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SIMONE: Building an SID Detector for Space Weather Monitoring

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PH 499 / Honors Research Project

Advisor: Dr. Nazirah Jetha

SIMONE, the Sun and Ionospheric Monitoring Network, began in 2007 in Germany as a student project for the purposes of researching space weather phenomena. Today, the project is supported by the DLR (Deutsches Zentrum für Luft und Raumfahrt), and functions to detect active solar flares by determining the intensity of low frequency radio waves from a low frequency radio beacon, and monitoring how the received signals change over time. Therefore, with little more than a receiver circuit and antenna, it is possible to identify solar flares by simply monitoring the intensity of low frequency radio waves from the ground.

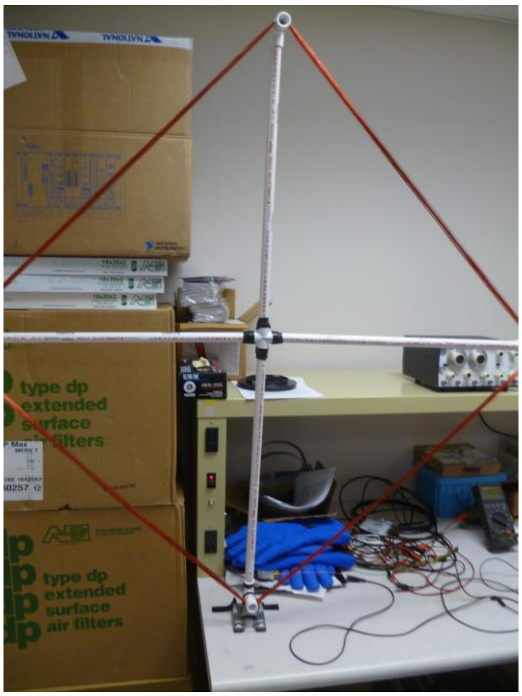
Today, SIMONE continues to grow as more students and scientists build their own receivers and add their data to the expanding network of detectors. Data collected by these receivers is uploaded to web servers via an Internet connection located after the amplifying stage of the receiver. Once this has occurred, the data is now available to the entire SIMONE web-portal to access for cross-referencing and confirmation purposes (*About SIMONE*).

SIMONE is able to probe the environment of the solar surface through an intermediary phenomenon call a sudden ionospheric disturbance, or SID for short. An SID is an immediate jump in the electron density of the ionosphere on the day side of the planet; it is this abrupt plasma disturbance that causes low frequency radio signals to be amplified while high frequency radio signals are stifled. The source of all sudden ionospheric disturbances is appropriately the Sun itself.

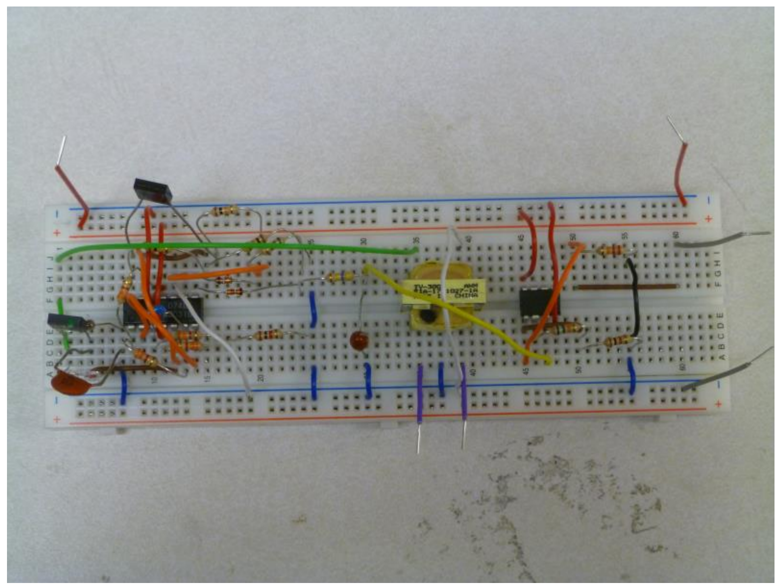
During a solar event like a solar flare or coronal mass ejection, the surface of the Sun erupts and launches a volume of solar material into interplanetary space. In addition to this quantity of solar plasma, the erupting solar flare also emits a volume of high energy X-ray and ultraviolet photons in the direction of the flare's eruption. It is these X-ray and UV photons that cause an SID. After their creation, these photons stream away from the solar flare at the speed of light and arrive at the Earth in approximately 8.3 minutes. Once there, these photons impact the Earth's ionosphere and begin interacting with the native terrestrial ionosphere. The terrestrial ionosphere has a typical electron to neutral atom ratio of about 1 to 10,000. During an SID, the sudden influx of high energy X-ray and UV photons causes massive photo-ionization of the neutral atoms present in the upper atmosphere. These newly separated ions and electrons increase the electron density of the terrestrial ionosphere and are responsible for the alteration in radio signals captured on the planet's surface (Petruzzellis 204).

The recently liberated electrons are the force behind the absorption of shortwave radio signals attempting to propagate through the lower ionosphere. The new electron density boosts the strength of very low frequency (VLF) radio signals, ranging from 3 kHz to 30 kHz, whilst simultaneously silencing shortwave radio signals, ranging from 2 MHz to 30 MHz. It is this sudden spike in VLF intensity that is sought by the SIMONE network of detectors and the SID detector (INAN 448).

The voltage spike indicative of an SID is tracked using a pair of rather simple tools: an induction loop antenna to capture the VLF radio waves and a receiving circuit to filter out noise and other radio signals, giving a clearer voltage readout. The antenna, seen in the picture below, is a 50 turn loop of wire built around a non-conducting, PVC pipe frame. The loop encloses an area of 0.7396 m^2, stands 1.22 m high, and is wrapped by 171.85 m of 24 gauge enameled copper wire. The antenna can be mounted outside, on a roof or in a field away from any unnecessary signal interference, or inside in a higher storey room with walls thin enough to allow the essentially free passage of VLF radio signals. The receiver circuit, also seen in the picture below, is a modified Stokes' Gyrator, a high gain circuit that minimizes signal oscillation (Stokes), and can be assembled from readily available parts. The circuit is comprised of 10 resistors, three potentiometers, five capacitors, four diodes, a 600 Ω matching audio transformer, and two integrated circuits: a Texas Instruments RC4136 Quad Operational Amplifier and a National Semiconductor LM353 Operational Amplifier. The circuit is powered by an external nine volt power source fed directly into the two op-amps. The loop antenna output is fed into the circuit block through the 600 Ω matching audio transformer.



Loop Antenna

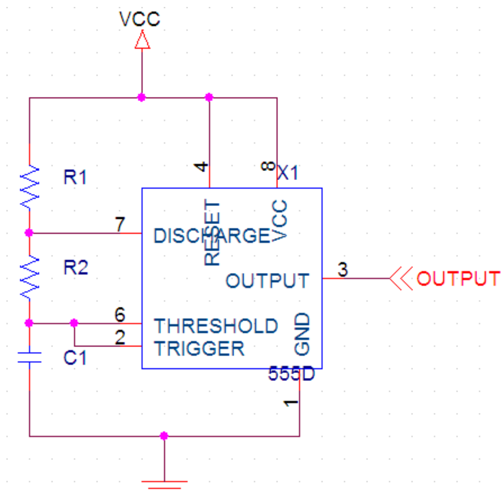


Receiver Circuit

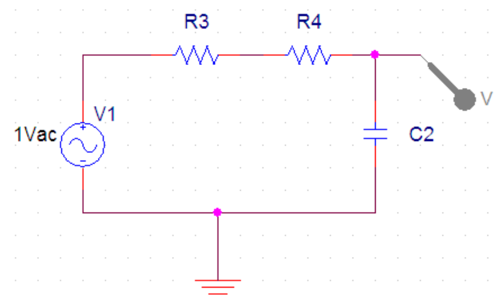
After being captured by the loop antenna, an incoming signal is washed through the 600 Ω transformer before meeting a pair of germanium protection diodes that prevent a destructively high signal from progressing into the integrated circuits. Following the diodes is a pair of capacitors that smooth out the incoming AC signal. It is here that the signal enters the Texas Instruments RC4136 op-amp, and undergoes four stages of amplification: amplification and filtering, tuning, a second amplification, and finally integration. The amplification stages, as their names suggest, serve to amplify the signal through their respective gain functions. The tuning stage serves to boost the gain of the amplification stages by serving as a resonator for the amplifiers optimal frequency. The integrator stage is a resistor-capacitor-op-amp combination that approaches an infinite gain as the frequency of the signal approaches zero, i.e. the integrator serves to provide additional gain to the system if the frequency of the signal is low. Since this is the case in a VLF receiver, the integrator supplies more gain to the signal (Fortney 298). The signal then flows through a pair of silicon diodes, meets a low-pass filter (a special combination of a resistor and capacitor that stifles high frequency signal passage), and enters the second integrated circuit, the National Semiconductor LM353 op-amp. It is here that the signal receives its final amplification before being exported from the system into an analysis program or data cache (Petruzzellis 206)

Before the actual construction of the SID receiver circuit was performed, a circuit analysis program called PSPICE was employed to explore the circuits. PSPICE (Personal Simulation Program with Integrated Circuit Emphasis) is a computer program designed to build and test virtual copies of real circuits without having to assemble any hardware. The program is sophisticated enough to allow variations in component capabilities, noise levels, thermal effects, and other relevant phenomena (Fenical xvii)

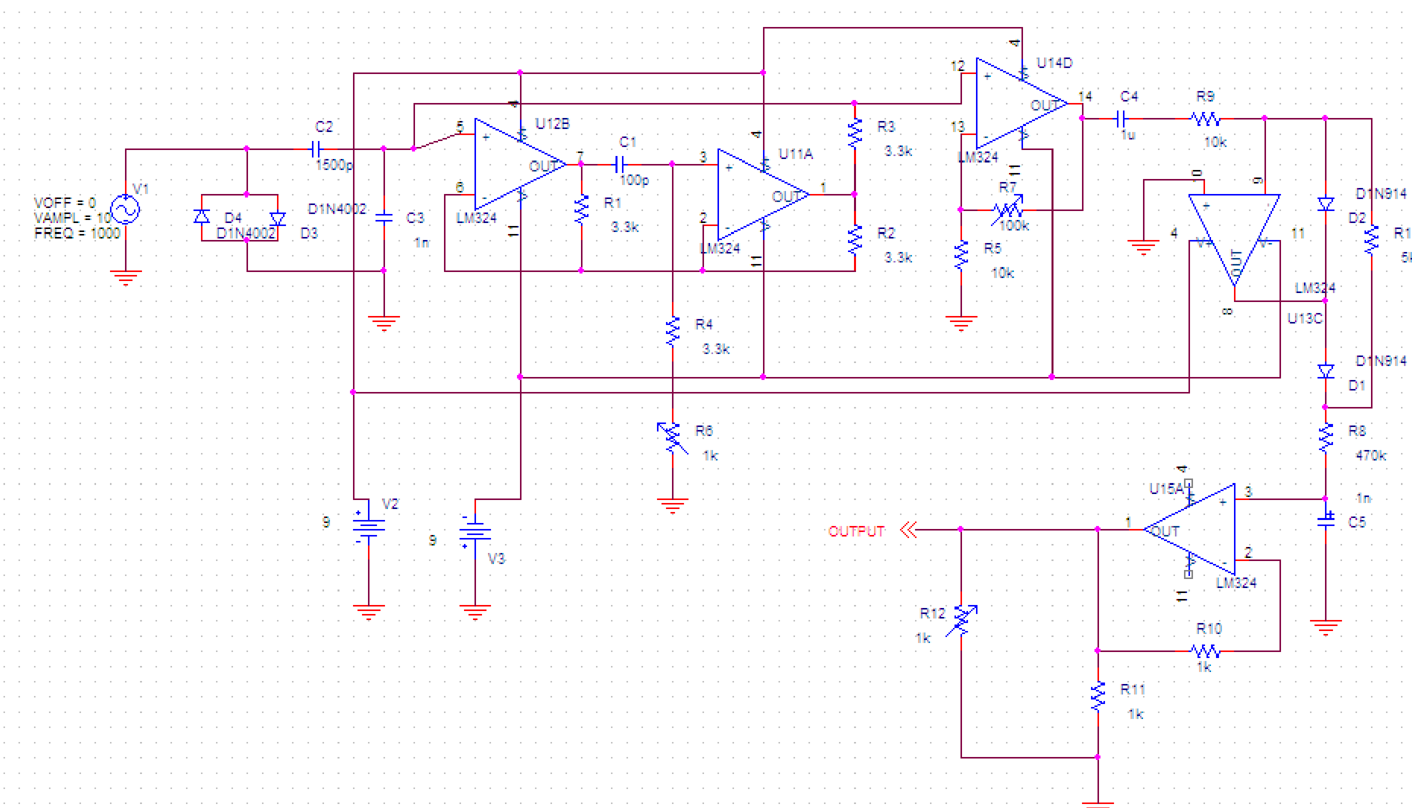
In order to attain a deeper understanding of the electronics skills required in undertaking the SID detector, several lesser, but equally important circuits were virtually built and simulated. Some of the circuits simulated were: an RLC oscillator, a transformer circuit, high-pass and low-pass filters, a 555 astable multivibrator, and the SID receiver circuit. All of the circuits were virtually built, explored, and broken in order to obtain troubleshooting skills for repairing or diagnosing faulty circuit components. Because of the preferential location in which the SID detector would physically be placed, noise levels, component capabilities, and frequency responses were the only parameters seriously tested on the virtual SID receiver circuit. In addition to the virtual experience PSPICE imparted, the junior level electronics course (PH 337) was taken simultaneously during this project, allowing for both virtual and laboratory skills to be learned.



555 Astable Multivibrator

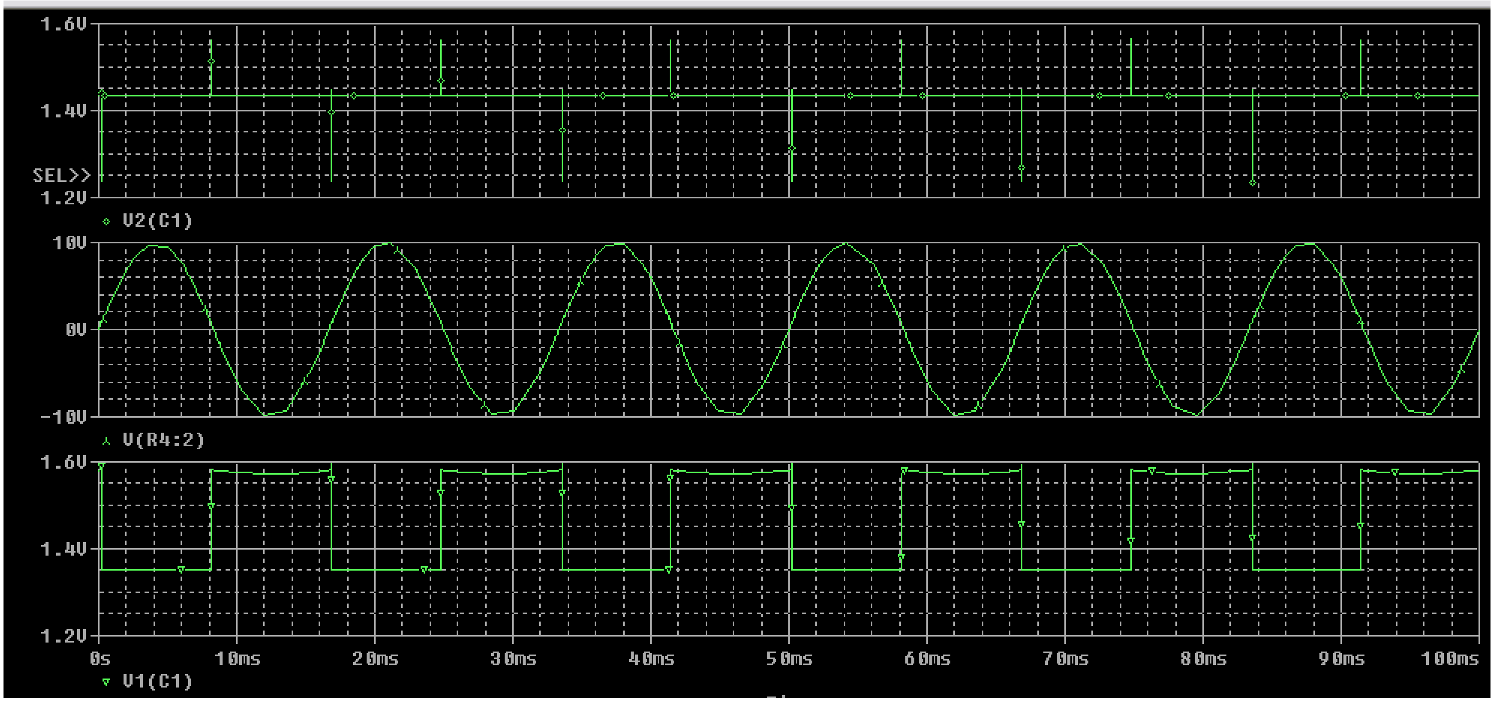


Low Pass Filter

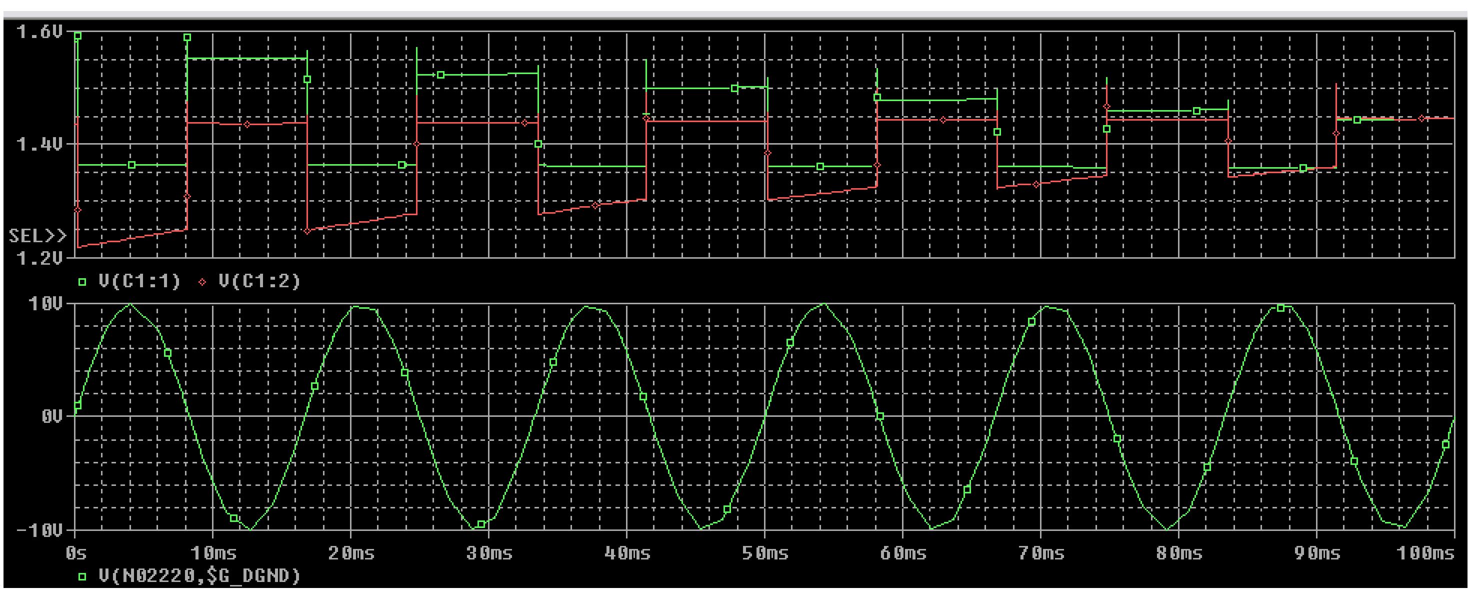


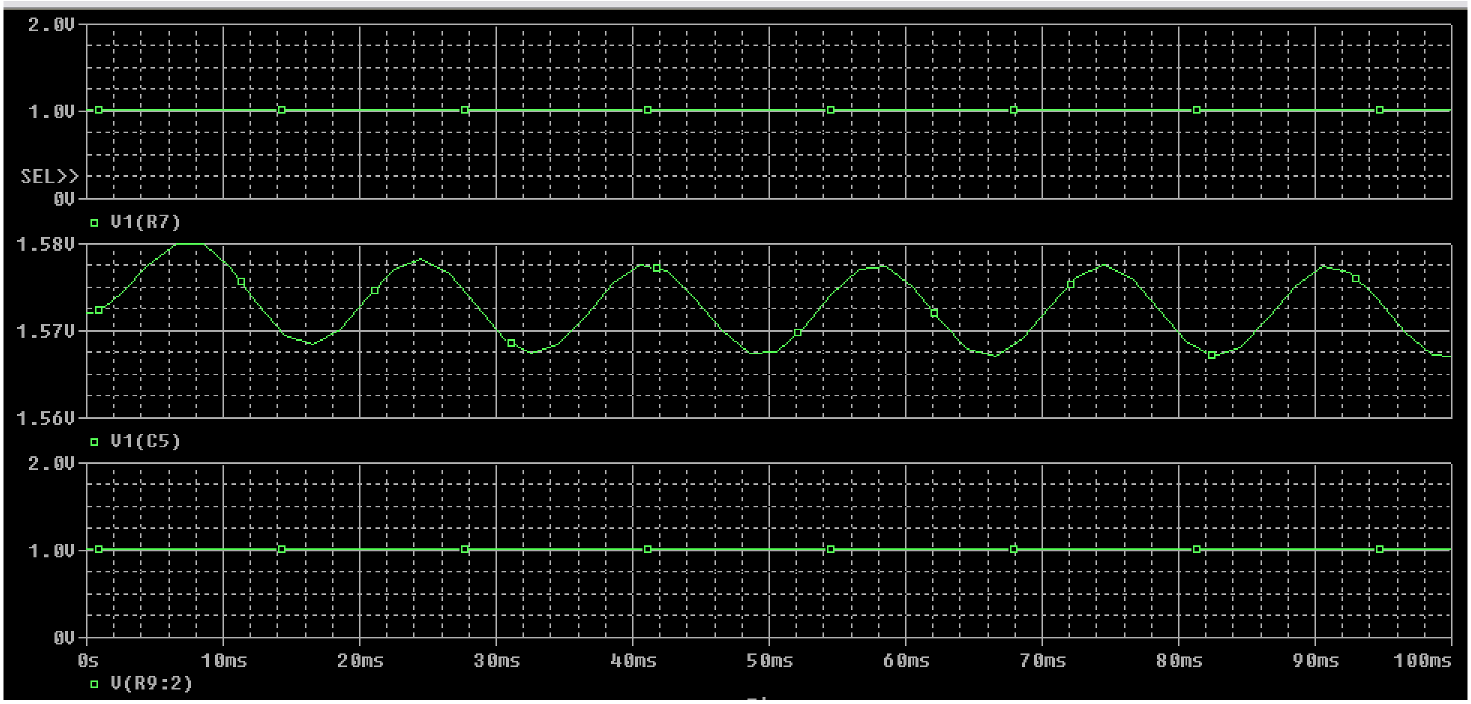
SID Receiver Circuit

Unfortunately, the library of components the PSPICE program contains does not include every integrated circuit ever made, including the integrated circuits used in the construction of the SID detector. As such, suitable substitutions were selected from among the available integrated circuits in the PSPICE library in order to construct a viable simulation of the SID receiver circuit. In order to ensure proper troubleshooting skills were honed during the simulation process, certain circuit elements such as critical capacitors, resistors, and diodes were often virtually simulated to be of an incorrect value. In severe cases of circuit failure, some parts were virtually "destroyed," and treated as such in the programs calculations. A few of these incorrect simulation outputs can be seen below along with their correct output counterparts.

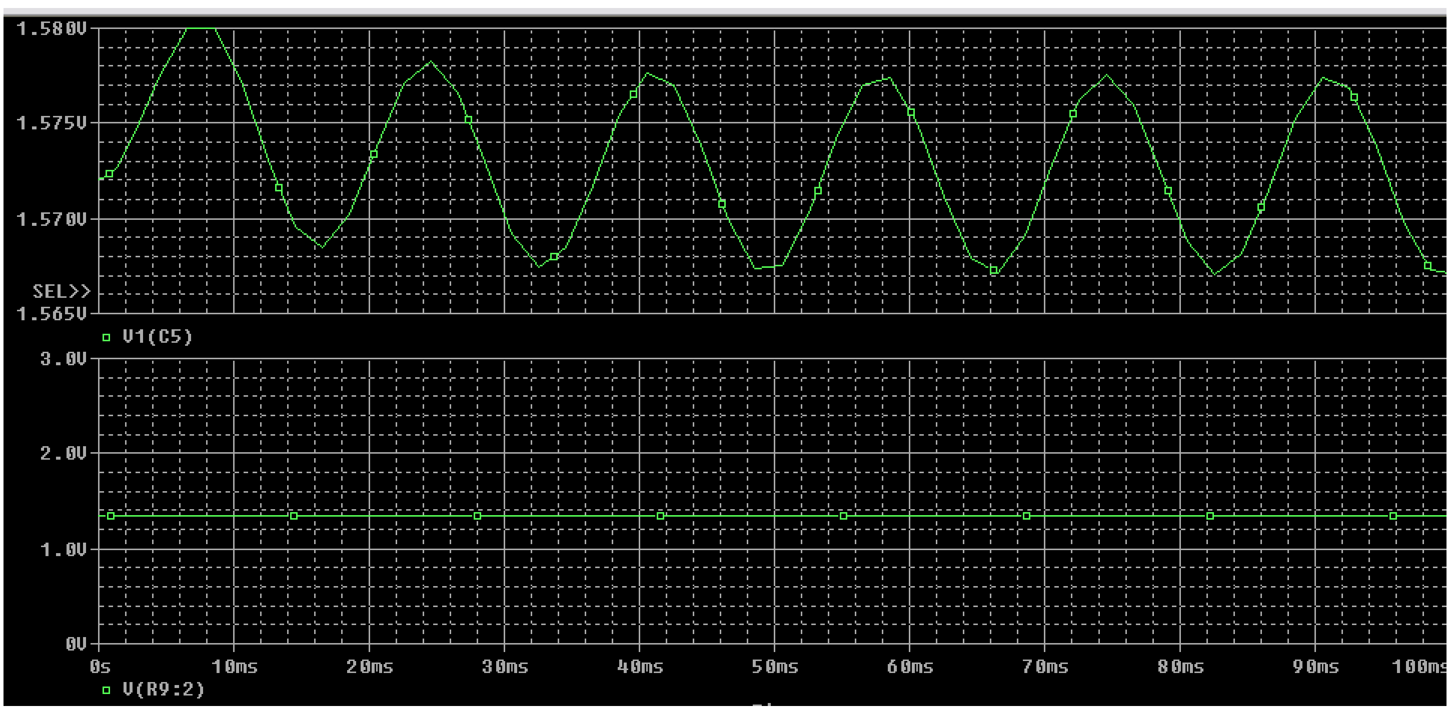


The figure above shows the PSPICE simulation of the voltage across capacitor C1 as a function of time under ideal conditions. The figure below is the same simulation, but capacitor C1 has been replaced with another capacitor with 1000 times more capacitive ability. This particular switch was performed because the numbering system on capacitors is incredibly small, and accidentally installing a capacitor with 1000 times the storage capability is a completely plausible construction error.



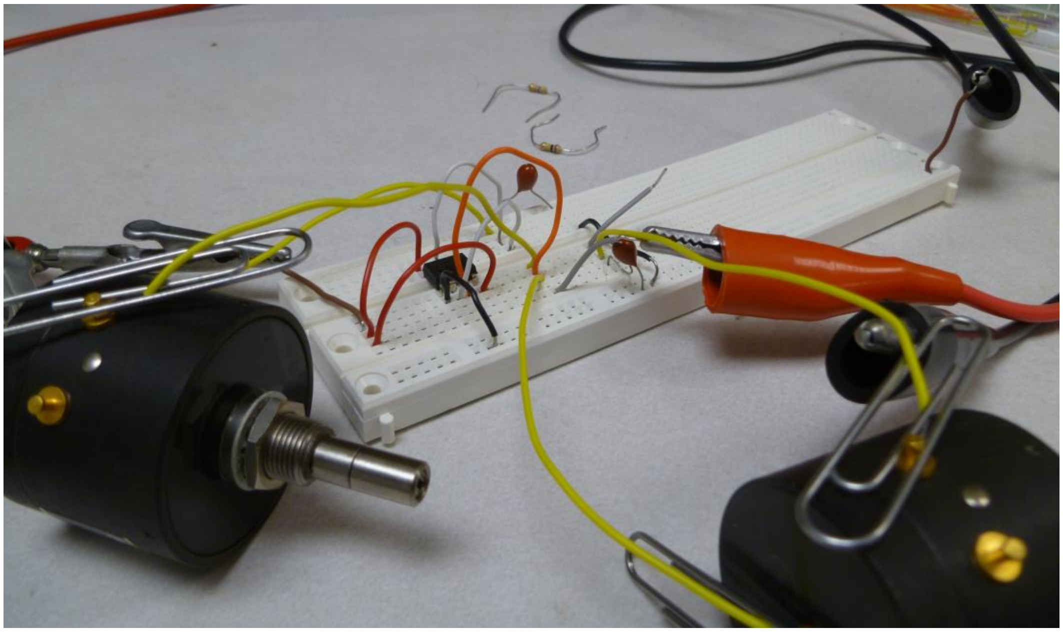


The figure above is the ideal output of the National Semicondutor LM353 op-amp.

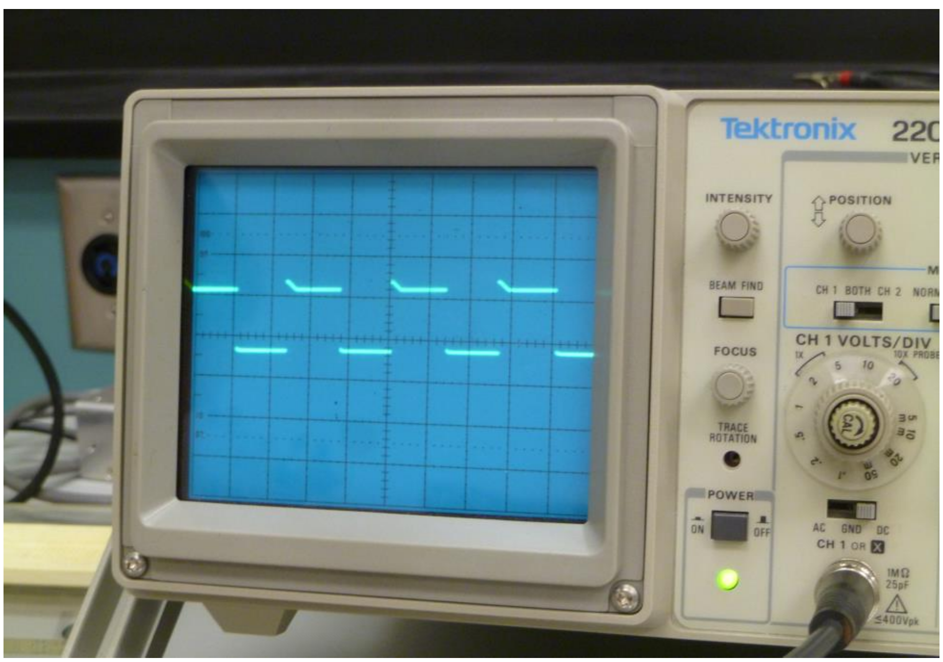


The figure above is the output from the LM353 when the resistor grounding the op-amp is increased by a factor of one million.

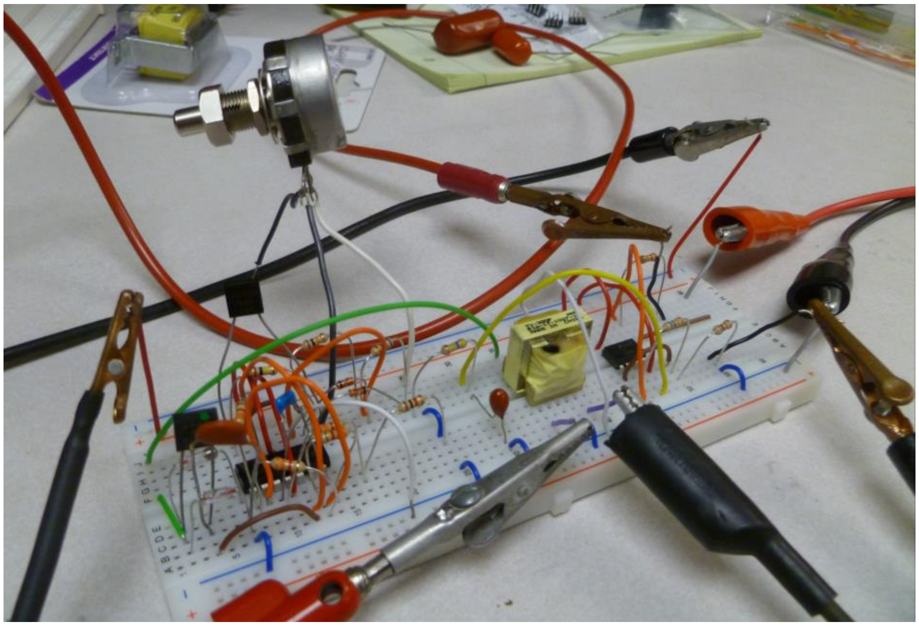
With the PSPICE simulations complete, the time came to physically build some of the virtual circuits. All of the circuits were built from readily available components, and few had to be actively sought out and purchased. Two circuits, the 555 astable multivibrator and the SID receiver are seen in the photographs below.



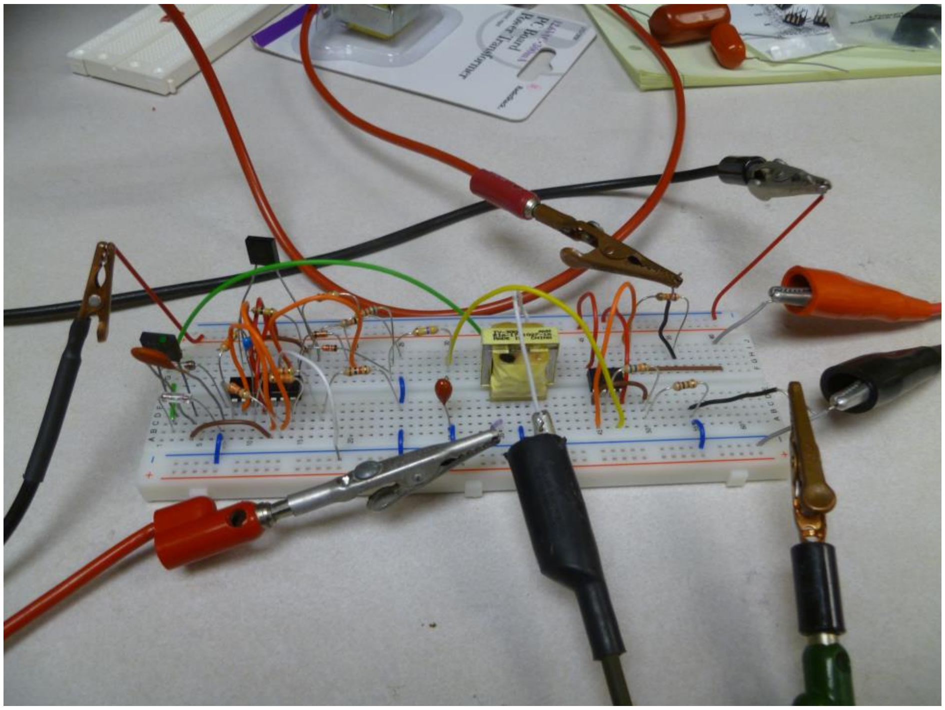
555 Astable Multivibrator with component potentiometers



555 Astable Multivibrator Output

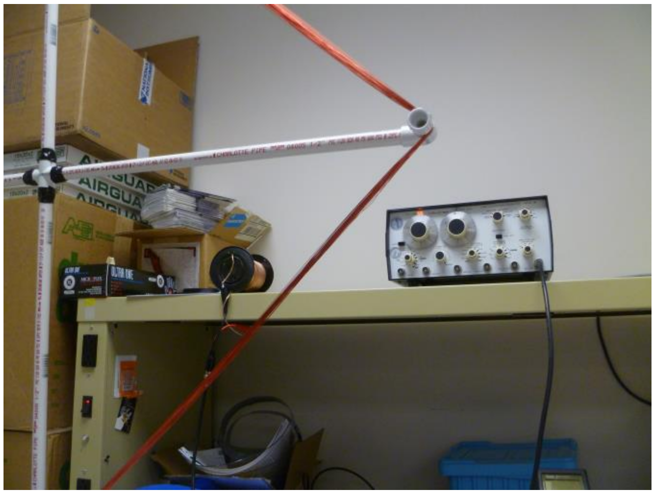


SID Receiver Undergoing Testing / Calibration

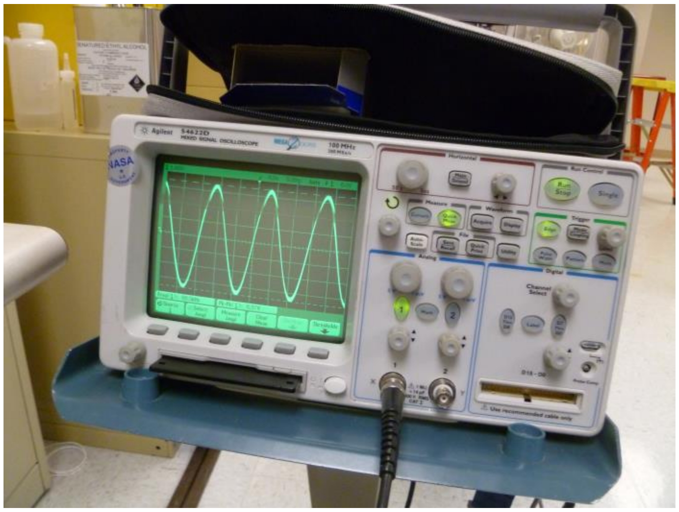


SID Receiver Undergoing Testing / Calibration

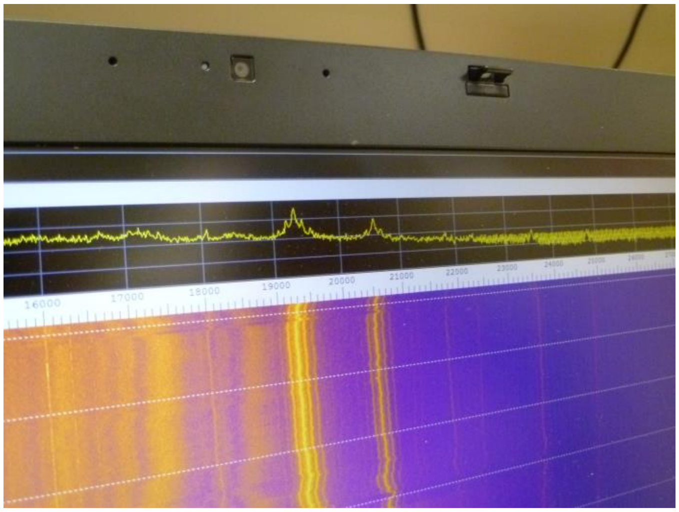
Once the receiver circuit was completed, the loop antenna needed to be tested to determine its ideal frequency response and its sensitivity to low frequency radio signals. To do this, a frequency generator was connected to a spool of copper wire which acted as a broadcast source for the generator. The spool was then placed next to the loop antenna so a flux could be measured and the frequency was modulated to determine the location of the greatest signal response. Additionally, the antenna was connected to both an oscilloscope and a spectrum analysis program on a laptop computer to ascertain its ideal frequency response.



Frequency Generator with Antenna

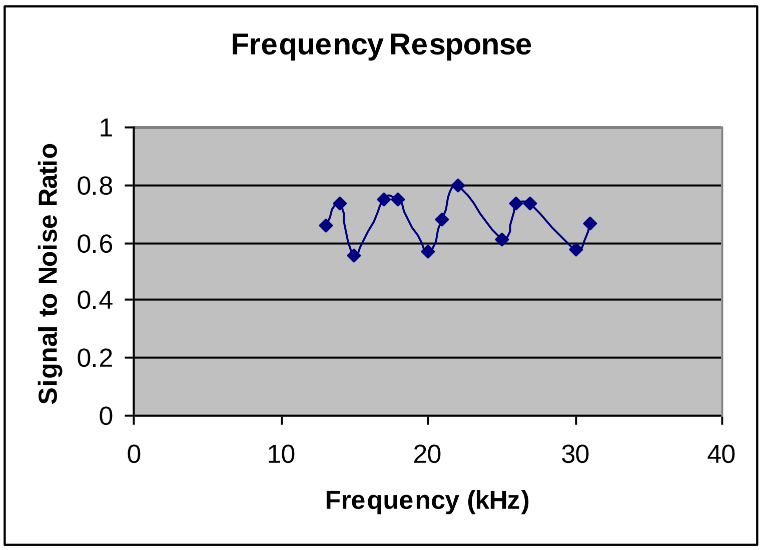


Oscilloscope Readout

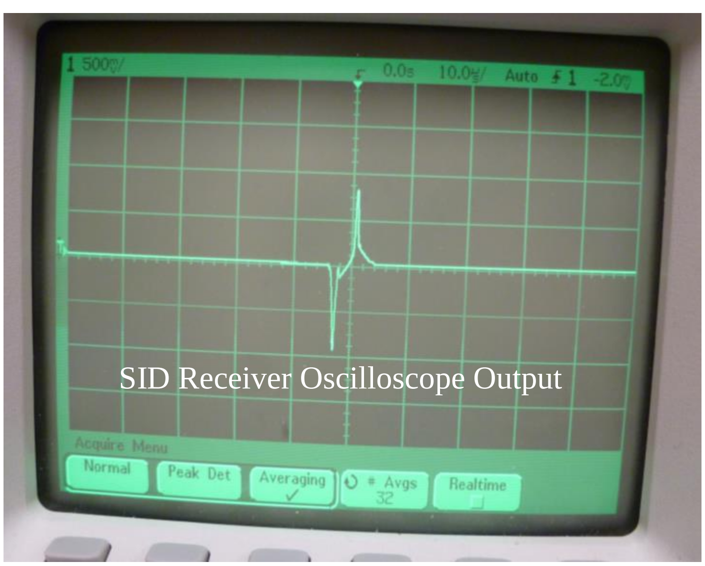


Spectrum Analyzer Readout

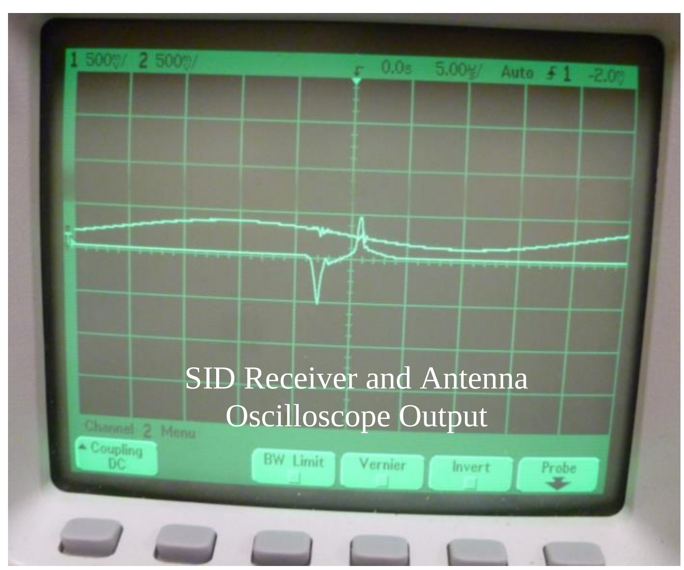
Following the calibration, it was found that the loop antenna's ideal frequency response was somewhat less than expected. The ideal response frequency was expected to be 24 kHz, the frequency of the United States Navy Transmitter located in Culter, Maine, and the original VLF beacon to which the SID receiver was to be tuned. After calibration, it was discovered that this antenna's ideal response was actually 22.03 kHz, and that the frequency response curve for the antenna fell off on both sides of the 22.03 kHz mark.



Following the calibration of the antenna, the entire receiver apparatus was compiled. The antenna was plugged into the circuit's transformer and the entire setup was plugged into an oscilloscope and activated.



SID Receiver Oscilloscope Output



SID Receiver and Antenna Oscilloscope Output

It was discovered from this output that the frequency generator used to generate the VLF testing frequency was not entirely without fault. The generator produced a waveform composed of many different amplitudes, but all with approximately the same frequency. At first, this was a problem; how could the viability of the receiver be found with a faulty generator? However, upon closer examination of the output, it was discovered that the receiver did work as it was supposed to. Closer inspection of the right oscilloscope output shows a small but distinct variation in the frequency generator's output amplitude (top wave) approximately 2.5 μs to the left of zero. This sudden amplitude modulation corresponds precisely with a 500 millivolt voltage response from the SID receiver (bottom wave). This minute detail shows that the SID receiver does indeed pick up sudden amplitude changes in VLF signals and amplifies them as it was designed to do.

Unfortunately, this was the last battery of calibrations that could be performed on the SID receiver. Weather restrictions and equipment problems prevented the SID receiver from undergoing its final phase of testing, namely, to be taken outside and focused on a VLF beacon and waiting for an actual solar flare to occur. However, this problem aside, the SID receiver does function as it is designed to do, and will be fully operational in the future.

Future operation of the SID receiver at the National Space Science and Technology Center is planned to commence. After the final external calibration, both the antenna and receiver circuit are to be weatherproofed and mounted on the roof of the building. A portable data recording device will be integrated into the receiver circuit and allow for SID data to be monitored and recorded. Whatever detections or findings come out of the SID receiver will be correlated with other members of the SIMONE receiver network and disseminated by the Center for Space Plasma and Aeronomic Research.

Works Cited

About SIMONE. DLR. Web. 19 Nov. 2011. <http://swaciwebdevelop.dlr.de/about-simone/?L=1>.

Fenical, L. H. "What Is Spice? What Is Spice Used For?" Introduction. *PSpice:A Tutorial*. Englewood Cliffs, NJ: Prentice Hall, 1992. Xvii-viii. Print.

Fortney, Lloyd R. "Chapter 8: Operational Amplifiers." *Principles of Electronics, Analog & Digital*. New York: Oxford UP, 1987. 296-99. Print.

Inan, Umran S., and Aziz S. Inan. "Chapter 6 / Field-Matter Interactions and Elementary Antennas." *Electromagnetic Waves*. Upper Saddle River, NJ: Prentice Hall, 2000. 414-53. Print.

Petruzzellis, Thomas. "Chapter 19: Sudden Ionospheric Disturbance (SID) Receiver." *22 Radio Receiver Projects for the Evil Genius*. New York [etc.: McGraw-Hill, 2008. 203-11. Print.

Stokes, Sr., Arthur J. *Gyrator II - An Improved Gyrator Tuned VLF Receiver*. *Http://www.aavso.org/improved-gyrator-tuned-vlf-receiver*. American Association of Variable Star Observers. Web. 20 Nov. 2011. <http://www.aavso.org/improved-gyrator-tuned-vlf-receiver>.