Electromagnetic Pulse Generator

Submitted To

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EXECUTIVE SUMMARY

The electromagnetic pulse (EMP) is a fairly recent phenomenon. This project tries to explore this phenomenon and create it. The goal of an electromagnetic pulse is for all electronics near the center of the blast to become damaged destroyed.

Any design will require constraints. For the sake of a research project for school, I have limited the effective range of my pulse generator to two feet to ensure I will not destroy any lab equipment in the process. Another limitation was that I have chosen a maximum voltage of 1000 volts for safety reasons.

From there the design begins. The pulse generator will be composed of two main parts, the first a charging circuit that stores energy in a capacitor, and the second a radiating circuit. Knowing an underdamped RLC circuit makes the change in current the fastest, I optimized the ideal resistor, inductor, and capacitor values using Metrowerks Codewarrior.

Once I obtained my solution I need to implement it. Gathering all the parts together took a significant amount of time. After I constructed the model I hoped to see that it works. Not unexpectedly, there were problems. I had trouble charging my two capacitors but figured it out quickly. Unfortunately another mishap came right after that. Shorting the radiating circuit with 1200 volts fried my high power switch so now the project will have to carry on with less voltage (150 volts). Good thing the voltage pulse from 150 volts was still very distinguishable on an oscilloscope.

It took me down to the last day to finish testing this project because of unforeseen complications. I am glad I finished it on time. As for the total monetary cost of the project, it more than doubled the budget set forth in the proposal. I learned that some parts required for the project were not readily available in general electronics stores and had to be specially ordered.

The safety aspects were tricky because this was an ongoing project. However, I have decided that once the project is complete, the whole circuit except the radiating coil will be enclosed on all sides to ensure the safety of those around the circuit. Also a “danger” label will be placed on a side wall of the project. Of course it is wrong to destroy other peoples’ electronics, but I do not have to worry about such accidents because this project does not have real electrical destructive power. It is a weaker version of the real thing. Although the project is not strong enough to fry electronics, but it is enough to observe the EMP principle behind it.

The project was completed successfully, but for a deeper understanding of how electronics can be destroyed, I believe that will require more time, and possibly more money as well.

1.0 INTRODUCTION

This report is about the electromagnetic pulse (EMP), how it is created from an electrical circuit, and what purpose it serves. I worked on this project by myself, but I received help and guidance from my TA, Kapil Gulati and sponsoring professor, Dr. Francis Bostick.
The purpose of the EMP is to destroy electronic equipment. This has military applications written all over it. Currently only our military communications infrastructure is protected from an EMP [1]. This leaves all other civilian infrastructure vulnerable, including cell phones, television, radio, and others. With additional research in the EMP, we will know better how to protect ourselves from foreign enemies employing such attacks against us. While at the same time, develop better weapons of this kind to maintain superiority.

In this report, I will first define the limits for this project, the problem statement. Then, I will offer a few solutions to this problem. Justification for choosing 'the solution' will be shown quantitatively. Once a solution has been chosen, it needs to be implemented. Following the discussion on implementation is test and evaluation. My results as well as test methodology will be presented. Important in any project, the time and cost issues will also be presented. Finally, I will discuss the safety and ethical aspects of this project and conclude with recommendations on any additional research that can be done on this topic.

2.0 DESIGN PROBLEM STATEMENT

This EMP generator will be designed to release an electromagnetic pulse. The purpose of the said pulse is to induce a potential, or voltage, that heats up semiconductor material so quickly that it changes the crystal lattice structure of the material and thereby electrically destroying it. Such a pulse generator can have good military applications. Since I am creating a research project, and not a weapon, my generator will be scaled down, meaning it will have a short effective range, just enough to demonstrate the principle behind an EMP. I have decided to limit the range to two feet as this will allow ease of testing in the lab. To specify effective range, I have decided to cap the induced voltage to 40 volts at two feet. The reason I chose 40 volts is because after preliminary research, I learned that many common transistors have a breakdown voltage between 5 and 40 volts, so 40 is enough. The highest voltage to be used in the generator is 1000 volts. The reason for such a limit is safety. Voltages even higher than this will further increase the risk of parts being ejected from the circuit, or someone being shocked by the high voltage and be seriously injured. Lastly, to obtain the power required to charge the generator, I decided to use wall outlets instead of batteries because obtaining a high voltage like 1000 volts is much more easily done with alternating current source (outlet) than a direct current source (batteries).

3.0 DESIGN PROBLEM SOLUTION

The EMP generator consists of two circuits. The first circuit is to store energy supplied by a wall outlet, and the second is to release that energy through a loop of wire. Sending a rapidly changing electrical current through a loop is what will create an electromagnetic field in the form of a pulse [2]. Please refer to Appendix A for a general picture of what the magnetic field will look like. Speaking with Dr. Bostick after becoming stuck at solving for the magnetic field, I figured out that I need a parallel RLC circuit that is controlled by a switch, that is, the switch controls the discharging of the energy in the circuit. Please refer to Figure 1 below. R1 and L1 represent the radiating copper loop.

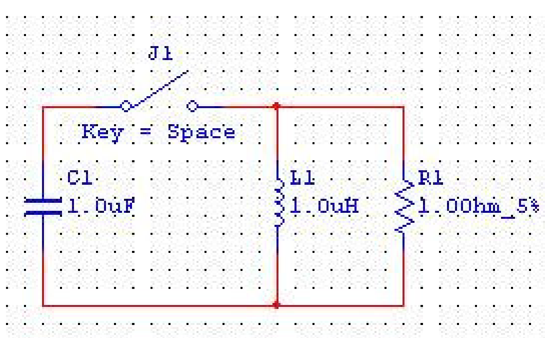


Figure 1. Starting design for the generating circuit

However, the circuit is not complete. Figure 1 only shows how the energy will be released but not how it will get there in the first place. Working backwards, to release a pulse, a voltage needs to be charged on the capacitor first. To do this, I will use a full-wave rectifier circuit to convert an AC voltage into DC, because a capacitor does not charge with AC voltage. In addition to the rectifier circuit, a high voltage transformer will have to be used to convert 120

VAC from our wall outlets into the 1000 VAC that I need to charge the capacitor with. Please refer to Figure 2 for the complete circuit diagram. I have opted for the 1N4007 rectifier diodes as they are the only diodes I know that can handle up to 1000 V.

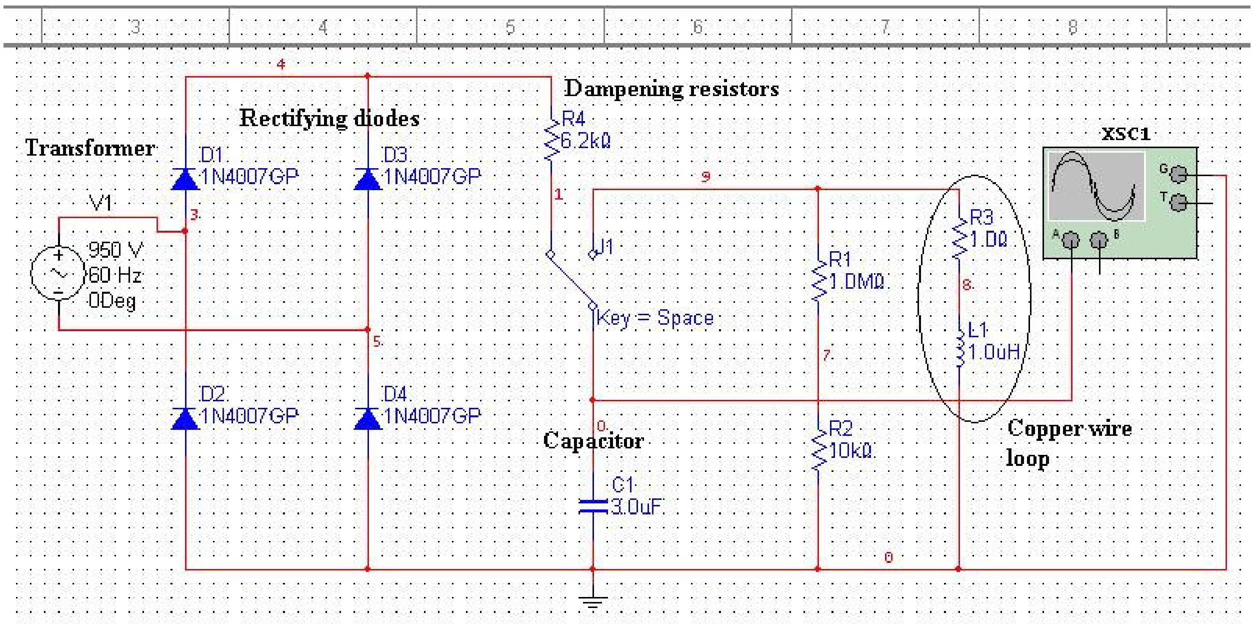


Figure 2. Complete circuit diagram

By now I know the release of the pulse is to be controlled by that switch, I need to obtain those R, L, and C values. Drawing from my knowledge in circuit theory, I know that an underdamped RLC circuit has the fastest changing current. I confirmed this fact with my electric circuits book as well [3]. I wrote a program in C++ with Metrowerks Codewarrior to optimize the R, L, C values for the highest capacitance C while keeping the circuit underdamped (different combinations of RLC values cause different damping). To see a set of the calculations done by the program, please refer to Appendix B. Having foresight that the inductor value L should be kept low, and that a copper loop of one foot in diameter that is to be used as the inductor is around 1uH, I assigned ranges of values for the program to search for a best solution.

3.1 OPTIMIZATION

For the inductance L the range was .1 ~ 200 uH, and for the capacitance C the range was .01 uF ~ 50 uF. The resistance R value was kept constant at 1 Ω because I had foresight in that a copper loop of one foot in diameter that is to be used as the inductor has characteristics of an L of 1 uH and an R of 1 Ω. After optimization I found the best solution to be R=1 Ω, L=1 uH, and C=3uF. The code for optimization can be found in Appendix C. Although many different solutions were found, the solution with the highest C value wins out because the energy stored in a capacitor is one-half times C times the voltage squared. Higher C means more energy is released in the pulse.

3.2 SIMULATION

Now that I have the best set of solutions I simulated the results in Multisim. I also simulated the other solutions to make a comparison to confirm that the best solution was in fact the best. Its simulation in Multisim and its corresponding voltage waveform can be found in Appendix D. The waveform in Appendix C has the most area under its curve when compared to the others, meaning that it released the most energy. For comparison to a lesser solution, refer to Appendix E. Unfortunately Multisim could only simulate voltage waveforms in the main circuit. To obtain the induced voltage waveform caused by the EMP I had to wait until the physical construction of the circuit to make measurements.

4.0 DESIGN IMPLEMENTATION

To bring a circuit diagram to life first I need to buy all the parts shown in Figure 2. Below is a table of parts I compiled. The total cost of the project is $306.66. The costs will be examined in more detail in Section 6. Finding the transformer, the switch, and the copper coil took the longest as they are not common equipment sold by electronics stores.

Table 1. Required parts for project

Part	Quantity	Cost
Transformer 950V	**1**	**$95**
Diodes 1N4007	**4**	**$1**
Switch MCO500	**1**	**$131**
Capacitor 1uF	**1**	**$30**
Resistor 1MΩ	**1**	**$.99**
Resistor 10kΩ	**1**	**$.99**

Copper coil	**1**	**$31.68**
Copper cables	**2**	**$16**

After I finished gathering all these parts, I started the construction of the circuit. To keep the heavier parts like the capacitor and the switch from sliding around on the wooden base, I hot glued them on the board. Refer to Appendix F to see the real life model of the EMP generator in its glory. I used the copper jumper cables to connect the terminals of the copper loop to the rest of the circuit. For all the other parts I used the alligator-to-alligator cables checked out from the second floor lab to connect them. Finally, I soldered together some resistors and the rectifier diodes like the way they are shown in the circuit diagram. The construction of the circuit did not take much time compared to the other phases of the project.

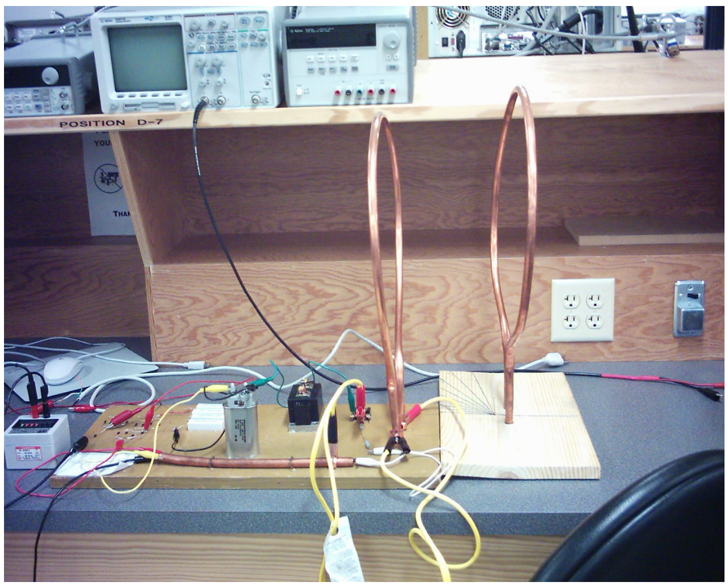
5.0 TEST AND EVALUATION

The construction of the circuit is complete. Now I am ready to test the circuit and see if the measured results match theoretical results. During the first test ever, my technical TA Kapil was next to me when my switch fried. After that, the switch is simply a short circuit and no longer has its original function. I have contacted IXYS, the manufacturer of that switch. I asked them why the switch got fried when it should not have but they have not yet responded. I even made sure the amount of current flowing through that switch was well below its maximum ratings. This was a setback in obtaining excellent results from the project as now I cannot use 1000 V on a capacitor but instead had to settle for 120 V from the outlet.

Nevertheless, the project must carry on. Not needing the transformer anymore, I disconnected it from the circuit, as well as the blown electrical switch. I replaced the blown switch with a mechanical switch, one that is flipped on and off by hand. Since I did not want to blow this switch also, I simulated this modified circuit on Multisim to double check that the new switch would not be destroyed too. After this, I was ready to go back to making measurements.

To measure the induced voltage, I place another copper loop, of which I will be referring to as the receiving loop, directly in front of and parallel to the loop connected to the circuit (Figure 2 below). Now I charge the capacitor. Here was when I ran into another problem. When I plugged in the power cord into the outlet, apparently the instantaneous current that flows through the circuit was too much for the diodes to handle and the two lower diodes fried too. This caused the outlet to short itself and the result was a blown fuse at the work station. After two blown fuses I finally figured out a solution. To lower the initial high current that flows through the circuit, I checked out a resistance decade box and set it at 9MΩ. Then I plugged in the power cord and was glad that neither the diodes nor the fuse at the workstation blew out.

Figure 3. Setting up for measurements



Now I measured the voltage across the capacitor using a multimeter and it does indeed say 152 V (120 V rms from the outlet). I flipped the mechanical switch, shorting the circuit, and the oscilloscope registered an oscillating, decaying voltage wave, which was an EM pulse [4]! The EMP generator worked! Then what I had to do was take a series of measurements, changing the distance between the transmitting and receiving loop each time. Compare the measured results with the theoretical calculated results in Table 2 below. At six inches and closer, the results were nowhere close to each other, and the calculated voltages were even greater than the initial voltage of 152 V. I believe this is because there is a limitation on the magnetic field equation for a small dipole [5]

$$B = \frac{\mu IA(2\cos\theta \vec{a}_r + \sin\theta \vec{a}_\theta)}{4\pi r^3} \quad (1).$$

For a certain distance r and beyond, this equation is valid. If r approaches a small number, then the magnetic field would go to positive infinity which makes no sense. So there would have to be a limitation for this magnetic field approximation. I suspect the limitation for this approximation is at 6 inches as the difference is way too large.

Table 2. Induced voltage with varying loop distances

Distance (in)	Calculated (V)	Measured (V)
36	.40	1.5
30	.68	1.6
24	1.32	2
18	3.08	3
12	11.11	5
6	88.88	10
5	136.55	17.5
4	300.00	20
3	585.94	23
2	2400.00	30
1	11111.00	48

After measuring the induced voltage for varying loop distances, I measured the induced voltage for a fixed distance but varying angle θ. If the loops were not lined up parallel to each together, I expect the induced voltage to be lower because less of the magnetic field was captured by the receiving loop. The theoretical and measured results are shown in Table 3 below.

Table 3. Induced voltage with fixed loop distance and varying angle θ

Angle (degrees)	Calculated (V)	Measured (V)

0	11.11	10
5	11.08	-
10	10.98	10
15	10.83	-
20	10.61	10
25	10.34	-
30	10.01	10
40	9.23	10
50	8.31	10
60	7.35	6
70	6.46	5
80	5.80	2
90	5.56	0

Measurements show that for 0 through 50 degrees of rotation, there is not much change in the induced voltage. For 60 through 90 degrees, however, the induced voltage steadily decreases, in accordance with Faraday's law. I suspect there is an error for my calculations for the theoretical induced voltages as it should be 0 at 90 degrees. I believe the error happened when I calculated the voltages using rectangular coordinates when I was supposed to use spherical coordinates (r and θ components, not x and y). To add a last piece of information, the pulses I measured had a frequency range from 5 kHz to 20 MHz, meaning each pulse will cause interference at the said frequencies, however only for a fraction of a second.

6.0 TIME AND COST CONSIDERATIONS

The EMP project met the time but not the budget constraints. Finishing the measurements and the project took me to the very last day. The Gantt chart for the project is in Appendix G. Even though I was dangerously close to not finishing, I am glad that was not the case. Waiting for the transformer and the switch to arrive in the mail contributed to this close call. Although I did spend my time productively during the wait, checking that the maximum rating for each component were not reached. As for costs, I estimated the total cost for this project in the proposal to be \$160. However, sum of the costs for the parts listed in Table 1 is \$306.66. The high prices of the transformer and the switch were what drove up the total cost. I had not foreseen this at all in the beginning of the semester as many switches and transformers were in the \$10 ~ \$40 range, but the ones that I needed do not fall within this range.

7.0 SAFETY AND ETHICAL ASPECTS OF DESIGN

The main safety issue with the EMP generator is that one has to be careful when a high voltage (150 V or higher) is charged on the capacitor. The person working with the generator has to be very careful not to touch the two terminals of the capacitor with any part of the body as doing so can potentially serious burn. To further protect the user and those around him, I wanted to include wooden side walls and a Plexiglas top cover to isolate the live electrical currents and charges. However, I ran out of time to add such features, but this can be easily implemented in the future as it only takes nailing wooden boards and mounting the Plexiglas cover with screws.

Another built-in safety feature are the 1MΩ and 10kΩ resistors in parallel with the transmitting loop. By measuring the potential across the 10kΩ resistor, the user can know how much voltage is still stored in the capacitor (multiply by 100), so he will know when it will be safe to get near and/or work on the circuit. The last issue I would like to mention is that if scaled up, meaning releasing an EMP with a much higher voltage, this device can be used for criminal activities, even though its original purpose was for research. So in my opinion, all EMP generators should consist of a detachable component that the owner can take with him to ensure that even if criminals get their hands on an EMP generator, they will not be able to use it.

8.0 CONCLUSIONS AND RECOMMENDATIONS

I am glad I had the opportunity to work on this research project. I learned how to design, construct, and test EMP generator circuits, and electrical circuits in general. Although I was unable to achieve my original goal of 40 volts at two feet or fry any transistors, but I know it can easily be achieved by replacing a few parts. With more a little more time, I believe I will be able to construct a generator with more destructive power and will thus actually be capable of frying electronics like it is intended. My recommendation is that there is more research to be done on the effects of an EMP on different integrated circuits and transistors so we may know how to destroy electronics with an EMP more efficiently. Conversely, more research can and should be done on metallic shielding to protect valuable electronics.

REFERENCES

[1] L. Wood, "Statement by Dr. Lowell Wood," http://www.house.gov/hasc/testimony/106thcongress/99-10-07wood.htm (7 Oct. 1999).

[2] R. A. Serway and R. J. Beichner, *Physics: For Scientists and Engineers*, Saunders College Publishing, Philadelphia, P.A., 2000, p. 982.

[3] J.W. Nilsson and S. A. Riedel, *Electric Circuits*, Prentice Hall, Upper Saddle River, N.J., 2001, p. 377.

[4] B. C. Gabrielson, "An Introduction to the EMP and Lightning Threat," http://blackmagic.com/ses/bruceg/EMC/EMP-Light.html (current 6 Dec. 2006).

[5] Plonsey and Collin, *Principles and Applications of Electromagnetic Fields*, McGraw-Hill, New York, N.Y., 1961.

APPENDIX A – MAGNETIC FIELD FROM AN EMP

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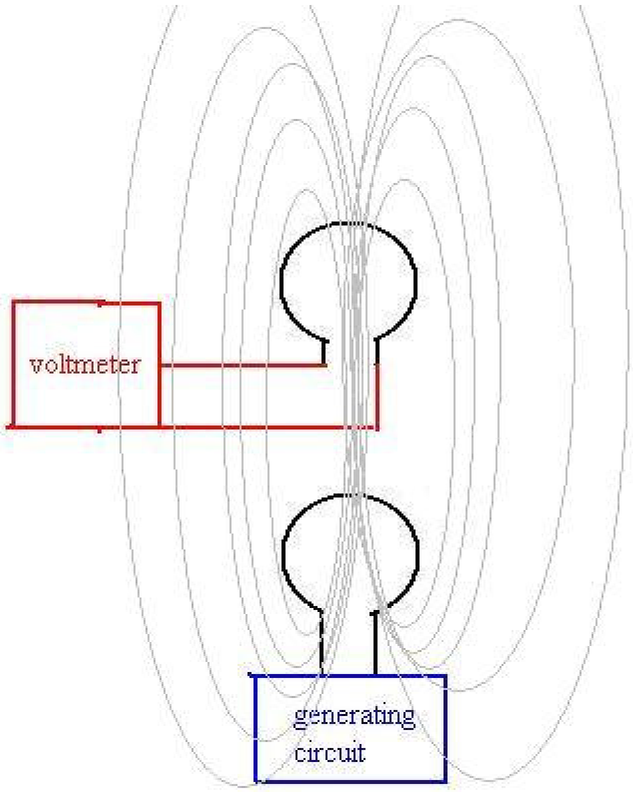

APPENDIX B – CALCULATIONS FROM A SET OF RLC VALUES

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For a capacitance of .5 uF and inductance L of 50 uH and resistance R of 10 Ω, let us examine the results for this setup. Since α = R/2L, ω = √(1/LC), ω_d = √(ω^2 – α^2), and for an underdamped circuit, the current through the inductor is i(t) = B_1exp(-αt)cos(ω_d*t) + B_2exp(-αt)sin(ω_d*t). Using the C, L, and R values above, after some number crunching, we have 10^10 = α^2 < ω^2 = 4*10^10, so the circuit is in fact underdamped so we can use the above i(t) equation. Knowing i(0) is 0 because the current in an inductor cannot instantaneously change, I set i(t) to 0, and the result is B_1 = 0. So, i(t) simplifies to i(t) = B_2exp(-αt)sin(ω_d*t). Now, knowing L di/dt(0) = V the voltage across the inductor, assuming V = 500 volts the voltage charged on the capacitor that will also be the voltage on the inductor right after flipping the switch, I differentiated i(t) with respect to time and substituted t = 0, and set that expression to equal V/L, I get B_2 = 57.7 so we now know i(t) = 57.7exp(-10^5t)sin(173205t).

APPENDIX C – C++ CODE FOR OPTIMIZATION OF L AND C VALUES

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```
#include <iostream>
#include <math.h>
using namespace std;

void main()        {

        //Vcap = 1000 V
        double L[2000];    //.00005;          //        .1uH-200uH
        double C[5000];    //.0000005;                  //        .01uF-50uF
        double R = 10;                                           //10 ohm internal
resistance
        double omega_n;
        double alpha;
        double omega_n_s;
        double alpha_s;
        bool underdamp = false;
        bool temp = false;
        bool change = false;

        for(int x=1;x<5001;x++) {
                C[x] = x*.00000001;                   //C incremented by .01uF
                for(int y=1;y<2001;y++) {
                        L[y] = y*.0000001;                     //L incremented by .1uH

                        omega_n = sqrt(1/(L[y]*C[x]));
                        alpha = R/(2*L[y]);
                        omega_n_s = omega_n*omega_n;
                        alpha_s = alpha*alpha;
                        if(omega_n_s > alpha_s) {
                                underdamp = true;
                                if(!temp) {
                                        change = true;
                                        temp = true;
                                }
                        }
                        else {
                                underdamp = false;
                                if(temp) {
                                        change = true;
                                        temp = false;
                                }
                        }

                        if(change) {
                                cout << "omega_n_s " << omega_n_s << " alpha_s " <<
alpha_s << " omega
greater? " << underdamp << endl;
                                cout << "C  " << C[x] << "   L  " << L[y] << endl
<< endl;
                                change = false;
                        }

                }
                //pause execution...
                //getchar();
        }
}
```

APPENDIX D – VOLTAGE WAVEFORM FOR BEST SOLUTION

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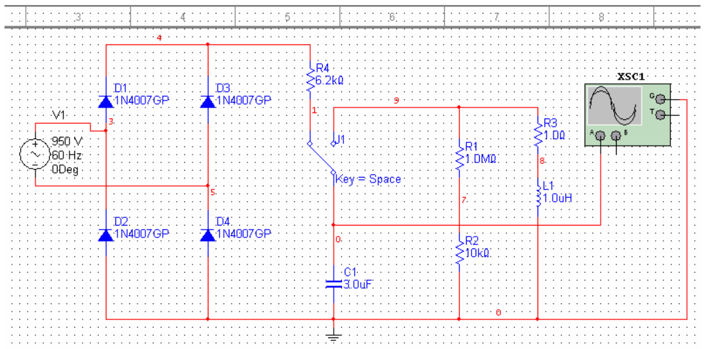
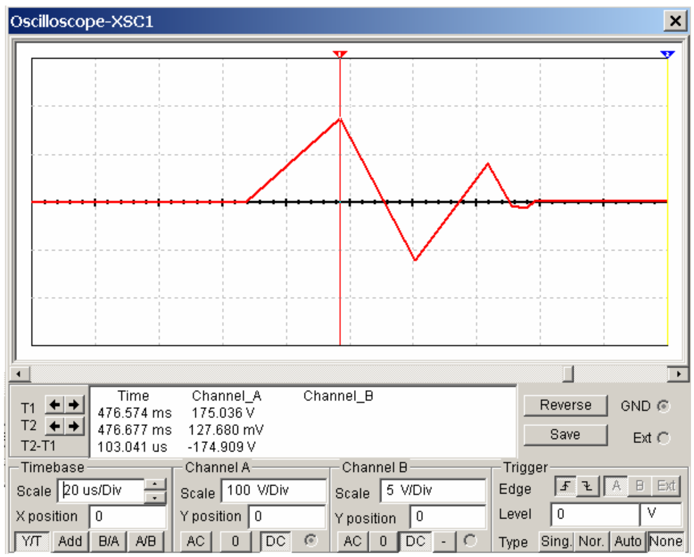
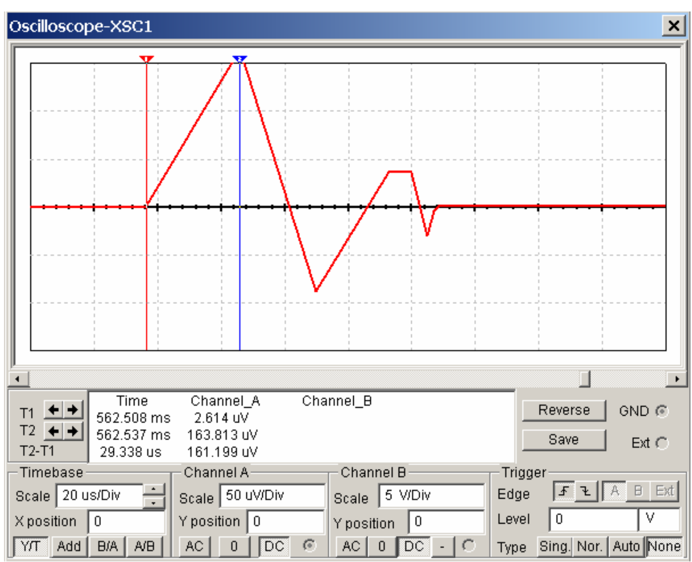


Schematic – C=3uF, L=1uH, R=1Ω



Voltage waveform



Current waveform

APPENDIX E – VOLTAGE WAVEFORM FOR WORSE SOLUTION

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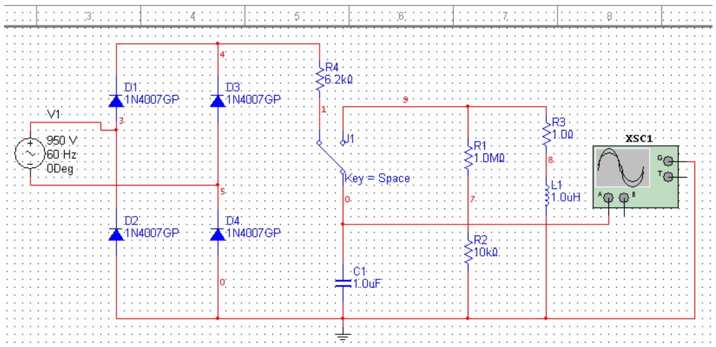
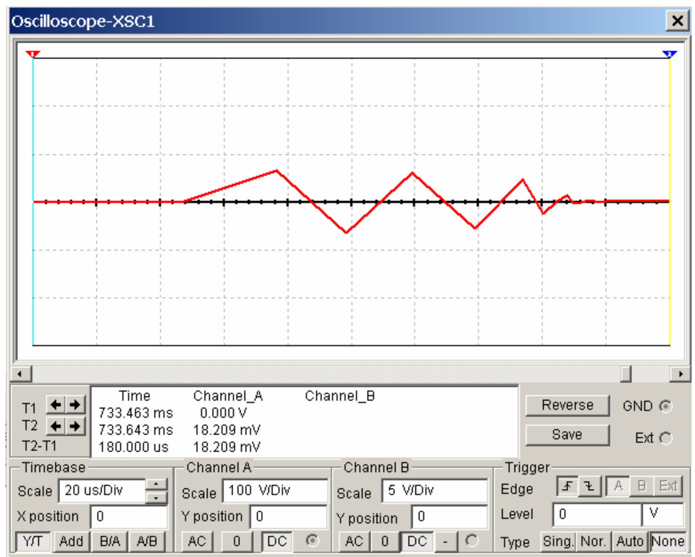
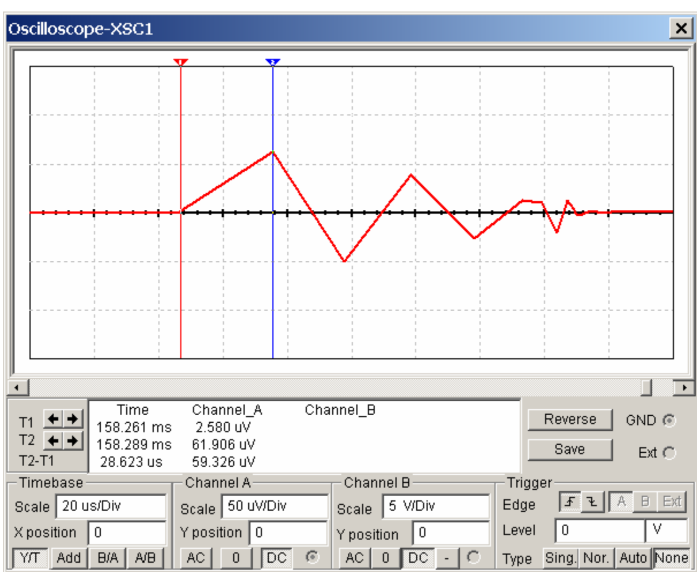


Schematic – C=1uF, L=1uH, R=1Ω



Voltage waveform



Current waveform

APPENDIX F – CONSTRUCTED EMP GENERATOR

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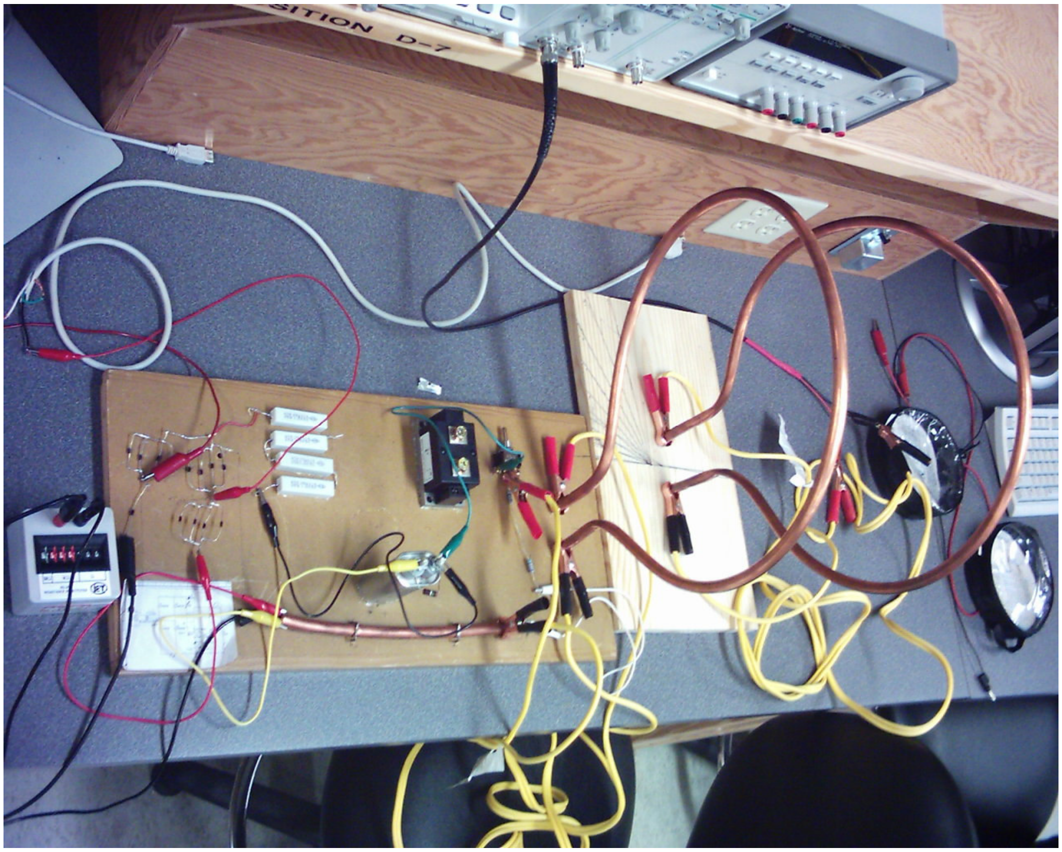

APPENDIX G – GANTT CHART

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ID	Task Name	Start	Finish	Sept 2006		Oct 2006				Nov 2006			
				9/17	9/24	10/1	10/8	10/15	10/22		11/5	11/12	11/19
1	**Learning Modules**	9/7	10/3	■	■	■							
2	Module 4	9/19	9/19	III									
3	Module 5	9/21	9/21	III									
4	Module 6	10/3	10/3			III							
5	**Design stage I**	9/15	10/3	■	■	■							
	Develop Design Concept												
6	Define the problem	9/15	9/17	IIII									
7	Submit Proposal	9/19	9/19	III									
8	*Initial Design*	9/15	9/21	IIII	III								
9	*Develop alternative designs*	9/21	9/26		IIIIIIIIII								
10	Design review (oral) and	9/28	9/28		IIII								
	Determine final design												
11	Submit notebook	10/3	10/3			III							
12	**Design stage II**	10/5	10/31				■	■	■	■			
	Implement Design												
13	*Research prices*	10/5	10/10				IIIIIIIIIII						
14	Pre-demo perf. assesm.	10/17	10/17					IIII					
	(simulation)												
15	Written Progress Report	10/19	10/19					II					
16	*Purchase parts*	10/10	10/21					IIIIIIIIII					
17	Submit notebook	10/24	10/24						II				
18	*Construct prototype*	10/21	10/31							IIIIIIIIII			
19	**Test and Evaluation**	10/31	12/7							■	■	■	■
20	*Testing*	10/31	11/7							IIIIIIIIII	III		
21	*Refine if necessary*	11/7	11/14								IIIIIII	IIIIIII	
22	Submit notebook	11/16	11/16									II	
23	Display project	11/30	11/30										II
24	Give final oral presentations	12/5	12/5										II
	and written reports												
25	Submit notebook	12/7	12/7										II
26	Submit course and peer	12/7	12/7										II
	evaluations												