VLF/LF and the 2017 Total Solar Eclipse

W. Liles[1], L. Lukes[2], J. Nelson[2], K. Kerby-Patel[3]
[1]Independent Consultant , [2]George Mason University, [3]University of Massachusetts Boston

ABSTRACT

The very first use of the solar eclipse to study the ionosphere was done in 1912 at a wavelength of 5,500 meters. Since that time, multiple studies have been done at VLF and LF frequencies. Most of these studies were performed at a single receive site with a single transmit location during a single eclipse, thus making it very hard to compare data from separate collections.

This paper addresses historical collection efforts, what has been learned about the sun's influence upon the ionosphere, and the role of neutral corpuscular particles ionizing the ionosphere. Questions raised by the above will be addressed.

A planned crowdsource effort will then be described that will attempt to address and answer questions raised by having multiple receivers all reporting on signals transmitted by the same VLF/LF stations. There are two approaches to the crowdsource collection. One approach uses the SuperSID network that is already reporting on changes in propagation of signals from VLF stations. The other approach uses a receiver and antenna based upon an instrumentation amplifier chip and a smart phone as a software defined radio. The later approach will be detailed.

1. INTRODUCTION

In 1912, William Eccles had the idea of studying the influence of a solar eclipse on radio wave propagation. By that time, the diurnal effect on radio waves was known and Eccles was a proponent of the Kennelly-Heaviside theory positing the existence of a layer in the atmosphere that enabled long distance radio communications.

Eccles conducted an experiment using the solar eclipse of April 17, 1912, recording the amplitude of sounds of "strays" at a wavelength of 5,500 meters. He did not record signal amplitude change for any transmitter, but did record that a transmitter's signal in Clifden was loud when strays were loud and vice versa [1].

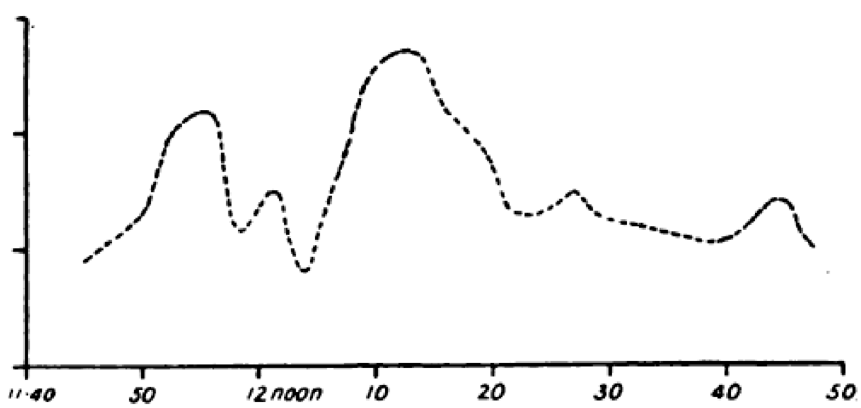


Figure 1. Eccles plot showing amplitude (y-axis) vs. time (x-axis). Maximum eclipse as viewed from London, UK was at 12:09:59.4 [1].

The plot in Figure 1 raises questions that are still being discussed today. For example, why are there two major humps and not just one? Why is there a hump before the maximum eclipse time? Why is the major hump the shape it is?

Since 1912 many attempts have been made using solar eclipses to study radio wave propagation at different frequencies using different transmitters and different receive locations. Comparing this data is difficult, since it typically comes from one or a few receive sites for a given transmitter, and not always with geometries that show all the conditions that one wishes to study.

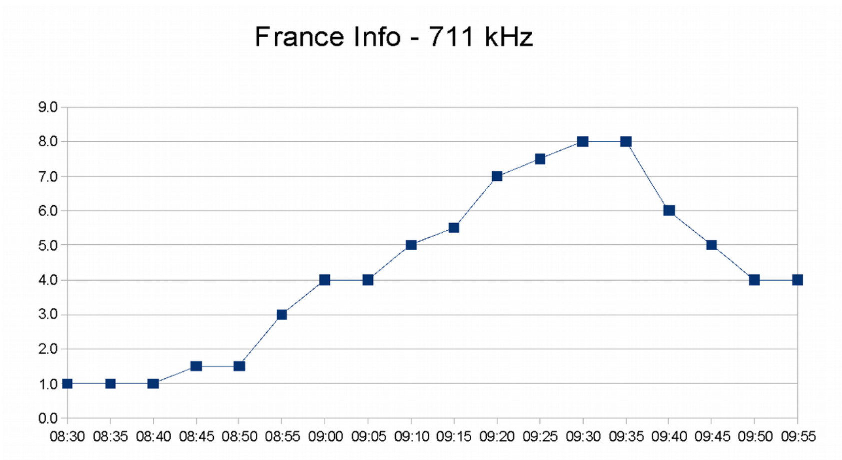
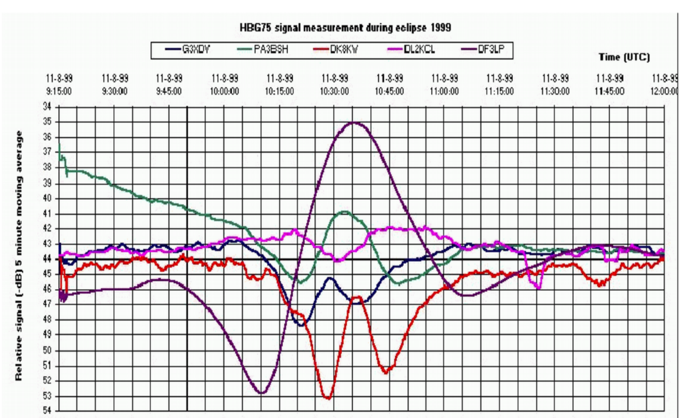


Figure 2. Received signal strength (in S units) at Wolverhampton, UK vs time (left) and eclipse path (right) for the transmitter located south of Wolverhampton at Rennes-Thourie, France [2]. Map from NASA shows the eclipse path.

During the 2015 partial solar eclipse north of the UK, the 711 kHz signal from France Info at Rennes-Thourie was received and collected at Wolverhampton, UK. Both transmit and receive sites were south of the eclipse path. Figure 2 shows the received signal strength and the eclipse path. On the signal strength plot, the slope of the increasing signal strength before the eclipse is more gradual than the slope for the decreasing signal strength after the eclipse. These differences might be associated with de-ionization and re-ionization rates. The plot in Figure 2 looks straightforward, with a low value early in the day when the signal cannot be heard, then rising signal strength during the eclipse and falling signal strength after the eclipse. But not all plots have been so straightforward.



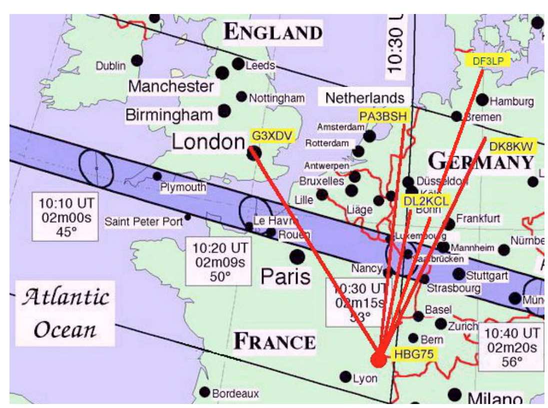


Figure 3. Relative signal strength from HBG Switzerland at 75 kHz during 1999 solar eclipse. https://misan.home.xs4all.nl/eclipse.htm

Figure 3 shows plots for reception of the 75 kHz time signal from Switzerland by four different receive sites during the 1999 solar eclipse. Notice that all signal paths cross the line of visual totality in the accompanying diagram.

The signal strength variations depicted in Figures 2 and 3 reflect changes in the D layer. This layer has very complex chemistry. Ionosondes primarily measure reflections from the E, Es and F layers, thus providing no insight into the D layer. While these figures show increased propagation strength during an eclipse, the F layer shows decreased propagation strength, as the critical frequency decreases during an eclipse.

During the 1920s and early 1930s, there was a serious debate as to what caused the ionization of the ionospheric layers. The diurnal effects were well known; as a result the sun was accepted as the main cause of ionization, however, the ionization mechanism was unknown. The two main theories debated were whether electromagnetic waves or neutral particles being emitted from the sun caused the ionization of the ionospheric layers [3].

Questions regarding the ionization mechanism were the basis of an experiment using solar eclipses. Since the moon blocks both the electromagnetic waves traveling at 300,000 km/s and the particles traveling around 2,000 km/s, the delay in ionization after the passage of the eclipse could be computed. If the ionosphere was ionized quickly, it was due to high speed electromagnetic waves. If there was a significant delay in ionization, it was due to the slow speed of the particles. The results showed that electromagnetic waves were the agent [4].

2. UPCOMING SOLAR ECLIPSE

On August 21, 2017, there will be a total solar eclipse over the contiguous United States and the eclipse shadow over the entire United States. This presents the rare opportunity for collecting signals over a large landmass, and in particular to collect signals from the same transmitters over such a large region.

Figure 4. Path of the August 21, 2017 total solar eclipse over North America. Image from NASA.gov.

In the case of VLF and LF signals, this collection capability can be implemented with any receiver capable of receiving the signals of interest. One such system is already in place, the SuperSID. For use of the SuperSID system for collection during the solar eclipse, please see the paper by Dr. Richard Russel in these proceedings [5].

Another way to collect the LF signals will be the EclipseMob effort.

3. ECLIPSEMOB SOLAR ECLIPSE EFFORT

EclipseMob is a crowdsourced project inviting participants throughout North America to record amplitude variations of signal strength from WWVB located at Fort Collins, CO at 60 kHz and also a US Navy transmitter located by Dixon, CA at 55.5 kHz.

The receiver consists of an instrumentation amplifier chip, mixer chips, and some external parts (capacitors, voltage regulators, batteries, etc.) feeding the receiver's output into a smart phone. The smart phone functions as a Software Defined Radio that also supplies location and time/date information. The receiver electronics and antenna design, a balanced loop, is based on a paper by Tom Hagen [6].

Kits for building EclipseMob receivers are provided at no cost to educational institutions. Educational materials have also been prepared, including learning activities for K-12 students. The kits are easy to build, with no soldering required.

The data collected in the EclipseMob experiment will be uploaded to a web server, where it can be analyzed to address some of the questions raised in Section 1.

3.1 ECLIPSEMOB ANTENNA KIT AND DESIGN

Figure 5. Components for the EclipseMob antenna.

The antenna for the EclipseMob project is a balanced loop antenna formed around the plastic container that the kit is shipped in. It consists of two loops, each made of 100 turns of magnet wire. Cord hooks are used to keep the wires in place.

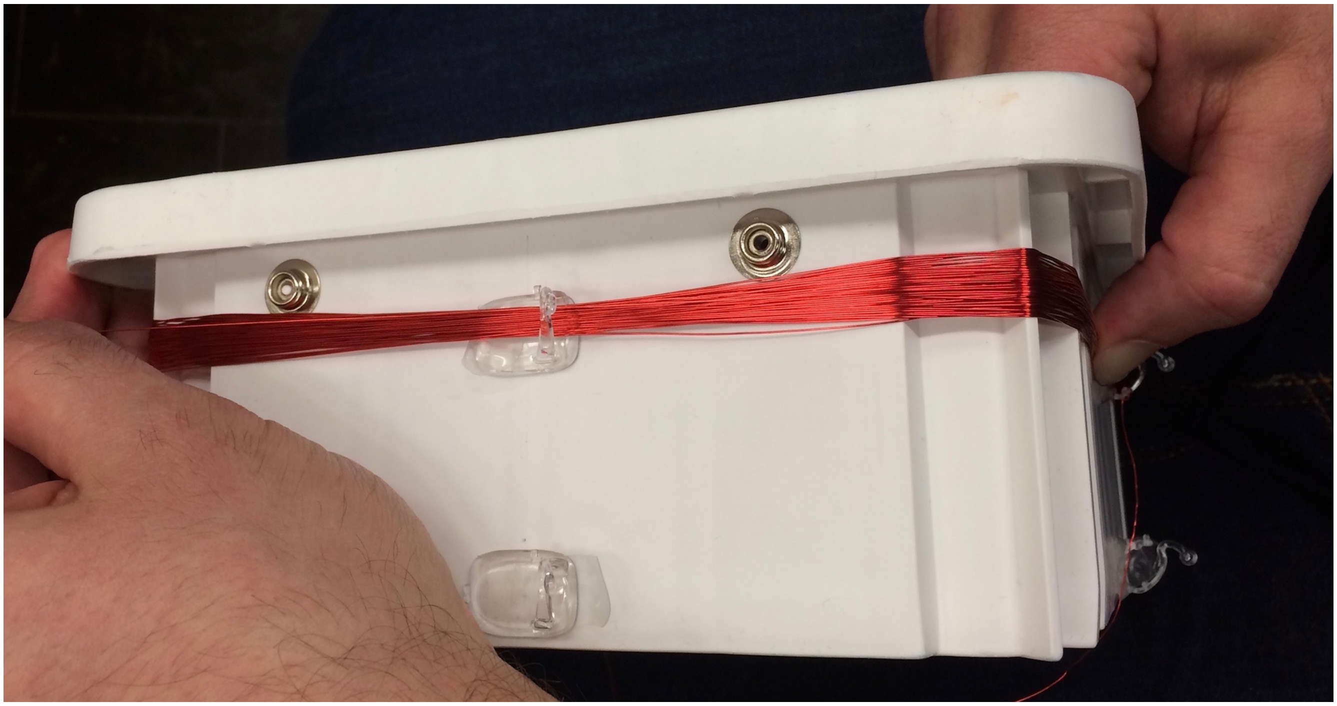


Figure 6. Showing the wires wrapped held in place by the cord clips.

3.2 RECEIVER

Since problems in the past with crowdsourced collections have included missing and/or incorrect items on the reports (such as errors in location, date and time), the EclipseMob receiver uses a smart phone to supply location, date and time services. While solving one problem, that introduced another problem, that the signals of interest are at 60 kHz and 55.5 kHz. A common sampling frequency for smart phones is 44.1 kHz with 16 bits with audio cutoff frequency in the low 20 kHz range. The receiver needs to mix the signals of interest down to the smart phone microphone input passband. Since there are not a lot of signals in that frequency range, the signals of interest are not mixing on top of other signals.

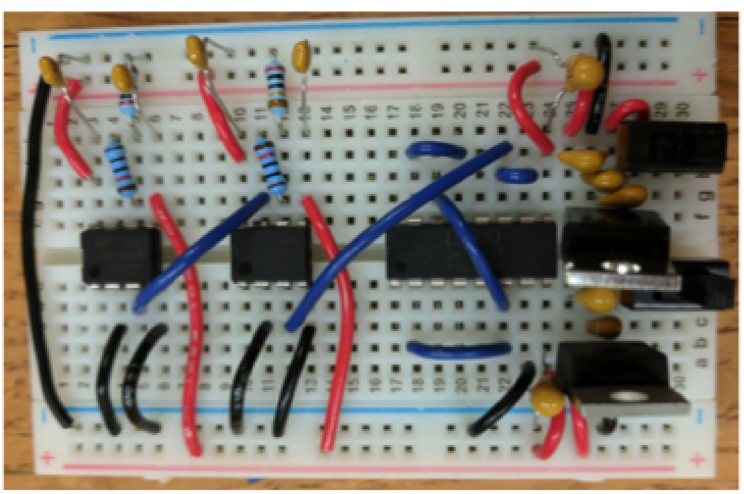


Figure 7. Complete EclipseMob receiver.

The receiver consists of a differential instrumentation amplifier, the large 16 pin DIP shown to the right of the middle in Figure 7. The two smaller 8 pin DIPs shown toward the left in Figure 7 are used to mix the signals down to the passband. The two mixer chips, the 8 pin DIPs, require a local oscillator. The smart phone generates local oscillator frequencies and supplies them to the board.

The other components shown on the receiver board are plus and minus 12 V voltage regulators, their associated capacitors, and resistors and capacitors required by the mixing chips.

4. CONCLUSION

Since the solar eclipse of 1912, many professional and amateur experiments have been conducted to study the effects of solar eclipses on radio wave propagation. Although more has been learned about the ionosphere and radio wave propagation through these studies, the results have been less than optimal for a variety of reasons, primarily equipment and logistics at the time the data was collected and analyzed.

The EclipseMob project intends to overcome challenges related to previous experiments by taking advantage of the large landmass that the 2017 solar eclipse will traverse and combining modern technologies with distributed collection sites.

For more information, please visit EclipseMob.org.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant Nos. 1638685 and 1638697. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

REFERENCES

[1] Eccles, W. H. (1912). The Propagation of Long Electric Waves during the Solar Eclipse. Nature, 89(2217), 191-192.

[2] Eclipse 2015 – RSGB Experiment downloaded from http://forums.thersgb.org/index.php?threads/early-results-from-eclipse-experiments.128/

[3] Chapman, S. (1932) "The Influence of a Solar Eclipse Upon Upper Atmospheric Ionization," MNRAS, March 1932, Vol 92, 413-422

[4] Appleton, E.V. and Chapman, S. (1935) "Report on Ionizaton Changes during a Solar Eclipse," Proc. IRE, June 1935, Vol 23(6) 658-669.

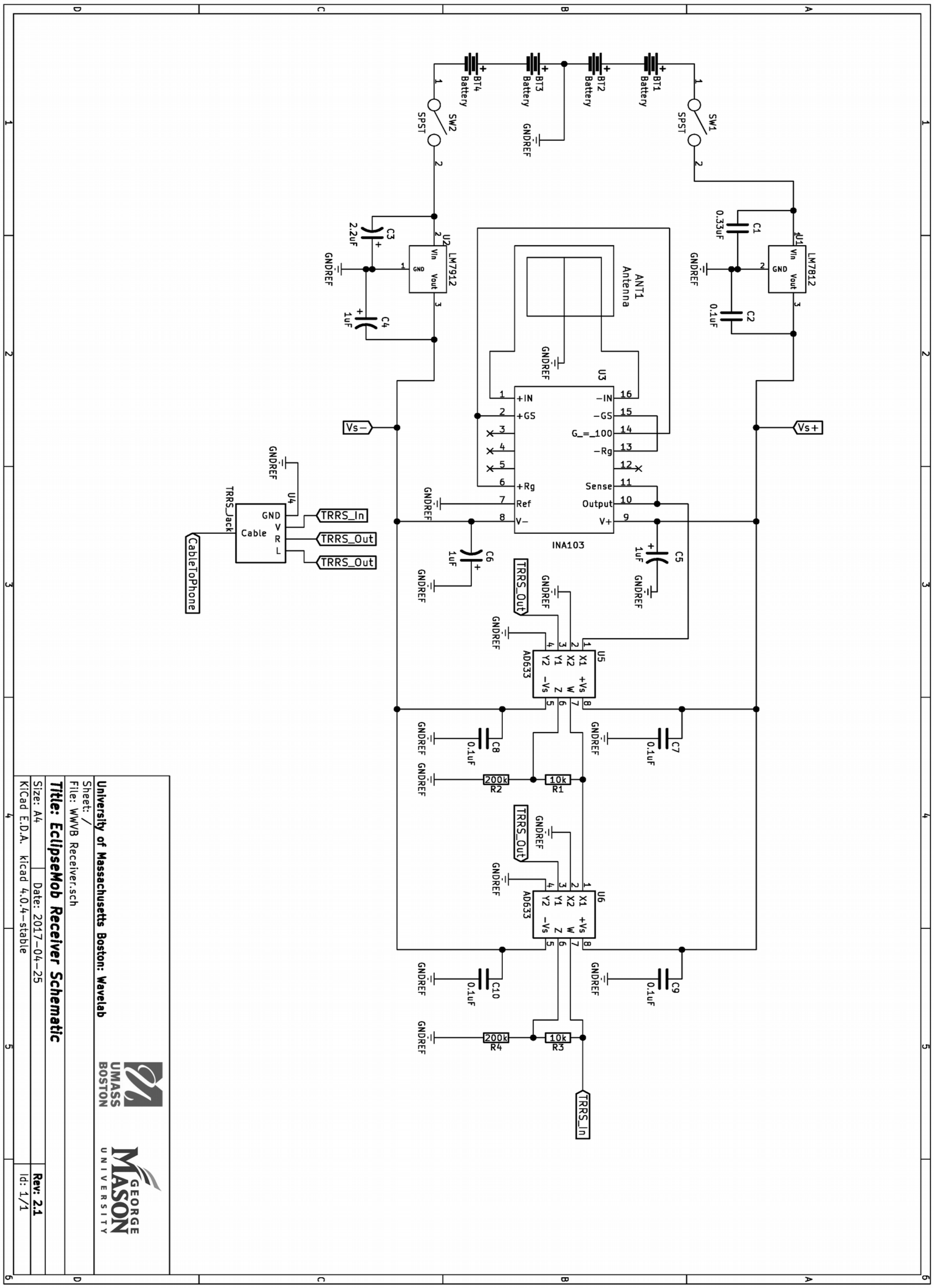
[5] Russel, R. (2017) "Plishner Radio Astronomy and Space Science Center: Total Solar Eclipse Sudden Ionospheric Disturbance (SID) Monitor Signal Predictions Using Sunrise and Sunset Measured Historic Data," Society of Amateur Radio Astronomers 2017 Conference, Green Bank, WV July 23-26, 2017

[6] Hagen, T. (2015) "A Portable, Calibrated VLF Field Strength Measurement Receiver and Loop Antenna," Society of Amateur Radio Astronomers 2015 Western Conference, Stanford University, March 20-22, 2015.

Appendix A. EclipseMob receiver Bill of Materials

part	vendor	price (each)	qty	total price	notes
half-size breadboard	Adafruit	$5.00	1	$5.00	
9V battery connectors	Adafruit	$2.95	4	$11.80	
Wire stripper/cutter	Adafruit	$6.95	1	$6.95	
22AWG wire spool (red)	Adafruit	$2.95	1	$2.95	
22AWG wire spool (black)	Adafruit	$2.95	1	$2.95	
22AWG wire spool (blue)	Adafruit	$2.95	1	$2.95	
TRRS terminal block	Amazon	1.999	1	$2.00	
SPDT slide switch	Amazon	0.479	2	$0.96	
28 AWG magnet wire spool, 8oz	Amazon	$13.92	1	$13.92	
Twist-on wire connectors	Grainger	0.0834	4	$0.33	
circuit enclosure	McMaster Carr	$27.25	1	$27.25	
Cable grommet	McMaster Carr	$0.39	1	$0.39	
Velcro (6")	McMaster Carr	0.5578	1	$0.56	
TRRS cable	Monoprice	$1.99	1	$1.99	
3M Command Cable Clips (8 pack)	Amazon	$3.03	2	$6.06	Umass bought through Office Depot - individuals should use Amazon
11"x8"x4" tote box	Webstaurant Store	$15.49	1	$15.49	
tote lid	Webstaurant Store	$8.49	1	$8.49	optional
INA103KP instrumentation amplifier	Mouser	$10.86	1	$10.86	
AD633 analog multiplier	Mouser	$13.38	2	$26.76	we actually used AD633JNZ, but you can use these (they will be equivalent)
7812 12V positive voltage regulator	Mouser	$0.44	1	$0.44	
7912 12V negative voltage regulator	Mouser	$0.55	1	$0.55	
10 kOhm resistor	Mouser	$0.10	2	$0.20	any vendor is ok
200 kOhm resistor	Mouser	$0.11	2	$0.22	any vendor is ok
1 uF capacitor	Mouser	$0.39	3	$1.17	any vendor is ok
2.2 uF capacitor	Mouser	$0.63	1	$0.63	any vendor is ok
0.22 uF capacitor	Mouser	$0.18	1	$0.18	any vendor is ok
0.1 uF capacitor	Mouser	$0.10	6	$0.60	any vendor is ok

Appendix B. Schematic



Appendix C. Antenna Bill of Materials

Component	Quantity
28 AWG Magnet Wire	~ 800 - 1000 ft
Antenna Winding Form	~ 10 - 12" square
Cord Hooks	8
Sandpaper (fine grit)	1 sheet
Wire Cutter	1
Pen	1
Textbook	2

The sandpaper is used to strip the enamel from the magnet wire. You can also use an Exacto knife or a blob of solder, but in our experience sandpaper works best.