Lab Report 1: Analog Lab

Eduardo Herrera

February 10, 2014

Abstract

In this lab, we were to use electronic components to create components to analyze and combine with appropriate values to get proper measurements of their effect on elctronic signals and how these effects could be used to build a circuit that could receive an fm transmission, and other uses in the latter weeks. At times there were missing or malfunctoning components that prevented some measurements from being taken, so in the case of missing components of certain values, we (meaning Marta and I, the others in our group were behind and so could not contribute) then used other values that were close to our calculated values to get closer to desired results. In following week, we then combined our fm receiver with other circuits to create an amplifier, with a greater knowledge of our circuit components. Our most important findings regarded the effect on signals by our circuits, namely filters, amplifiers, transistors, etc. and what methods we used to find appropriate values. The first and second weeks of results are the most complete because the third week's supplies were malfunctioning, rendering data collection regarding John-Nyquist noise impossible, but we did manage to understand how to use code to get a better understanding of the central limit theorem and the use of larger data samples to get more accurate results.

1 Introduction

At this current stage, we have circuits, which are a tool for transferring current from one place to another, in Radio Astronomy this is required to make any type of measurements at all, unlike optical, measurements, there are objects in the universe that are impossible to analyze with just optical equipment, there is radiation that just cannot be read. With radio astronomy, we can broaden the amount of information we can analyze, and threfore learn more about the Universe around us. In this lab, we are introduced to the theory and practice of electronic circuits and their effect on current, so that these effects can be used to detect, receive and amplify a radio transmission which is related to what we will be doing with actual data later on in the course. With the limited data I got, I cannot say I have a well-grounded base of knowledge, but it was enough to do some of the lab and still get a good understanding of what happens to current in certain configurations.

2 Methods

2.1 The Voltage Divider

In this activity of the lab, we constructed the simplest of circuits to see how voltage can affected by two resistors(both of the same resistance,820Ω, as there were no 1000Ω resistors present) put in series. The effect is to have the incoming voltage be a fraction of what it originally was once it has passed through both resistors. When we measured the voltage out, we found the voltage to be 2.5 Volts, half of the incoming voltage of 5 Volts that was applied.

2.2 Impedance

Impedance is defined as the amount of opposition a circuit has to a current when some DC voltage is applied. For resistors, it is fairly easy to calculate since impedance is resistance for a resistor. In general, impedance is the general form of Ohm's law

$$V = IR, \tag{1}$$

when extended for components like capacitors, and inductors. Impedance generalizes this law by presenting V and I (the Voltage and Current) as complex waveforms. In regards to the voltage divider above, it would be a good idea to have a high impedance when you are applying a large DC voltage across a circuit, this is to prevent excess voltage from damaging componenets down the circuit. And as for lower applied volatges, it would be better to have low impedance, otherwise you would end up blocking too much of the current thus blocking any attempt to measure any relevant data you may want.

2.3 Capacitor

$$I = C\frac{dV}{dt}. \tag{2}$$

The purpose of a capacitor is store energy in an electric field between the plates of the capacitor. This acts to eventually stop current from getting through if the voltage is constant, as seen in the equation 2. But with and alternating current, a displacement of current occurs. In regards to the impedance that this contributes to a circuit, we use Z which is the relation for Voltage and Capacitance. For resistance it is simply Z=R=V/I. But for capacitors, Z is given by

$$Z_c = \frac{1}{jwC} \tag{3}$$

where j is is the imaginary unit, and w is the frequency.

2.4 RC Filters

There are two varieties of filters, the high-pass and low-pass filters, both of which make use of the imaginary, frequency-dependent impedences of the capacitors. Both types have a charecteristic frequency at which their frequency response evolves most rapidly, with a time-scale of R*C. The frequency response of the filters is given by the cutoff frequency at which a signal is attenuated at 3dB that frequency is

$$w_{3db} = \frac{1}{RC} \tag{4}$$

The designs for both a low pass and high pass filter are as follows.

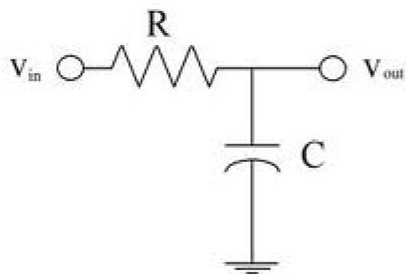

Figure 1: a diagram of a low pass filter

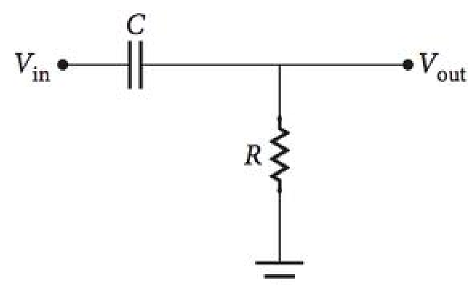

Figure 2: a diagram of a high pass filter

2.5 LC filters

Inductors are resistant to changes in current as seen in

$$V = L\frac{dI}{dt} \tag{5}$$

where L is the inductance. when a current passes through, they store a portion of the energy in their magnetic field. they behave like wire if a current continuosly flows, but once the current stops, the magnetic field collapses, and so the energy stored goes into pushing electrons in the direction they were flowing in. For a larger inductor, a larger volatage is induced when the field collapses. The impedance of an inductor is

$$Z_L = jwL \tag{6}$$

For an RLC bandpass filter, it's purpose is to not allow a band

2.6 Diode

A diode has nearly zero resistance to current flow in one direction and bery high resistance in the other direction. Because of this, it serves to convert alternating current into direct current, including modulation (the varying a signal so that it may carry information in a waveform) here namely an incoming fm signal so that the signal can be read. The following is a table of data for a diode in series with a resistor, which changed values for every set, and with a varying Voltage applied across it.

R = 56 Ω	$V_{in} = 1.2V$
R = 150 Ω	$V_{in} = 1.2V$
	$2V_{in} = 2.7V$
	$3V_{in} = 4.7V$
R = 1200 Ω	$V_{in} = 1.6V$
	$2V_{in} = 3.1V$
	$3V_{in} = 5V$
R = 2700 Ω	$2V_{in} = 3.1V$
	$3V_{in} = 4.7V$
	$4V_{in} = 7.3V$
R = 1200 Ω	$3V_{in} = 5V$
	$4V_{in} = 7.2V$
	$5V_{in} = 9.3V$

Table 1: Table showing the measured voltage across a diode with varying Voltages and resistances

2.7 FM Demodulator

Our finished FM receiver is presented in the following figure

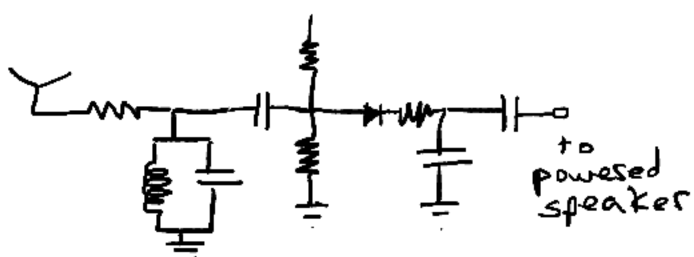

Figure 3: An FM Demodulator, consisting of an antenna, an RLC circuit, a high pass filter, a diode, a low pass filter and a capacitor

In the FM Demodulator, The antenna acts acts as a tool to capture and transmit radio signals to send down the circuit. When the current goes into the RLC bandpass filter, there is a certain range of frequencies that will be selected, from lab instructions, we had to use apprpriate values for a change of frequency of 200 kHz given a 1 MHz sine wave, we ended up calculating a resistance of 27 Ω using the equation

$$Q = w_0 RC = \frac{f_0}{\Delta f_{3dB}} \tag{7}$$

where we were given f_0 and $\Delta\ f_{3dB}$ and we had to choose an appropriate Capacitance, so due to a lack a capacitors, I chose 1 μF. To further simplify, I used $w_0 = 2\pi f_0$. And so that is how we got our value for the resistor we'd be using. Next came the high pass filter which served to filter out lower frequencies and only allow the higher frequencies to get through after a bandpass had been selected from the RLC, the cutoff point for which the -3dB point was reached was defined to be 100 kHz. After this point, the band would have to pass through the diode, which demodulated the incoming signal so that the information (the music) could get through and to prevent any signal from getting back thorugh. The signal was alternating but was changed to direct current once it passed through the diode. From there there was a low-pass filter in which its capacitor helped bring a continous signal to the powered speaker. To elaborate more, the signal coming in was in pieces, and as it got to the capacitor, it held charge, when another sine wave of greater amplitude comes in, then it held more energy, but as soon as there is a sine wave of a lower amplitude relative to the previous one before it, the capcitor dissipates some of the energy and when an even lower amplitude wave comes in, more energy is disspated, this cycle continues so that a constant sine wave is created and can be clearly heard through the speaker.

As for plots for this receiver, I did not do them, due to neglecting it until some later time, which I then overestimated for the amount of time I had left.

3 Amplifiers, Week 2

3.1 Impedance mismatches in a transmission Line

For a 15 meter cable, the pulse takes 2 that distance to make a round trip from the source, through the cable, and back again to the source so

$$\frac{30m}{750ns} = 4 \times 10^7 m/s \tag{8}$$

The 750 ns came from observations of the oscilloscope of 3 divisions multiplied by 250 ns per division thus giving us 750 ns travel time. This speed of 4×10^7 m/s comes out to be a fraction of the speed of light (2/15) When a resistor of 10 Ω was added, our square wave became distorted; meaning that this 10 Ω resistor was not the proper one to to terminate the the reflected wave, it seemed to be too small a value because there was still a reflected wave coming back. When instead a 56 Ω resistor was added, we got our original square wave back, so the reflected wave was properly terminated.

3.2 Follower Circuit

This circuit consists of a biased resistors acting as a voltage divider. The emitter resistor is there for the purpose of measuring the gain across the transistor. The gain in general is calculated as

$$g = \frac{Z_c}{Z_e} \tag{9}$$

where the subscripts C and E refer to the collector and emitter components respectively. Since for this follower the impedances are just the two resistors, the gain is simply

$$g = \frac{R_c}{R_e} \tag{10}$$

3.3 Amplifier

For the NPN BJT amplifier below

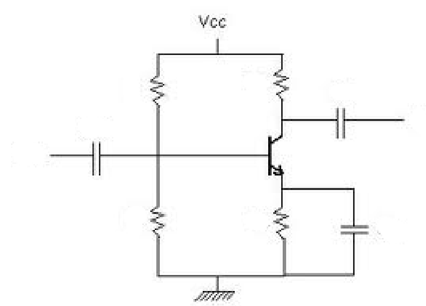

Figure 4: Our Amplifier Circuit

The way we measure gain is more complicated, since noe the emitter is no longer attached to a resistor, but to a resistor and capacitor in parallel. So now, Z_c is represented by

$$Z_c = \frac{1}{\sqrt{\frac{1}{R^2} + w^2 R^2}} \tag{11}$$

so now our gain can be calculated by 9. So to get any gain, all you would need to do, if you have known resistances, is simply solve for the capacitance to get the gain you wanted. Also w = 2πf, where f is the frequency given by the lab. So to calculate gain now, then

$$g = \frac{1}{R_E \times \sqrt{\frac{1}{R^2} + w^2 R^2}} \tag{12}$$

3.4 Speaker-Amplifier

For our speaker amplifier, the receiver part has already been explained, so after the signal has been demodulated by the diode and the signal comes in as a continous sine wave it has to go through the amplifier where it first meets a high pass filter (figure 4) to make sure no lower frequencies will interfere, from there there the signal enters the voltage divider, this is set a biasing point for the trnsistor to work in the range we want it to be in. The transistor is used to isolate the two stages of the circuit. The emitter resistor creates a voltage from the current passing through the emitter of the transistor. If it wasn't there wouldn't be any voltage would go straight to ground, preventing measurements. The Capacitors are there to stop DC voltage from coming through and messing with the audio.

The net effect of the amplifier is to take an incoming current and amplify it. In our speaker-amplifier, we only measured a small amplification of gain = 2 so our initial values for our resistors and capacitors must have been wrong

If we attached a long cable between our amplifier and speaker, then we should match the value of the impedance of the speaker 8 Ω and the total impedance of the amplifier circuit, which totals to the sum of the impedances of the emitter and collector as well as the resistances of the voltage divider and the capacitor. If it matches this, then there shouldn't be reflections that would otherwise create an echo.

4 Week 3: Noise and the Central Limit Theorem

4.1 minicircuits amplifiers

Unfortunately, with only one working amplifier supplied, our group couldn't do any of the experiments rearding the amplifiers. Instead there will just be a summary of some topics

4.2 John-Nyquist Noise

This is the thermal noise generated by the random motions of electrons within a resistor, this current has a zero mean, but can vary. This causes a fluctuating voltage across a resistor. The variance in the voltage is

$$V^2 = 4k_B TBR \tag{13}$$

where T is the Temperature of the resistor, and B is the bandwidth of the frequency that will be measured. By Ohm's law, the power of the signal generated by the resistor is

$$P_{sig} = 4k_B TB \tag{14}$$

Not all the power generated by a resistor can be passed through the circuit, the only way in which the maximum amount of power can be disspated is if the impedance of the load matches the resitor.

4.3 The Central Limit theorem

In this theorem, if we consider a random sample size of size n, so that the sequence of numbers are independently and identically distributed, the mean of all samples will be normally distributed in 'a bell curve'. From coding when we choose some maximum value for our distribution and choose a sample size, and set some number of iterations (number of times randomly chosen numbers go into a set sample size) we get a Normalized distribution as shown by the following two graphs.

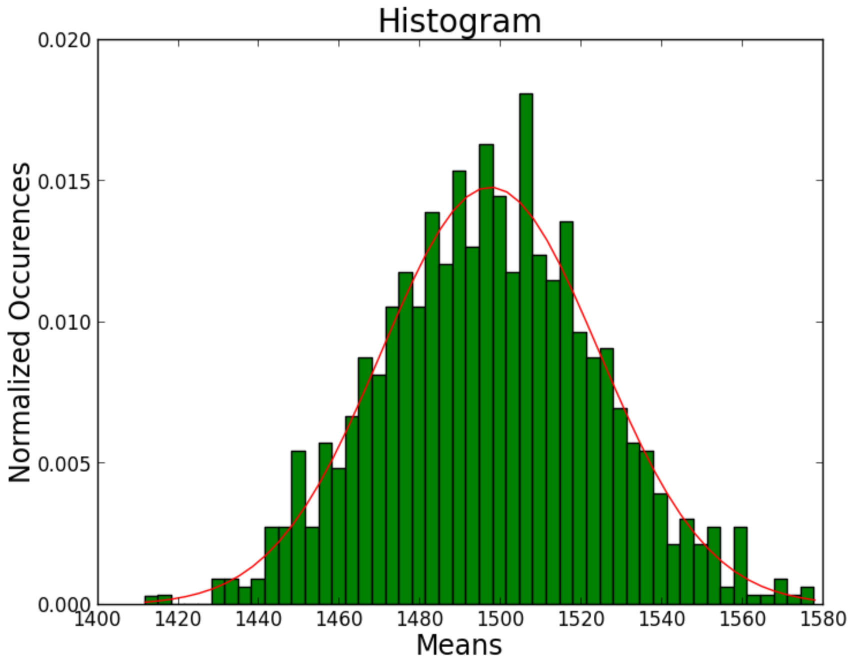

Figure 5: A normal distribution for 1000 iterations

In this figure, I instructed my code to have sample sizes of 1000 numbers with numbers chosen randomly from a minimum value of 0 to 3000. After this, I chose for there to be 1000 samples (iterations) and so when the means are plotted we see that there is a normalized curved around 1500, which is the average of 0 to 3000. To show that the Central limit theorem does in fact conform better when a larger amount of iterations are made, I ran the same numbers but instead of 1000 iterations, I had it perform 1500 iterations so what we get now is

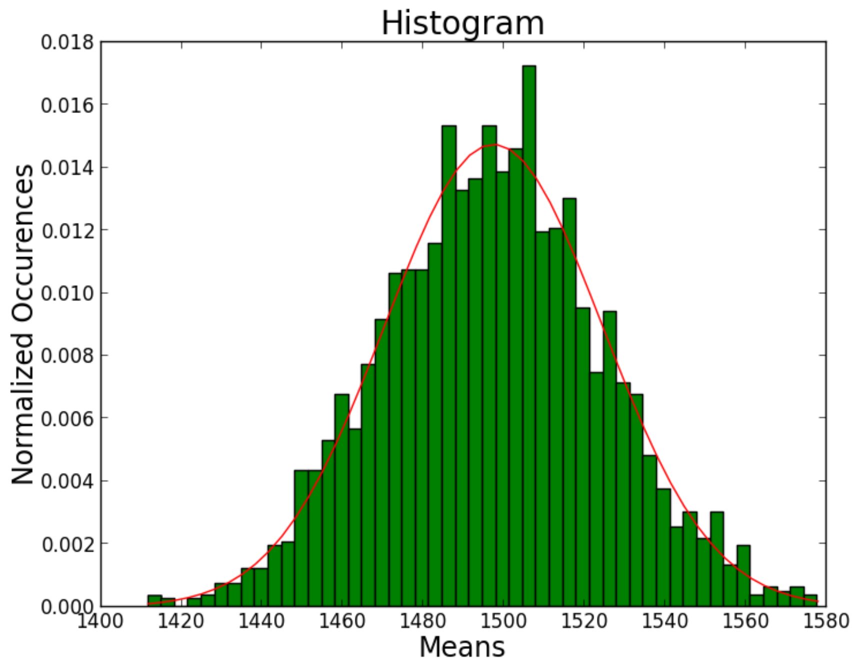

Figure 6: A normal distribution for 1500 iterations

The diffrence in this graph compared to the previous graph is that we see a greater conformity to a normalized distribution, with less variance (as seen by the outliers not fitting under the gaussian curve), therefore, if I were to run this program again for 2000 iterations then my plot would reach a unit variance, and have a 0 mean around the value of 1500. As you increase the number of samples, N, then we would see that the standard deviation would decrease by $\sqrt{N}$

4.4 Amplifier Noise Results

We could not measure any final noise due to the amplifiers being broken, so there isn't even an estimate.

5 Discussion

In this lab I had problems, mainly with my own priorities, I would put off the work for the week-ends and neglect plots for activities, which hurt the results of the the main things we needed to include in the report. Aside from that, the amplifier issue did prevent data collection that would have been useful to analyze in future labs. As for results I did manage to gain, there is a greater knowledge of how circuits work, though not a thorough one, it was still enough to understand what each configuration of circuit components can do. There is still a lack of knowledge by my own fault.

6 Conclusion

The results of these activities have proven useful for getting future labs done in a shorter amount of time, at least if they are constructing circuits from diagrams. These components acting as one will lead to an easier undersdtanding of potentially more difficult circuits, like a radio telescope, or at least understand the net effect on a signal by some apparatus. For Radio astronomy in general, this practice with circuits will at least help with trouble-shooting problems you could potentially have; narrow the reasons why some thing may not be working.