

## Introduction to the Grape 1.12 PSWS Project

The ionosphere, an electrically conducting region surrounding the earth, is responsible for long-distance propagation of radio waves, generally in the high frequency spectrum, 3-30 MHz. Because of the ability to reflect radio waves back to earth at long distances, it is essential to a lot of commercial, government, and amateur communications. As early as 1839, the German mathematician and physicist Carl Friedrich Gauss postulated that an electrically conducting region of the atmosphere could account for observed variations of Earth's magnetic field. Sixty years later Marconi (probably unknowingly) used the ionosphere to send a radio signal across the Atlantic. Amateur radio operators are said to have discovered ionospheric transmission of radio signals in 1923.<sup>i</sup> A century later we have a better understanding of how the ionosphere works, but there are still gaps in our understanding. One of the objects of the HamSCI<sup>ii</sup> organization is to advance understanding of the ionosphere, using citizen scientists, in this case hams and other short wave enthusiasts, to study the ionosphere. You can be a part of this study by building and operating a low-cost, simple receive station. Read on to learn what to expect should you decide to participate.

### What You Will Need, What To Do With It

You will need to assemble a special-purpose receiving system which measures the Doppler shift of a standard frequency stations such as WWV/H or CHU. The Grape system collects data and sends it automatically to a data collection server. The receiving system consists of mostly purchased items but also include a special-purpose down-converter and amplifier called the Grape receiver, currently on version 1.12. This page tells you how to assemble the Grape v1.12 receiver and what else you need to assemble the complete system.

The Grape v1.12 is a very simple heterodyne receiver, as illustrated in the block diagram below. The GPSDO signal acts as the local oscillator, whose signal, set to 1 kHz below the carrier frequency of interest, is mixed with the filtered input signal. The output of this operation is an intermediate frequency at the difference frequency of 1.000 kHz. This is the signal that is used to measure the Doppler shift of the carrier frequency.

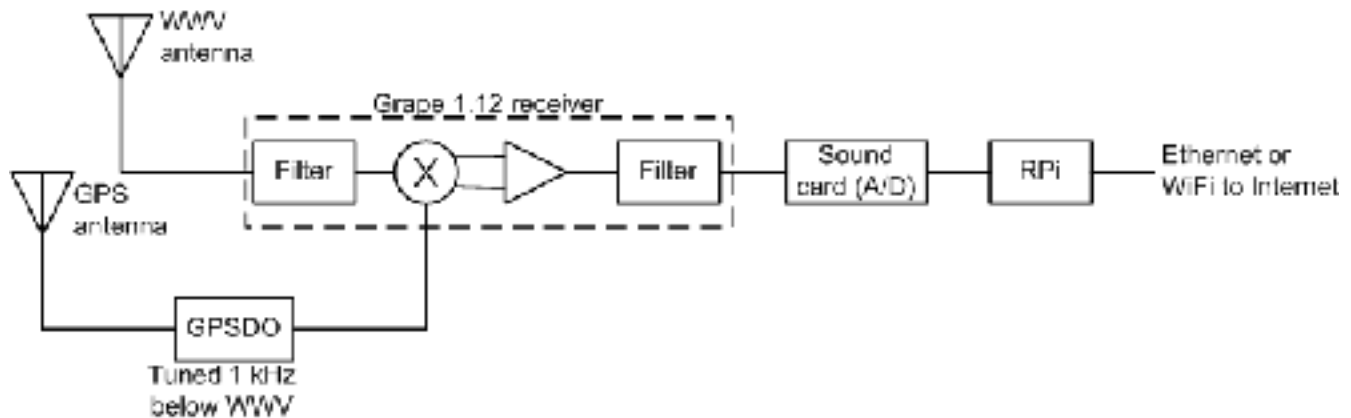
In order to provide the best data for researchers, you will should keep the equipment running 24/7. Some folks do take things down if they need to use, say, the antenna, for other ham activity. Gaps in the data are to be expected. The best and more useful results will be obtained if Grapes are kept on the air as much as possible. **Note: Always use best practices when it comes to safety**, especially if you are in an area prone to lightning storms. Some Grape sites use indoor antennas to mitigate the risk from lightning. Do not let the desire to record 24/7 override the need to 'pull the plug' (especially the antenna connections) if you feel lightning damage is a possibility.

## Components:

1. The Grape 1.12 receiver, which you build from the information provided here. It's very simple, but remember, it is a special-purpose instrument, so you're not going to be able to use it for a lot except the HamSCI experiment.
2. A Leo Bodnar Mini Precision GPS Reference Clock, which comes with a GPS antenna.
3. A Raspberry Pi Model 3 or 4 computer, with free software available on the HamSCI website.
4. A miniature sound card to get analog audio from the Grape into the Raspberry Pi.
5. An antenna for receiving WWV or CHU on the frequency you will use (your choice, but 10 MHz is common). The writer uses an MFJ receive-only loop, but other antennas work fine. A number of folks use dipoles or long wire antennas.
6. Power supply for the Raspberry Pi (it should be RF-quiet, capable of supplying about 3 amps)
7. Cables to hook it all up.

Except for the Grape receiver (which you build), everything is available from Amazon as well as from other sources – your choice. Parts for building the Grape are also available from the usual sources (Mouser, DigiKey etc.), except for the printed circuit board, which is available for only a few dollars from OshPark. Detailed parts info is available on the [hamsci.org/grape1](http://hamsci.org/grape1) web page.. Let's take a look at what it is that we're doing, then we'll talk about building the Grape receiver.

## How it Works

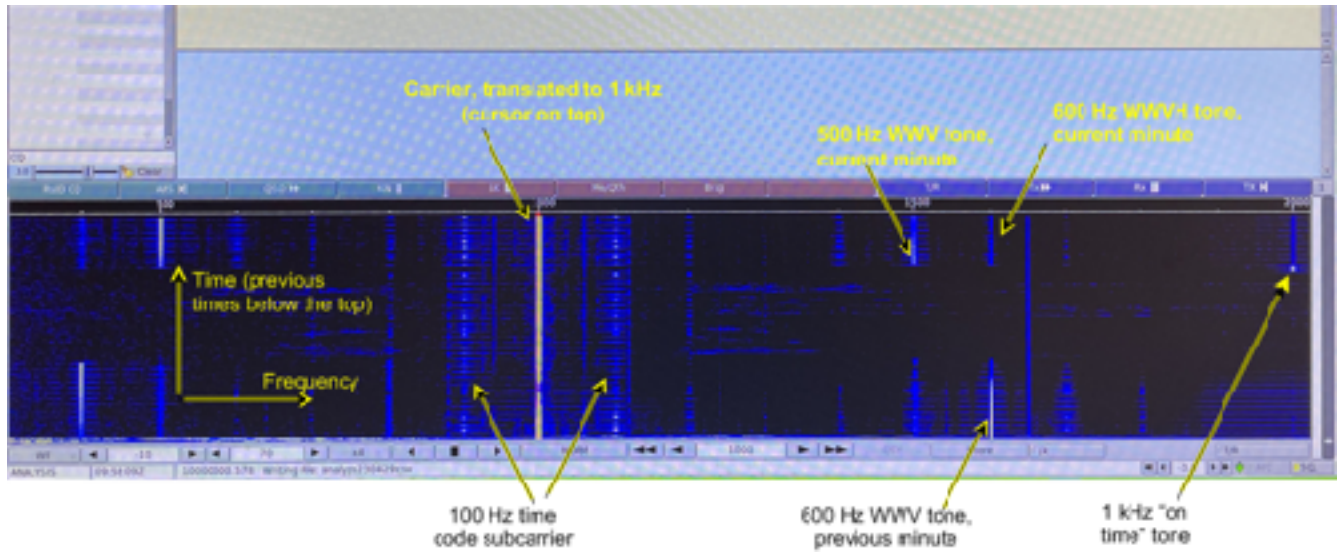


This figure is a block diagram of Grape 1.12 system. A WWV (or other frequency standard station such as CHU) antenna feeds bandpass filtering on the Grape receiver. A mixer converts the carrier to 1 kHz using the GPS disciplined oscillator (GPSDO), tuned 1 kHz below the selected carrier, as a local oscillator. The output of the mixer is thus a 1 kHz tone plus other components of the WWV receiver output. This is converted to a digital signal in the sound card and fed to the Raspberry Pi computer, which is running a Grape-specific version of the fldigi program (popular for ham radio digital communications). It is running in the WWV mode, selected within the software.

The RPi monitors the amplitude and frequency of the WWV carrier converted to 1 kHz, on a second-by-second basis. The frequency can vary by sometimes more than 1 Hz due to Doppler effect as the

ionosphere rises and falls. This information is automatically transmitted each night to a server that stores the information and makes it available for research.

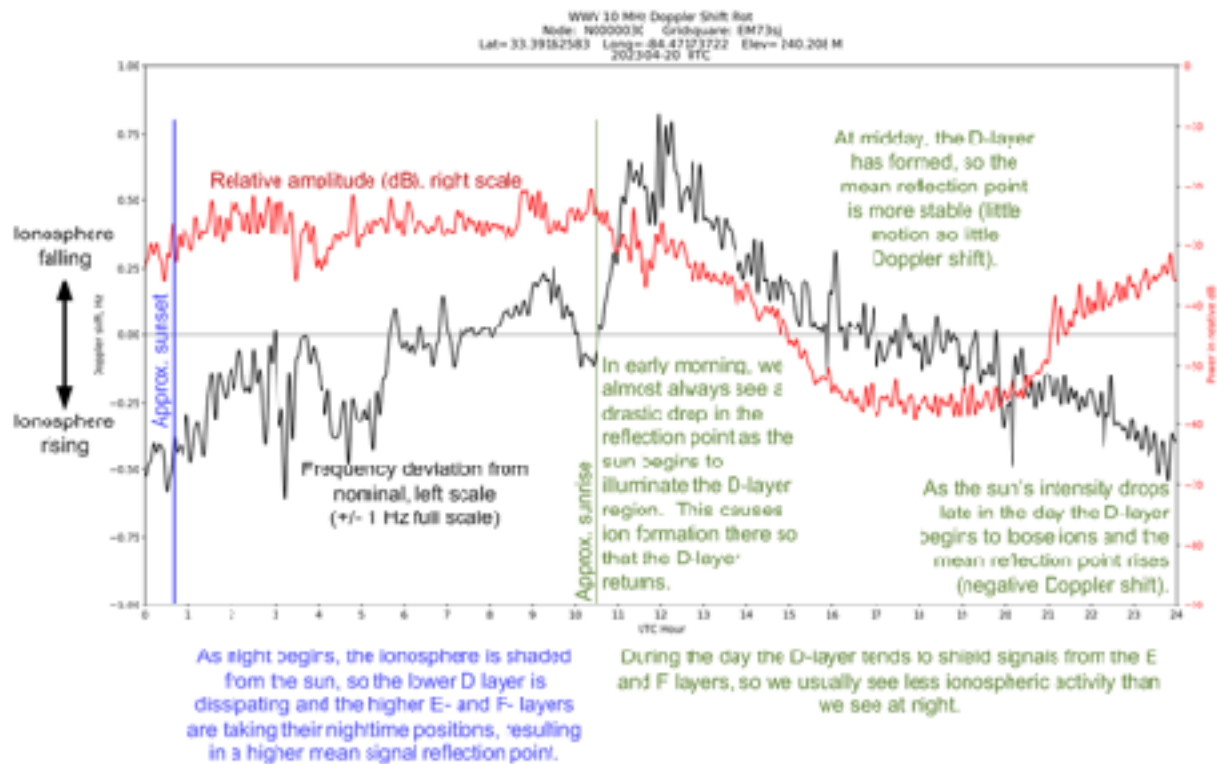
### The Received Signal



This screenshot illustrates a typical waterfall display taken from the screen display of the RPi. The top part of the screen has been cropped out to save space. Recall that in a waterfall display, frequency is plotted horizontally and time vertically, with the current time at the top of the waterfall and previous times below. The amplitude of a signal is represented by color and intensity of the display. You can see the WWV carrier translated to 1 kHz a bit left of the center of the display. This is the signal that the software will be looking at to get amplitude and frequency information. Appearing 100 Hz away on either side is the time code carrier.

During most minutes of each hour WWV and WWVH transmit alternating 500 and 600 Hz tones, with alternate tones on each of the two stations. Both stations were being received, with WWV being stronger, when this picture was taken. Both tones can be seen in the waterfall. You can also see the 1 kHz tone burst transmitted to mark the start of every minute. Other tones are intermodulation products of the identified tones or are unrelated to the WWV/H transmissions.

## A Quiet Day on the Sun



The above illustrates the result of one day's measurements taken by a Grape receiver located a little south of Atlanta, GA. Ignore the blue and green on the figure for a moment while we explain the graph. The horizontal line represents one UTC day. The right, red, vertical scale represents the relative strength of WWV's signal at the received location stated in decibels with an arbitrary and meaningless reference level. Thus, the red line shows the changing strength of the signal.

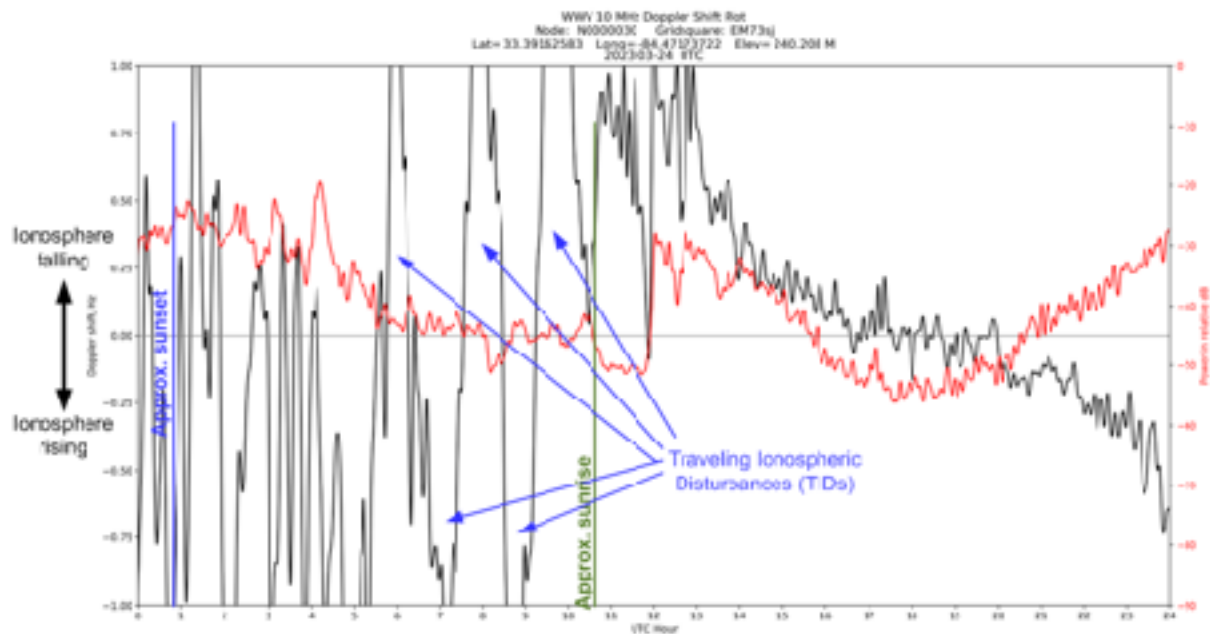
The black line shows Doppler shift in the frequency of WWV's 10 MHz signal and is measured on the left scale, which extends to  $\pm 1$  Hz. When the ionosphere is rising the path from WWV to the receiver is lengthening, so Doppler shift is negative. When the ionosphere is falling the path is getting shorter so the Doppler shift is positive. Remember that the black line is showing the *motion* of the ionosphere, and not an absolute position.

We should probably be talking about the day/night conditions at the mean point between the transmitter and receiver, and not the conditions at the receiver, since that is the most likely occurrence of reflection from the ionosphere. In this case, the day and night lines should be shifted about one hour to the left of where they are shown, but showing them at the receive location doesn't introduce much error. Night-fall occurs at the extreme left of the graph, represented by the blue vertical line. Daybreak is approximately at the time of the green vertical line. A crude explanation of what is happening in the ionosphere at night is shown below the nighttime portion of the graph. Approximate explanations of what is happening during the day are shown in green in the daylight section.

While we should probably see more ionospheric activity on a disturbed sun day in the daylight side of the graph, we usually see more activity at night. The reason is that during the day the D-layer shields us from seeing a lot of the ionospheric activity. Being formed lower in the (thin) atmosphere, D-layer ions are most plentiful and close together, so it takes a lot more solar energy to effect change in this layer. On very disturbed days, though, we sometimes see a good bit of activity during the day.

### A Very Disturbed Sun

Forecasters did not see this one coming. On March 23-24, auroras spread into the United States as far south as New Mexico during a severe (category [G4](#)) geomagnetic storm - the most intense in nearly 6 years. The cause of the storm is still unclear; it may have been the ripple effect of a near-miss CME (Coronal Mass Ejection) on March 23rd.<sup>iii</sup> The ionosphere noticed the storm. When the HamSCI Grape team looked at the data from this day, they also noticed.



Note the considerable number of times that the ionosphere was either rising or falling at a rate such that the Doppler shift exceeded 1 Hz (the actual data file keeps valid data for very high values of Doppler shift; it is just the graphing program that exceeded its range). Note these and all other times at which the graph rapidly deviates from what it would have been on a quiet day. We call these *traveling ionospheric disturbances* (TIDs). TIDs have been known for some time but little is understood about them, and this is one of the phenomena that HamSCI is studying. What researchers need now to study such phenomena scientists need much more data, and that is where HamSCI comes in.

## Assembling your Own Grape 1.12

The Grape receiver, once built, can be configured to receive one of four WWV frequencies, 2.5, 5, 10 or 15 MHz. Only one frequency can be monitored at a time. Those who have trouble receiving WWV or WWVH may choose to receive one of the CHU frequencies (3.33, 7.85, or 14.67 MHz). You may have to experiment a bit to find the configuration best suited to the CHU frequency of choice (ie use the 15 MHz configuration for 14.67 MHz, and go back and forth between the 5 and 10 MHz configuration to see which receives best).

**In order to build the receiver circuit board, you'll need to order from Digikey or other sources and then assemble the circuit board using surface mount components and techniques.**

In order to avoid duplication of information, the following is available on the [hamsci.org/grape1](https://hamsci.org/grape1) web page:

1. Schematic of the Grape 1.12 circuit board
2. Bill of Material (parts list) - Grape 1.12 circuit board
3. Components list - To complete the Grape 1.12 system
4. Instructions for obtaining the Raspberry Pi software image
5. Instructions for obtaining a node number and for setting up data uploads

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<sup>i</sup> <https://en.wikipedia.org/wiki/Ionosphere>

<sup>ii</sup> <https://hamsci.org/>

<sup>iii</sup> <https://spaceweather.com/archive.php?view=1&day=24&month=03&year=2023>