19-1094; Rev 2; 4/05

[5] Datasheet, SA602A “Double-balanced mixer and oscillator,” NXP, Rev. 3 — 27 May 2014

[6] Datasheet, JTOS-50P+ “Voltage Controlled Oscillator 5V Tuning for PLL IC’s 24 to 29 MHz,” Mini-Circuits, Rev. E

[7] Datasheet, IS31AP2145A, “2.9W@5.0V Mono Clip-less & Filter-less Class-d Audio Power Amplifier”, Integrated Silicon Solution, Inc,1 Rev.A, 11/20/2011 2

[8] Rutledge, David B. The Electronics of Radio. Cambridge Univ. Press, 2008.

[9] Hayward, Wes, et al. Experimental Methods in RF Design. American Radio Relay League, 2012.

Appendix:

Initial circuit schematics used for fabrication of the board. Later, these were modified as per testing. Some of the subcircuits don't contain exact design values, only the configuration as we found the values later through testing.

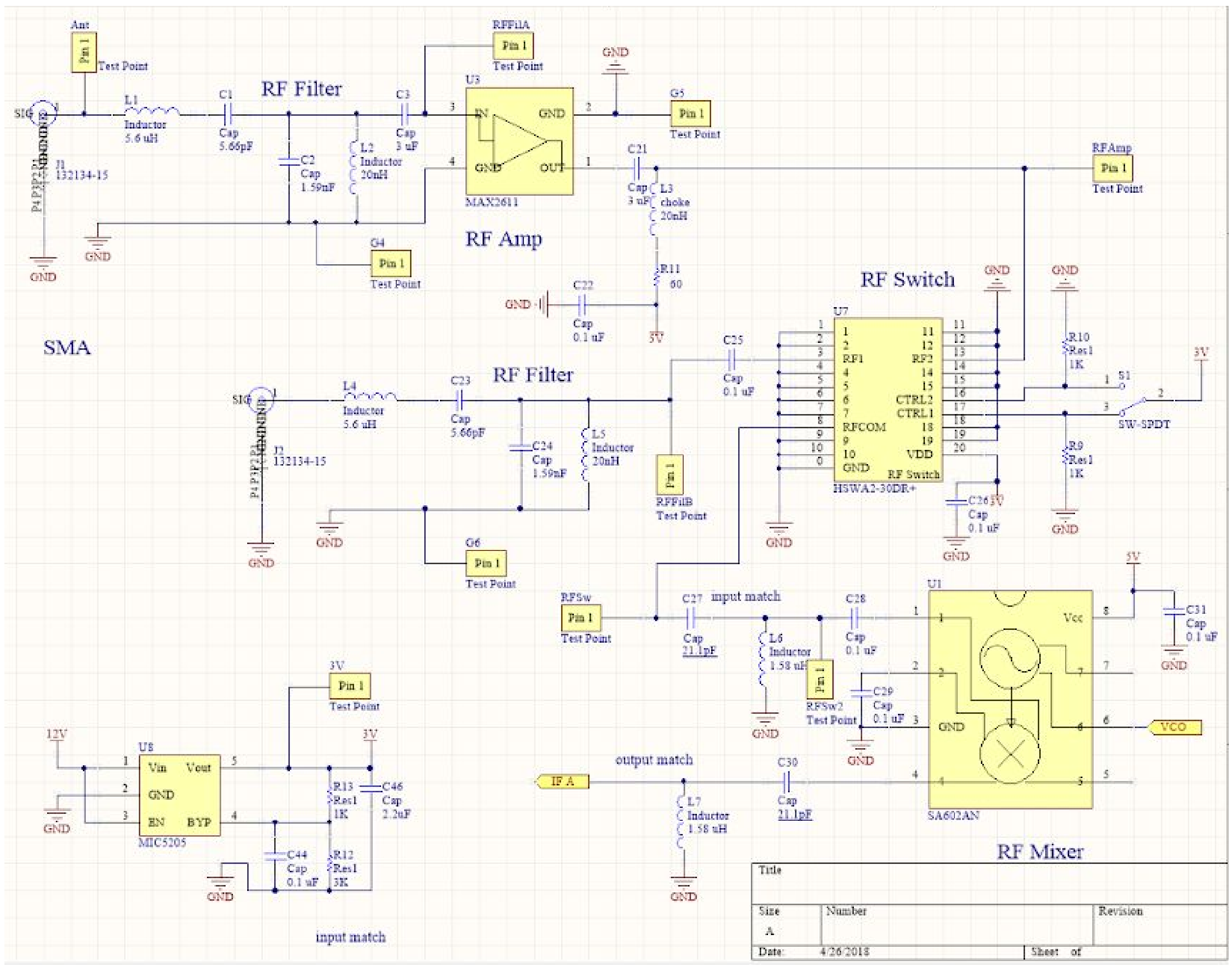

Figure 29 : Initial schematic 1 containing SMA input points, RF filters, RF switch, First mixer stage and 3 V supply voltage schematic

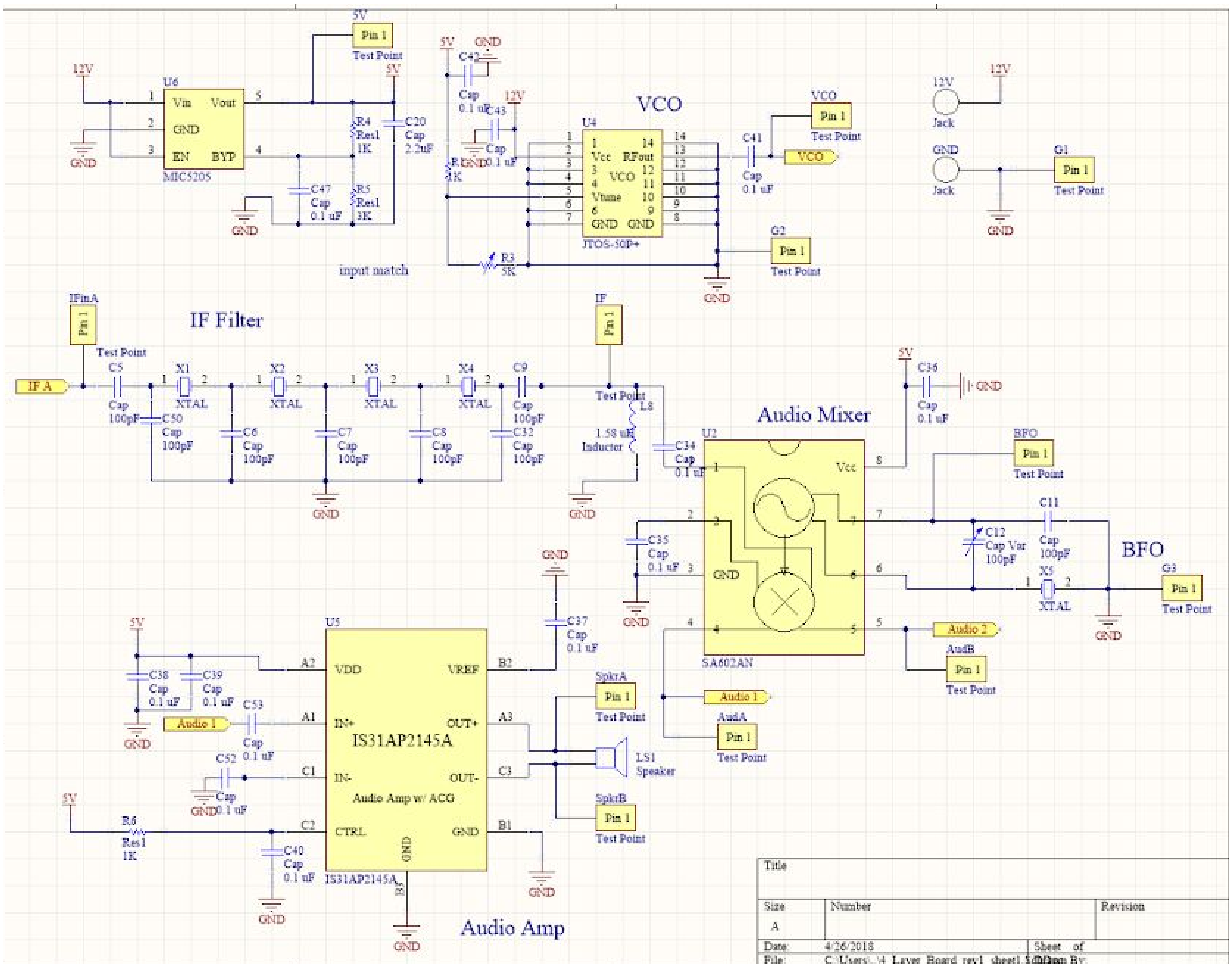

Figure 30 : Initial schematic 2 containing 5V voltage regulator, VCO, IF filter, second mixer stage, audio amplifier and speaker