Project 3: Single-balanced Active Mixer

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Fall 2022

ECE-393-A Junior Lab

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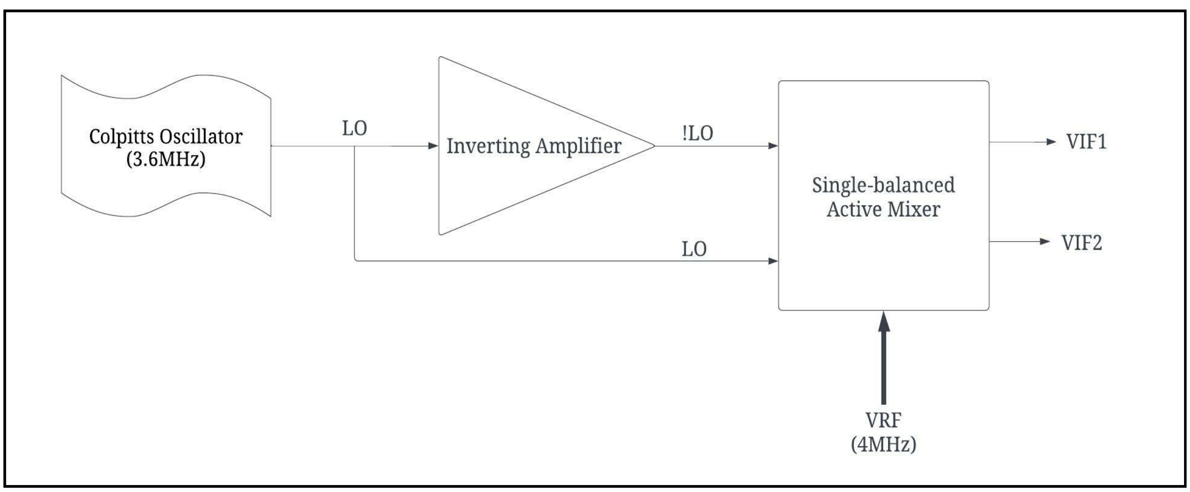
Project Description

The goal of this project was to build an active mixer by using NMOS technology. The design would take three inputs: $LO,\ \overline{LO}, V_{RF}$ which represent the local oscillator, inverted local oscillator, and the radio frequency signal input, respectively. The output of this mixer is the intermediate frequency, V_{IF} . In this project, we will use the previously designed Colpitts oscillator to drive the local oscillator in this mixer, and run its mirror through an OPAMP to get the inverted output for the inverted local oscillator input. We use a function generator to drive V_{RF}, and the output of the mixer, V_{IF}, should show several peaks representing the LO, V_{RF}, and $LO - V_{RF}$ (fundamental tone). We should observe the peaks shift left or right as the radio frequency is lowered or increased in real time. Finally, we should implement a low pass filter to remove unwanted tones above the fundamental tone.

Block Diagram

Below is the basic block diagram describing how the mixer operates. It receives the LO signal from the previous project which involved a Colpitts Oscillator. We will tweak it so that it operates at around 3.6MHz. The Colpitts Oscillator feeds this signal to the input of the Active Mixer and in parallel through an inverting amplifier that generates the $\overline{LO}$ signal which is also fed as an input to the mixer. Another input is the V_{RF} signal which will be generated by a function generator at 4MHz. The output of the active mixer will be the two differential voltage points that represent the intermediate frequency V_{IF} .



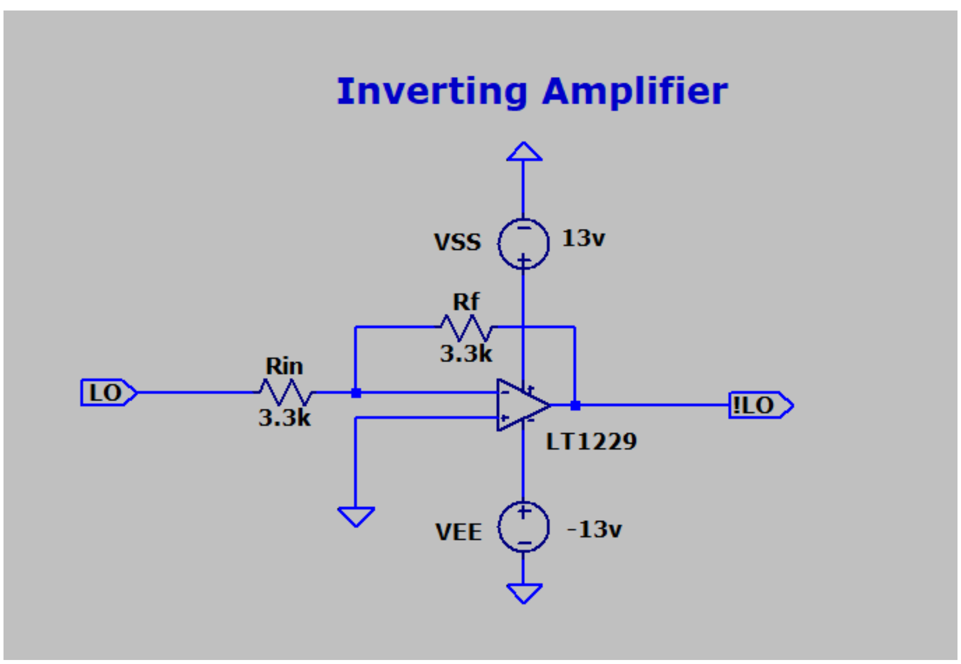
Local Oscillator

As mentioned before, we reused the Colpitts Oscillator from the previous project to generate the Local Oscillator signal for the mixer. However, we had to swap out one of the capacitors in the LC tank to generate a 3.6MHz signal instead of the 4MHz. To do this we found the right C1 and C2 values by applying the formula for the resonant frequency of a Colpitts Oscillator:

$$fr = \frac{1}{2\pi\sqrt{L \cdot C_T}} \quad ; \quad C_T = \frac{C_1 C_2}{C_1 + C_2}$$

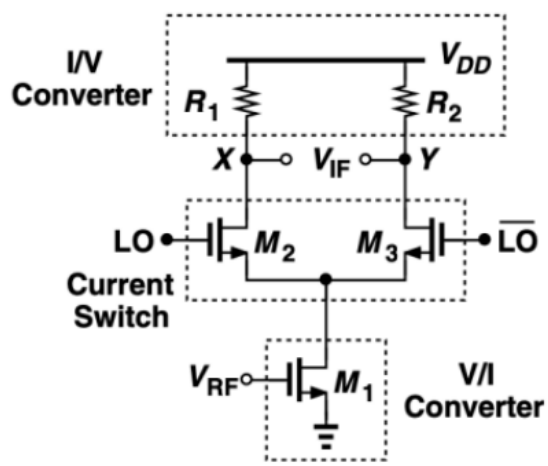
Since we want the oscillator to operate at 3.6MHz, $f_r = 3.6MHz$. Furthermore, we chose an inductor with a value of 10µH. Previously, we had chosen C1 and C2 values of 220pF and 560pF, however we want to change the oscillator frequency of 3.6MHz. We chose to swap the 560pF with a 2000pF capacitor, which roughly approximates the desired frequency.

To generate the inverted version of the signal, $\overline{LO}$, w had to feed the Colpitts Oscillator output to an inverting amplifier which was the LT1229. To keep the gain 1, we used equal values for Rf and Rin, 3.3kΩ; However in practice we replaced the Rf with a 5kΩ potentiometer to fine tune the gain and ensure the phase is 180 degrees between the LO & $\overline{LO}$. For this inverting amplifier to work, it needs a negative voltage, which we chose to be around -13V. Below is the schematic of the inverting amplifier.



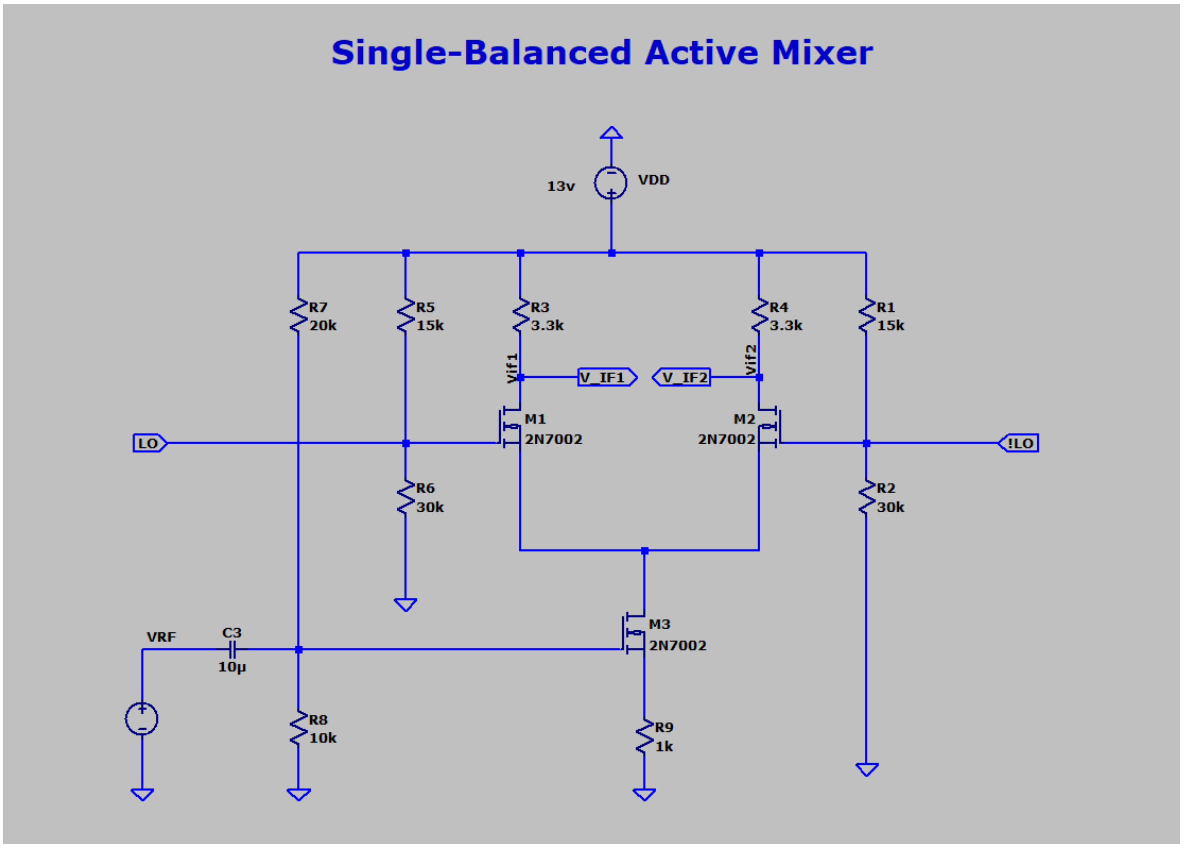
Active Mixer

The type of mixer that we are building in this project is a single balanced active mixer which uses three MOSFETS to generate a differential signal that represents the output signal. One of the main advantages of a balanced active mixer is that it can provide good common-mode rejection, which means it can reject signals that are common to both input channels. This can be useful in situations where the input signals may be subject to noise or other interference. In addition, a balanced active mixer can provide good isolation between the input and output signals, which can be useful in preventing interference between different signals. On the other hand, a disadvantage of a balanced active mixer is that it can suffer from a phenomenon known as IF-LO feed-through, which occurs when the local oscillator (LO) signal leaks into the intermediate frequency (IF) signal if the frequency of the IF signal is not significantly lower than the frequency of the LO signal.

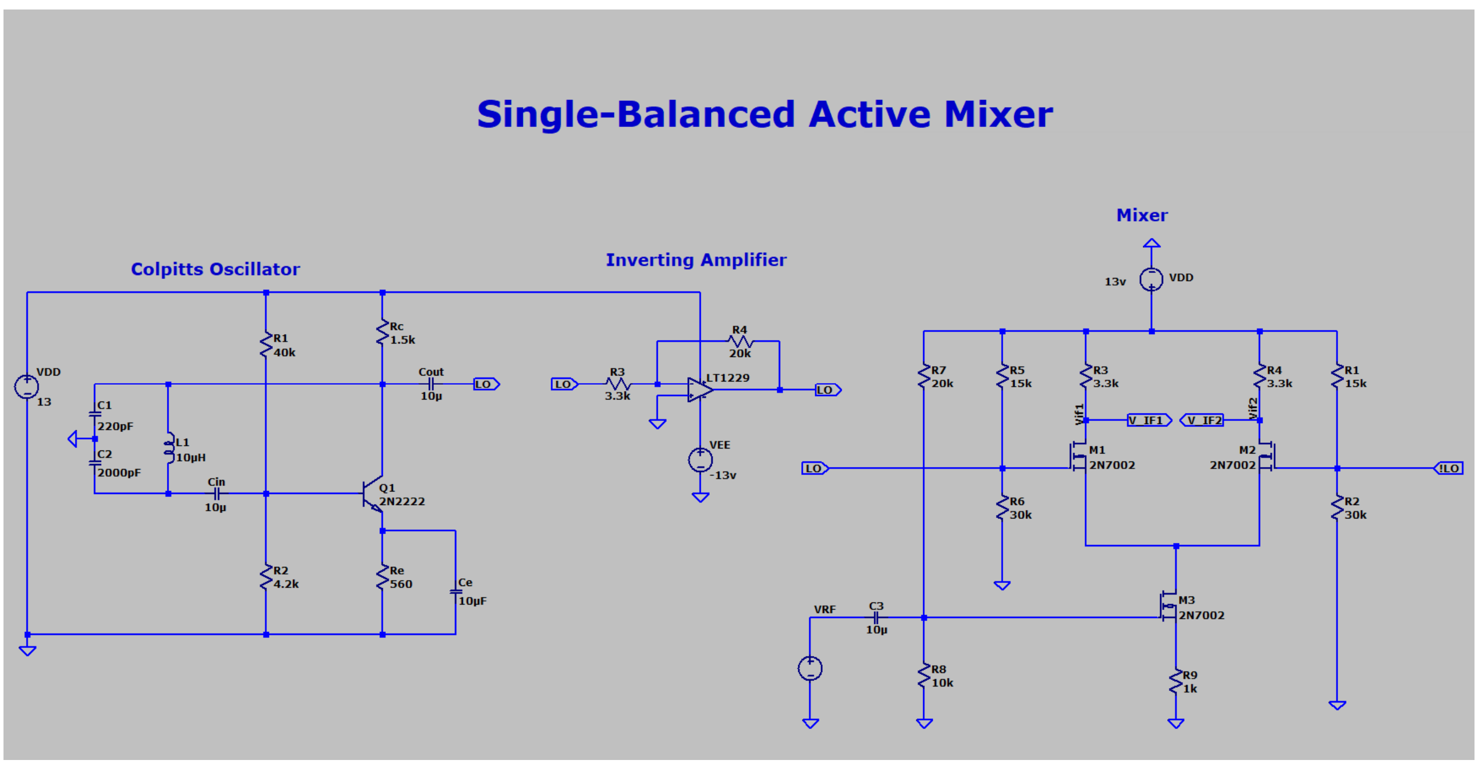


When biasing the MOSFETS, an important factor to consider when biasing MOSFETs is the gate-source voltage (VGS), which determines the amount of current that flows through the MOSFET. The VGS should be set to a value that allows the MOSFET to operate in its active region, which is typically around 2-4V for most MOSFETs. Another factor to consider is the drain-source voltage (VDS), which determines the voltage drop across the MOSFET when it is in the active state. VDS should be set to a value that allows the MOSFET to operate in its linear region, which is typically around 0.5-1. In biasing the gates of our upper two MOSFTS (M2 and M3), we used 15k and 30k resistors which resulted in a nominal gate voltage of 8.6v if VDD is 13v. Assuming a max drain to source current of 1ma, we used 3.3k resistors on the drain then, so VDS>VGS. For the bottom MOSFET (M1) we biased the gate with 20k and 10k resistors, giving a gate voltage of 4.3V. We used a 1k degeneration resistor so that the MOSFET wouldn't run hot since without it, the source current would be grounded, almost like a short that could create thermal heat and noise. Assuming 2ma flows through M1, VDS>VGS.

Below is the schematic of the Active Mixer.



Final Schematic



LTSPICE Simulation Results

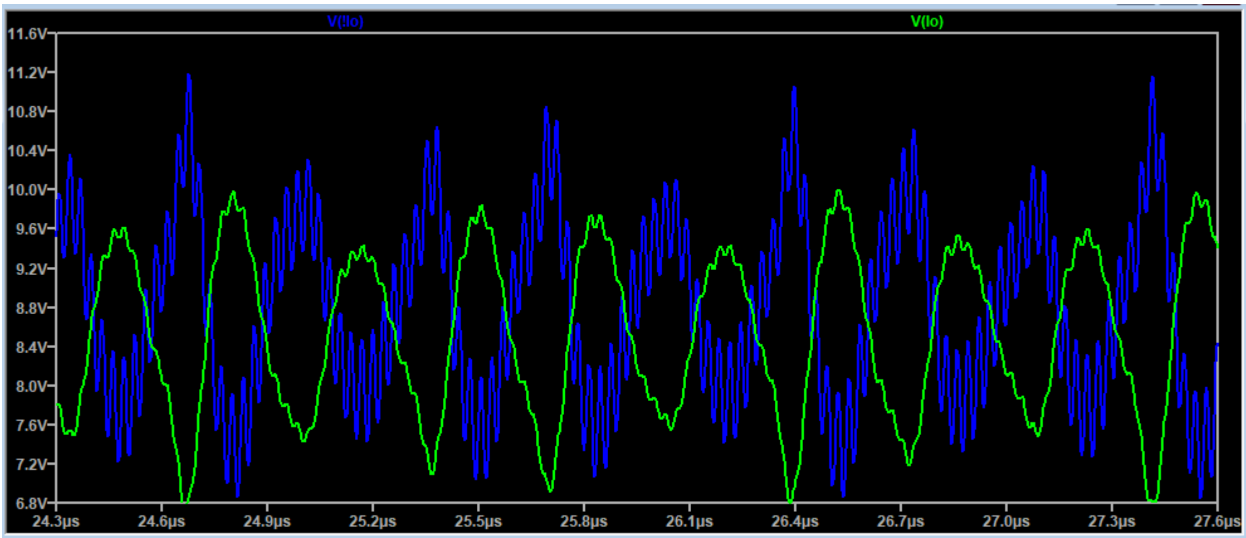


Figure 1: Output waveform of LO and LO! The output of inverting amplifier (blue) seems to show a lot of high frequency distortion of the input LO (green).

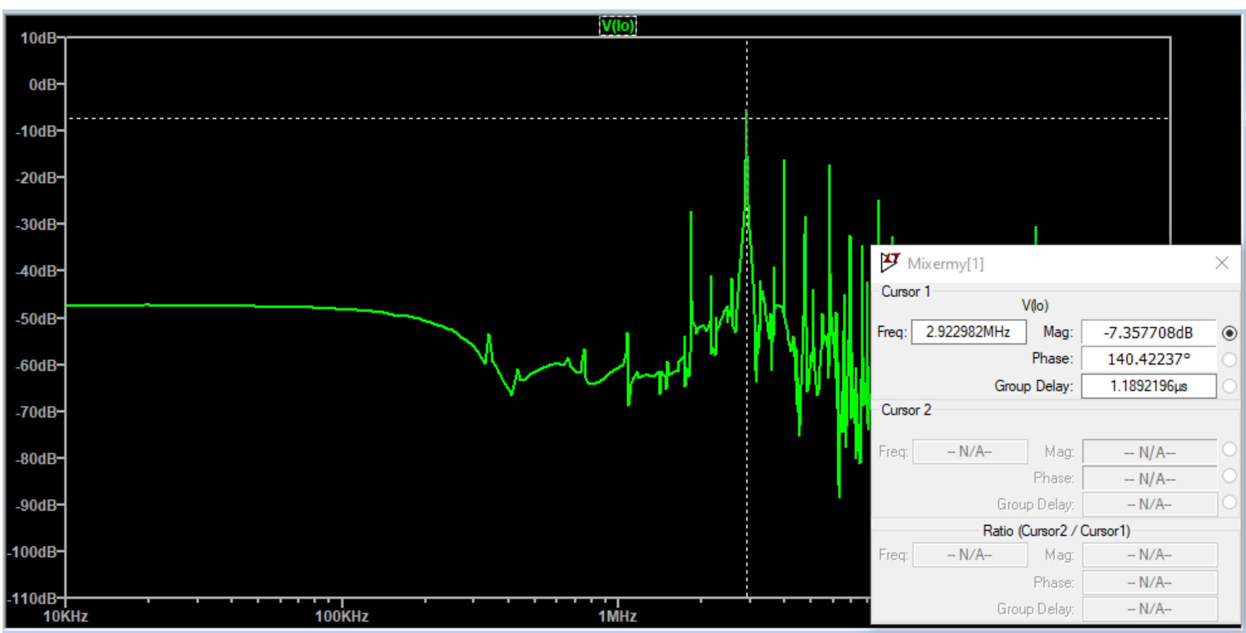


Figure 2: The FFT of the Local Oscillator seems to indicate that it is operating at 2.9MHz instead of the 3.6MHz we had initially calculated. This is quite odd considering the circuit operates exactly as expected when we later test in the lab (we archive 3.6MHz)

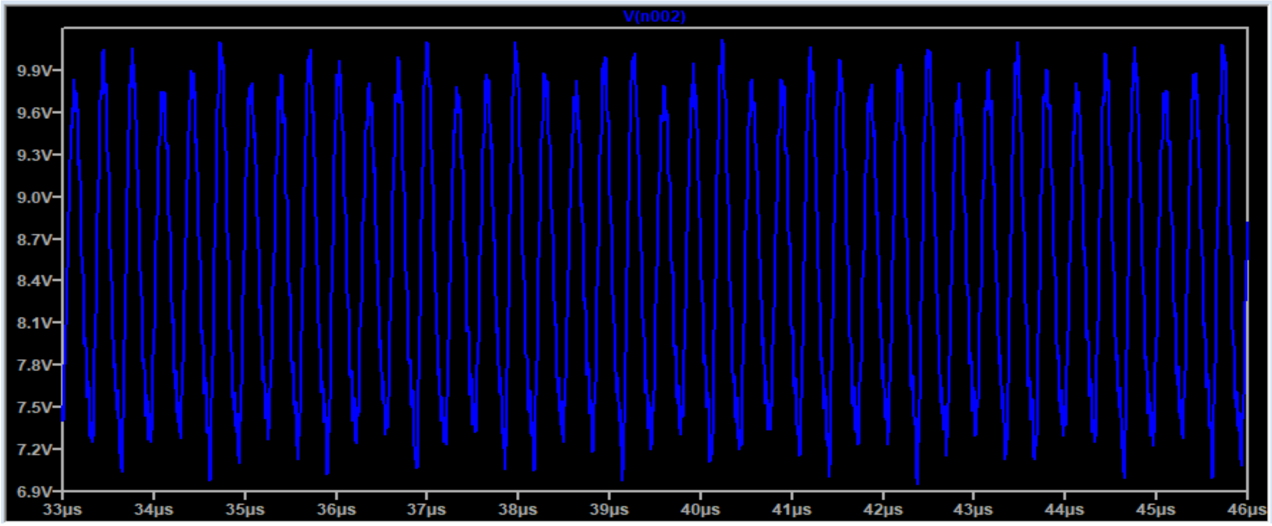


Figure 3: Mixer Output Waveform of Intermediate Frequency

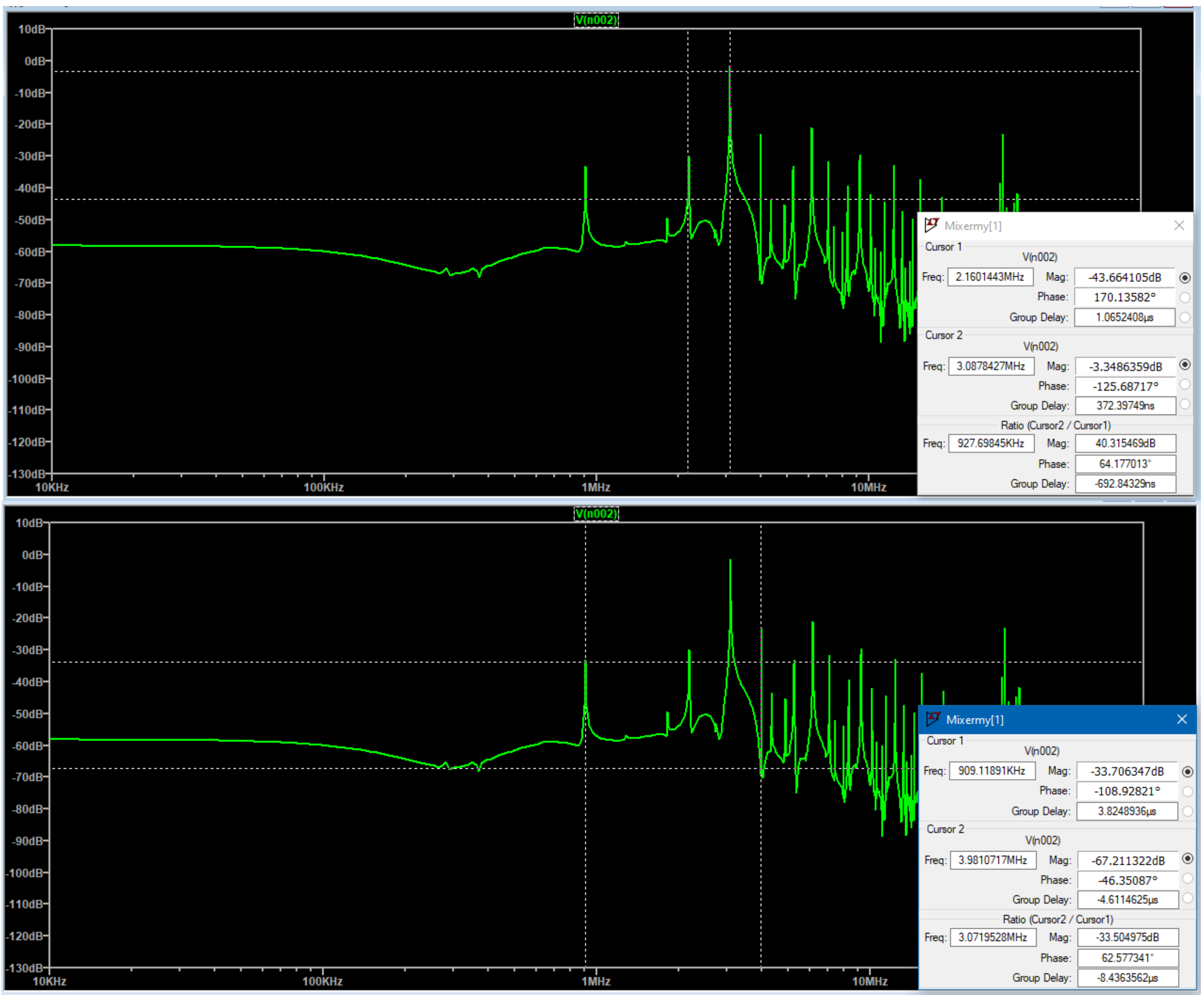


Figure 4: The FFT of the mixer output is consistent with what we expected the output to look like. We see the local oscillator is operating at around 3.1MHz and we can see a low frequency tone at 900KHz. This makes sense since 4MHz-3.1MHz should be 0.9MHz.

Lab Results

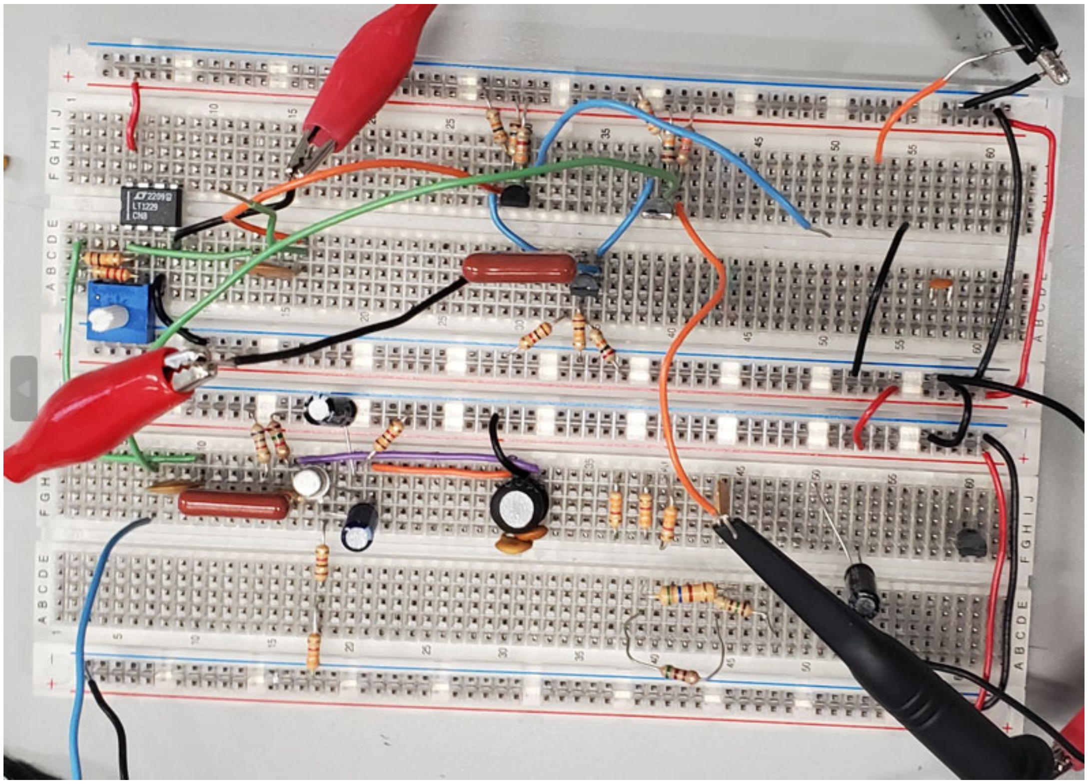


Figure 5: Completed Active Mixer

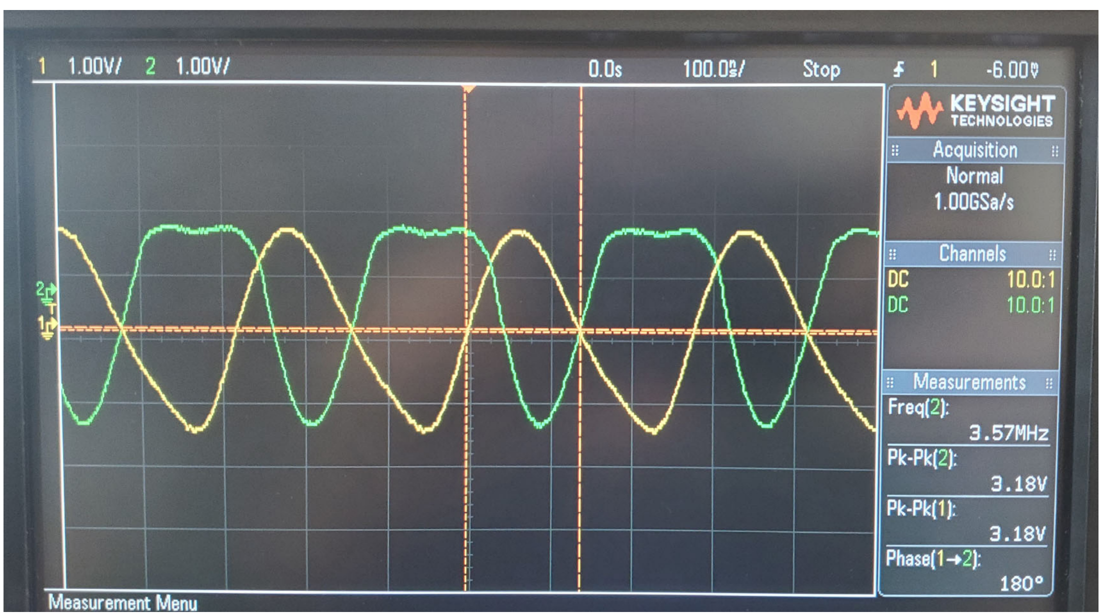


Figure 6: Local Oscillator LO and LO! Shows similar peak to peak voltages, are 180 degrees out of phase and are operating at 3.57MHz

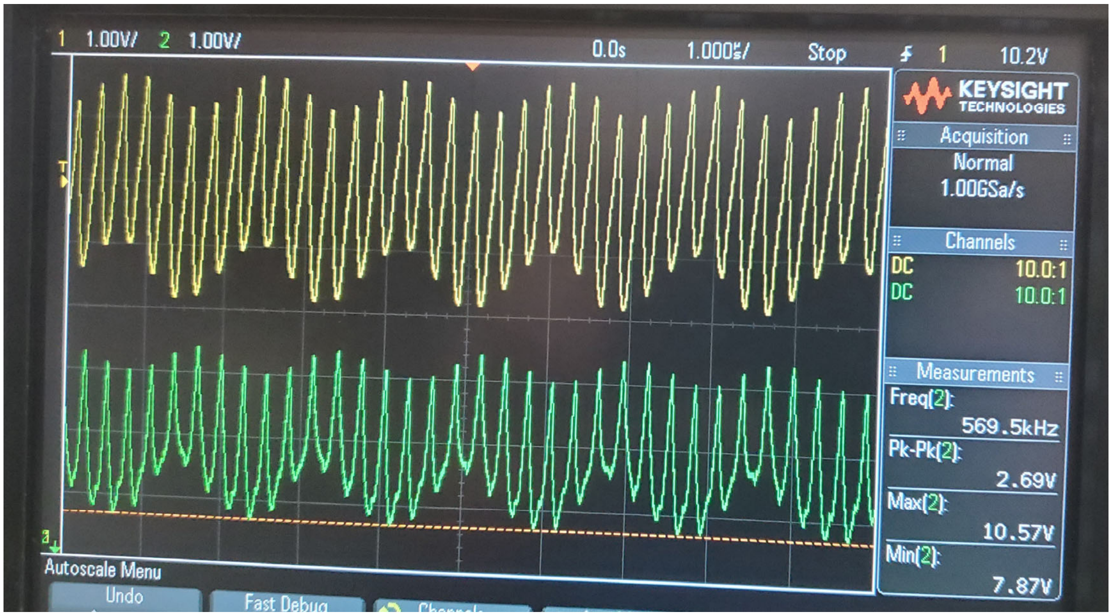


Figure 7: Output Waveform of Intermediate Frequency Signal

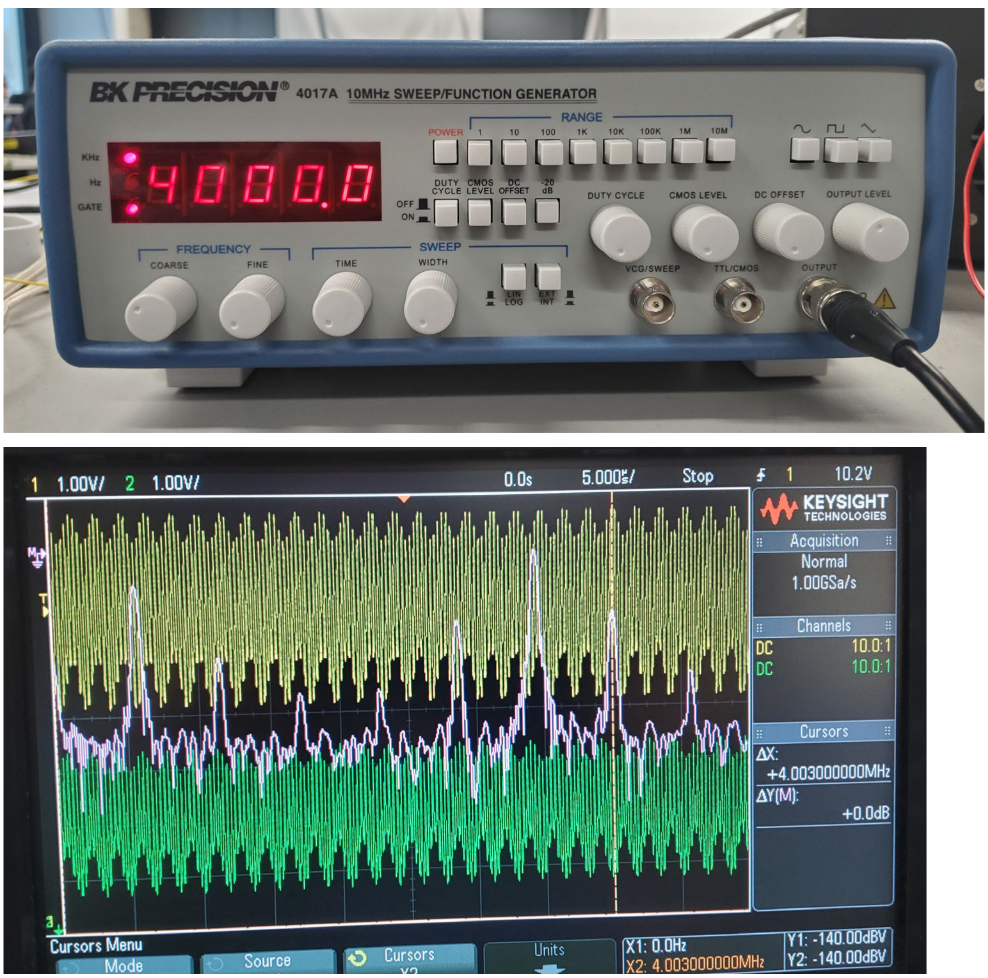
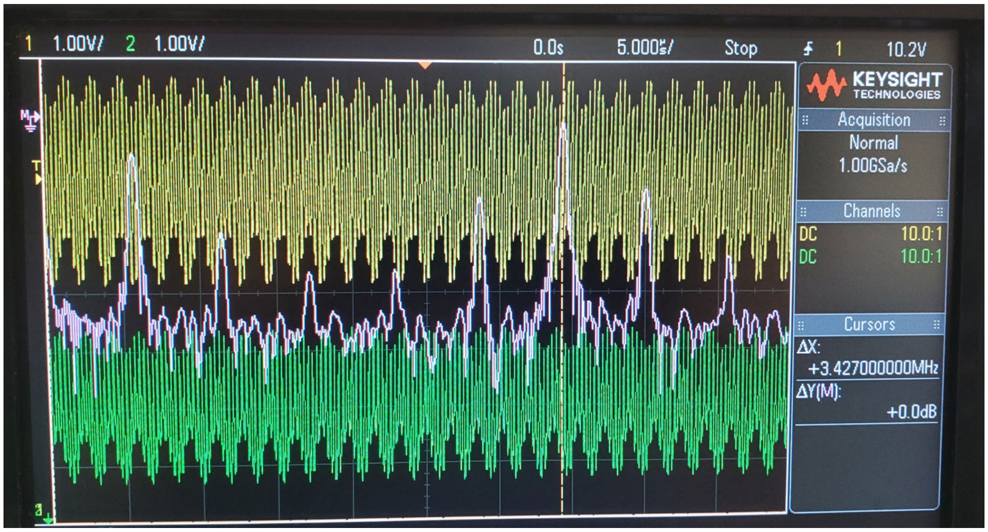


Figure 8: We can see the 4MHz signal from the function generator is present in the FFT



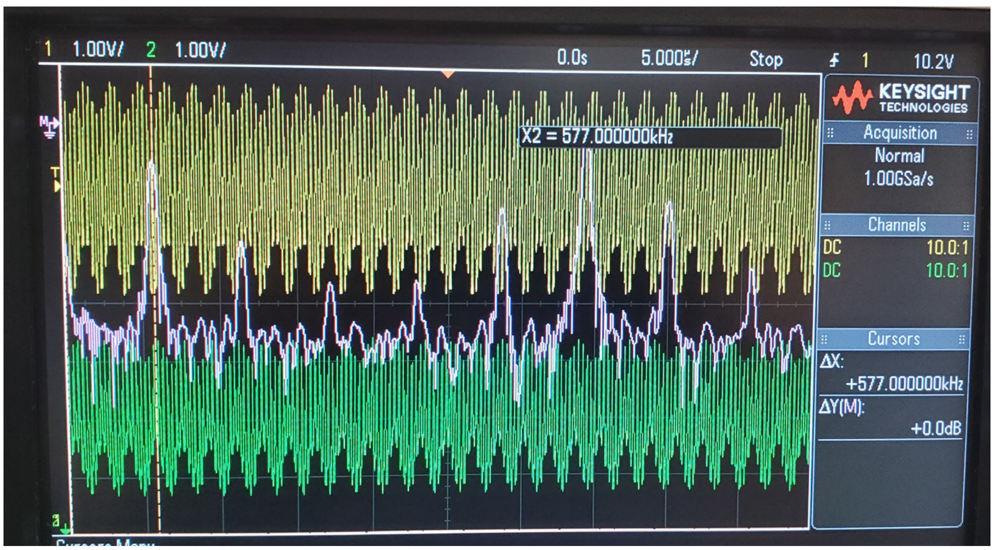
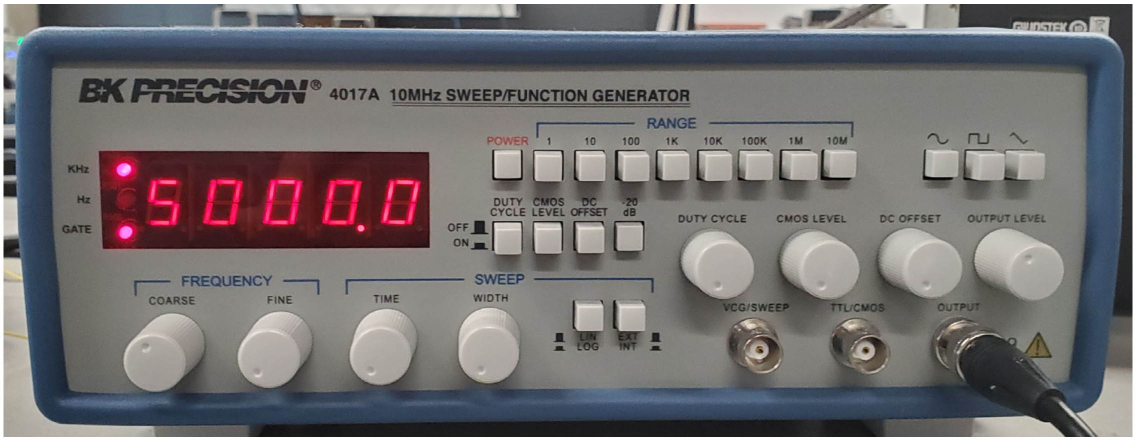


Figure 9: We can see the Local Oscillator is operating at 3.427MHz and the low frequency tone is being shown at 577KHz. This makes sense because VRF-LO = 577KHz



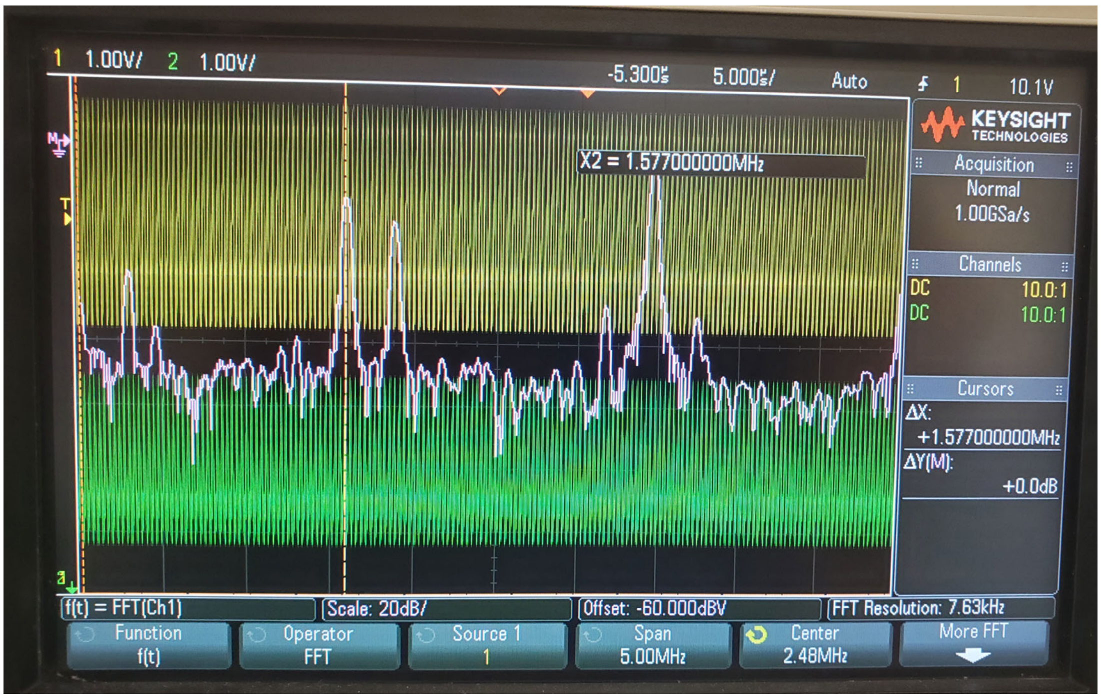


Figure 10: Changing VRF to 5MHz results in the tone frequency to shift to 1.577MHz. This makes sense because VRF-LO = ~ 1.577MHz

Figure 11: We added a lowpass filter with corner frequency of 1MHz and we can see a somewhat significant drop i strength of the high frequency signals, losing about 10db.