ADC AM Radio Lab

Grace Montagnino, Prava Dhulipalla, Allison Basore

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1 Introduction

For this lab, we built an AM Radio using a bandpass filter, an RF amplifier, an envelope detector, and an audio amplifier. Our goal was to learn how these components could be used in practice to build a receiver for a known radio frequency. Approximately 2 miles away from where we tested and built the radio, a WEEI ESPN radio station antenna is located. Our radio was designed to be a receiver for this station.

2 Circuit Design

Figure 1 shows a block diagram of our AM radio circuit. An antenna is used to receive signals, including the one from the pertaining radio tower. A band pass filter attempts to isolate this signal from any noise (or other signals we are not interested in). We then use an RF amplifier (with a gain of 200) to boost the signal. Next an envelope detector is used: a diode helps to discard the negative half of the signal, and a LPF helps to actually get the envelope. Finally, we use an audio amplifier connected to a speaker so that we can hear the transmission from the ESPN station.

Figure 2 shows the detailed circuit diagram. Our bandpass filter was an LRC circuit (calculations below). For the RF amplifier we used two inverting operational amplifiers in a row: the first with a gain of -100 and the second with a gain of -20. This signal is then passed through the diode (to cut out the negative frequencies) and then passed through the low pass filter. This then goes to an audio amplifier with a gain of 20 and connected to the speaker via a capacitor.

When constructing the circuit, we made use of a LM6172 Voltage Feedback Amplifier chip that had two operational amplifiers, as well as a LM386 Power Audio Amplifier, which is an audio amplifier with an in-built gain of 20.

3 Bandpass filter

The purpose of the bandpass filter is to isolate the $850kHz$ frequency signal. First, we needed to calculate the necessary values that would target the $850kHz$

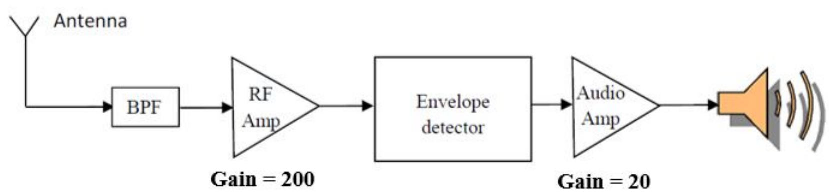

Figure 1: Block Diagram of AM Radio Circuit (Credit to Siddhartan Govindasamy for the original image.)

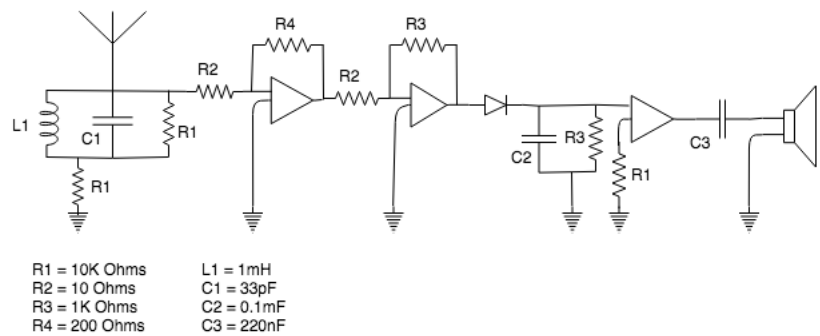

Figure 2: Circuit Diagram of AM Radio Circuit

signal. We specifically used an LRC circuit.

The following process shows how we calculated the capacitor value given an inductance of $1mH$ (corresponding to $0.001H$) and a natural frequency of $850kHz$ (corresponding to $850000Hz$). With the given values, we needed a capacitor value of $3.5 \times 10^{11}F$.

$$f_o = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$850000 = \frac{1}{2\pi\sqrt{0.001C}} \tag{2}$$

$$1700000\pi\sqrt{0.001C} = 1 \tag{3}$$

$$sqrt0.001C = \frac{1}{1700000} \tag{4}$$

$$C = 3.5e - 11 \tag{5}$$

Figure 3 displays our Matlab analysis of the frequency response of the band-pass filter given the above values. Notably, the peak is at about $850kHz$ - which is exactly what we want.

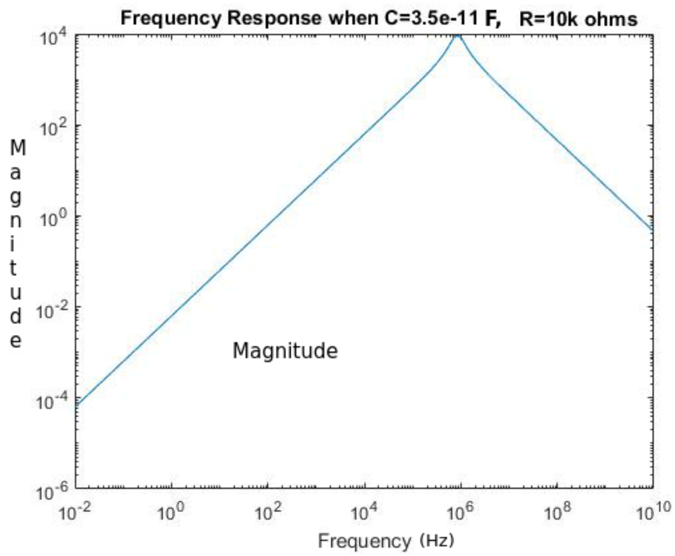

Figure 3: Band Pass Filter Frequency Response

4 RF Amplifier

To boost the signal after we isolated it, we used an RF amplifier. This was done using two inverting operational amplifiers in a row (first with gain -100 and second with gain -20) to produce a total gain of 200.

Prior to constructing, we analyzed our expectations of the behavior of the RF amplifier. Figure 4 shows the expected input to the RF amplifier after the BPF in the frequency domain. Figure 5 shows the expected output of the RF amplifier in the frequency domain.

Lastly, Figure 6 shows the measured signal in the frequency domain after the RF filter. Due to large windows by the testing area, the image is low quality. In it we can see audio signal spikes in the frequency domain. On the left side of the figure we see two relatively large spikes surrounded by slightly higher amplitude signal. We believe this may be the impulses we expected at f_c. However, when taking this data, we found the measurement to be volatile. We also realize that there is a high chance of error with the oscilloscope reading, both human and machine error.

5 Envelope Detector

We had to determine the appropriate RC values to use in order to 'follow' the peaks well enough to have a define envelope, but not 'overshoot' or 'undershoot' it. As a result, we needed to make sure that $\frac{1}{f_c} << RC << \frac{1}{f_m}$. f_c was $850kHz$, while f_m was $6kHz$. Thus we figured an appropriate value for RC would be on

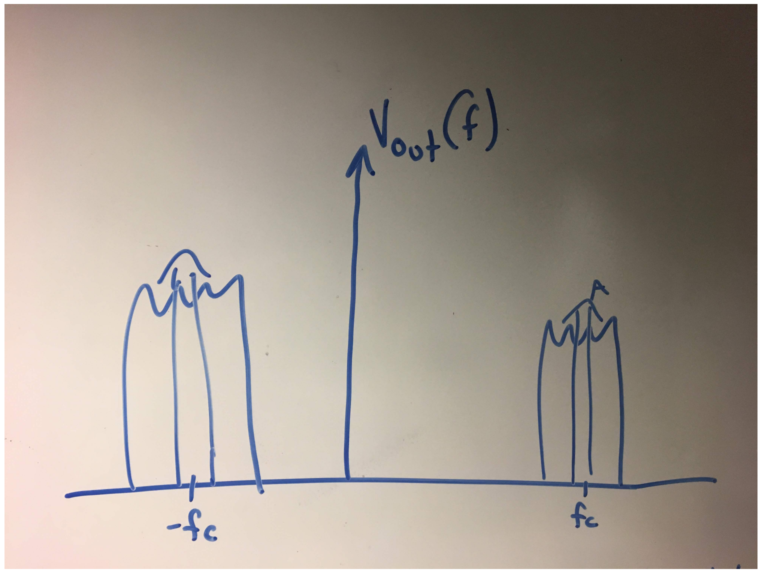

Figure 4: Expected input before the RF Amp

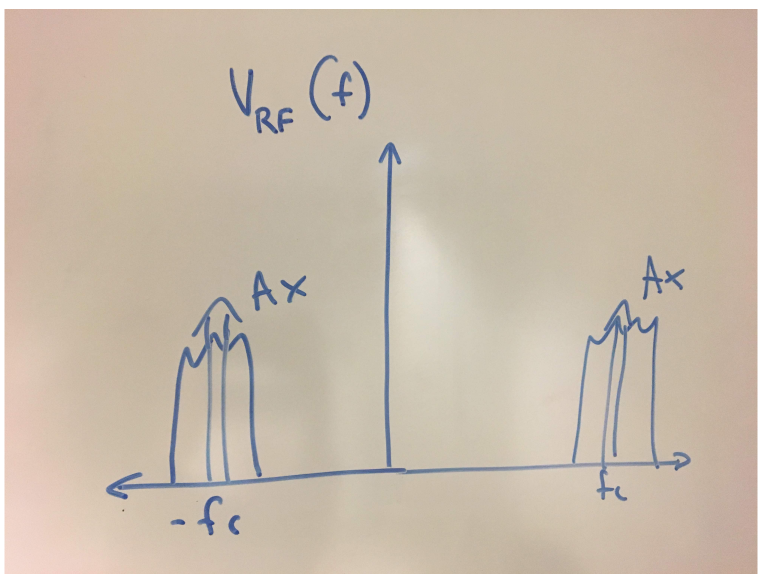

Figure 5: Expected output after the RF Amp

the order of magnitude of 1×10^{-5}. We then chose our R value to be $10kHz$ and our C value to be $1 \times 10^{-7}F$ for our low pass filter.

Before building the radio, we conducted some analysis based on our expec-

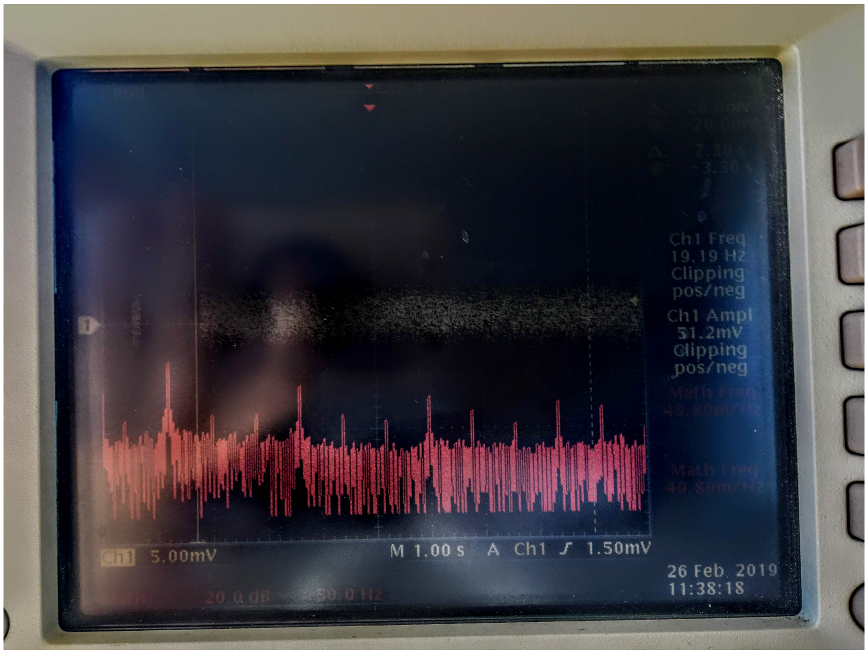

Figure 6: Measured output after the RF Amp

tations of how the system should work.

The top left of Figure 7 shows the signal just before the diode.

Figure 7 also shows what we expect the output of the diode to be, as it is mimicking the behavior of this signal multiplied by a square wave with a 50 percent duty cycle and a DC offset of 0.5 in the time domain. The expect output is plotted in the frequency domain and resembles the sinc function. The bottom graph on Figure 7 shows that an ideal low pass filter applied to the output of the diode/V_{out} will produce $1 + m_n(t)$ where m_n is the original signal.

Figure 8 shows the output of the LPF of our circuit in the time domain. It is a $60.05 Hz$ signal that will be feed to the speaker.

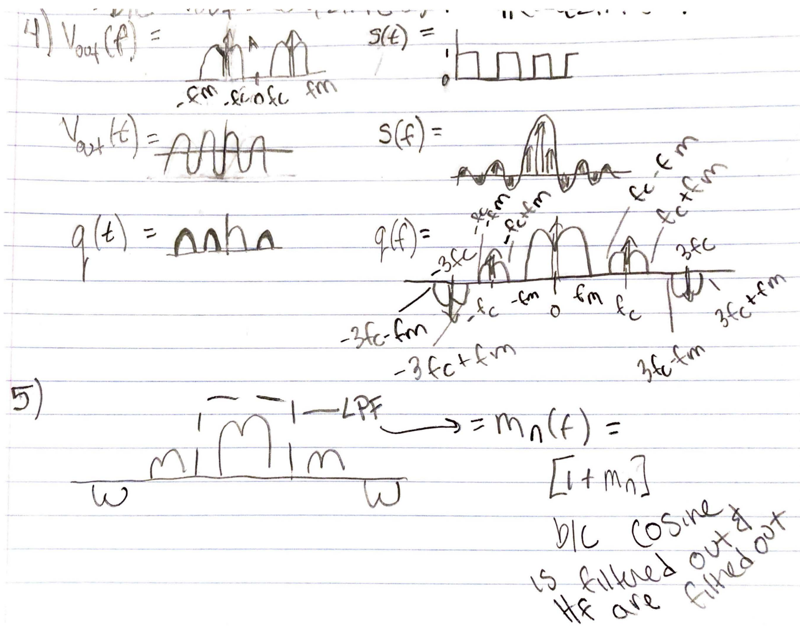

Figure 7: Expectation of signal across the diode

6 Lab Process

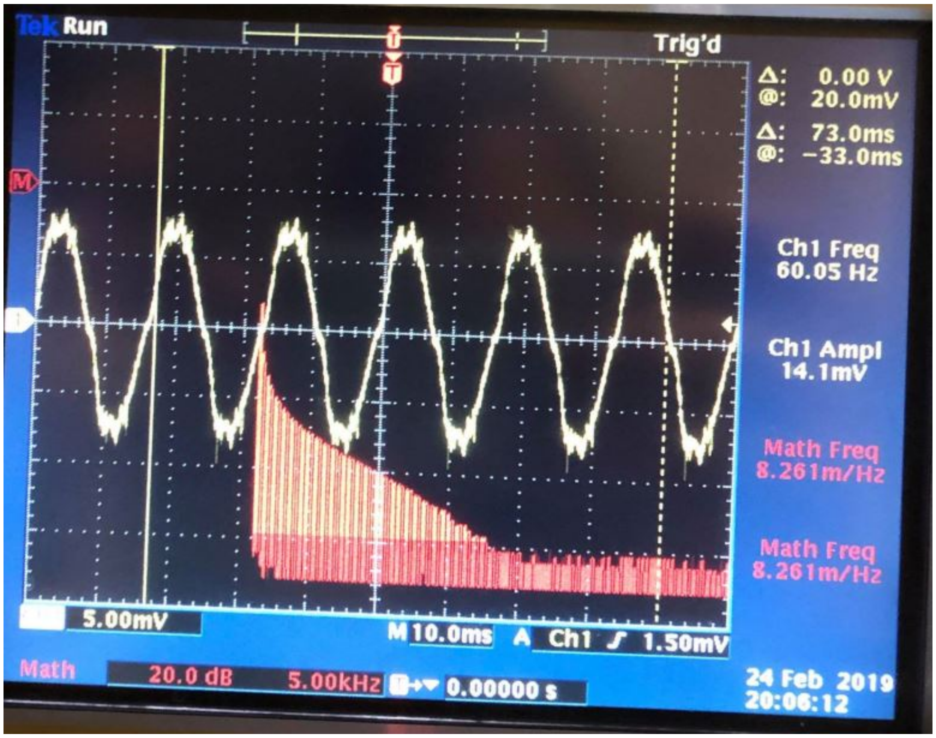

Figure 8: Output of the LPF in the frequency domain

We approached this lab by building incrementally each part of the circuit and testing each component as it was added to make sure its performance matched up with our expectations. Through this process, we were about to either determine some configuration was incorrect or that our own understanding was slightly mistaken. Initially we used an Analog Discovery device and the Waveform software to create and test signals.

Initially we spent a lot of time debugging our RF amplifier, which consisted of a non-inverting operational amplifier with a gain of 101. We learned that we were missing two key elements here: first, we needed bypass capacitors in order to remove the noise from the power supply (we were using the Analog Discovery and Waveform, but this bypass capacitor was still needed for when we ultimately connected the power supply. Second, the specific chip we were using required that any resistors connected were below 1 kΩ (we were using a 10 kΩ and a 100 kΩ resistor. So, we switched it out for a 1 kΩ resistor and a 10 Ω resistor.

We then wanted to narrow the bandpass filter slightly, as when running a Bode plot it seemed like very high frequency signals were still propagating through the circuit. We tried adding capacitors in parallel (two 2.2 nF capacitors) and it seemed to narrow the frequency response slightly, but not to a large degree. Later we ended up removing it because a later test made it seem like the frequency response had changed non-trivially, potentially because there were issues with the circuit the first time we tested it so the frequency response may not be entirely accurate.

We then changed our RF amplifier to use an inverting operational amplifier, but instead using two of these: the first with a gain of -100 and the second with a gain of -20 (for a total gain of 200). It was then we realized that we were incorrectly placing the bypass capacitors - we initially used the bypass capacitors to go from op amp chip LM6172 Vs+ and Vs- pins to 5V and -5V respectively. Instead, we were supposed to connect Vs+ and Vs- to 5V and -5V directly, and then have the capacitors go from the pins to ground.

We also lacked a capacitor that would have to go from the audio amplifier to the speaker, so we added that in. Our radio only worked, however, after removing a low pass filter (with a cutoff of 1 MHz) between the RF amplifier and the envelope detector (that we had added before adding the above capacitor).

Ultimately, what was helpful in debugging our circuit was constantly testing the circuit at various points in the block diagram and probing it with an oscilloscope to see the measured frequencies of the signal being captured.

Throughout the debugging process we found several human error when building the circuit. However, we were surprised at the volatility of the circuit even when the circuit was correct. With our final working circuit, it only works when the conditions are just right for the antenna to pick up the signal.