Autonomous Platform for Distributed Ionospheric Studies and Citizen Science Initiatives

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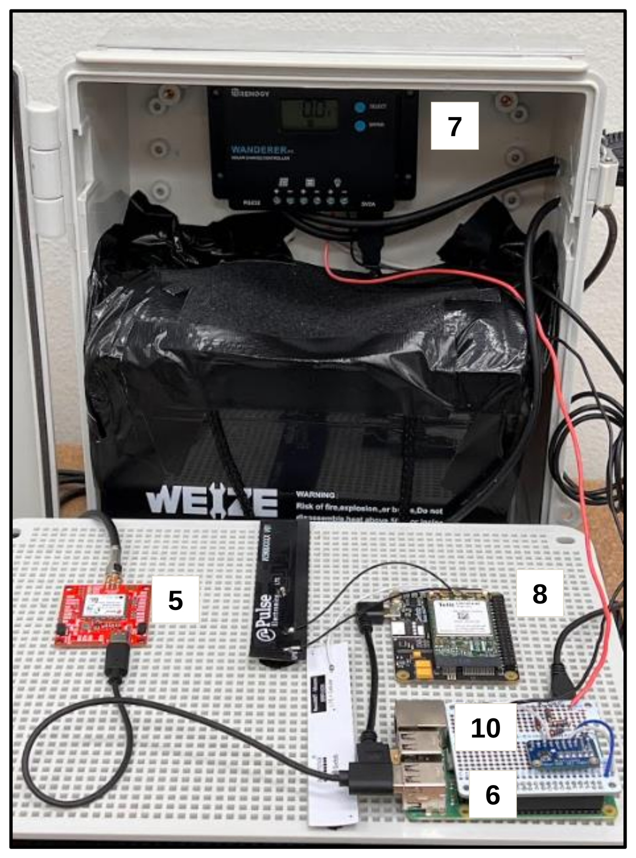
1. MOTIVATION

- ScintPi 3.0 is a low-cost multi-constellation, dual-frequency ionospheric scintillation and total electron content (TEC) monitor costing a fraction of the amount of commercial ionospheric monitors [1].
- Because of its low cost, ScintPi 3.0 presents many opportunities for studies that require distributed observations and for educational or citizen science initiatives.
- A difficulty for deployment in certain scenarios is the sensor's need for an external power source and internet connection.

2. GOALS

For Spring 2022, we defined a student-led project with the following goals for ScintPi 3.0:

1. The ability to run uninterrupted without the need of external power provided by a user/host.
2. The ability to be monitored and accessed without the need of internet provided by a user/host..
3. To supplement the curriculum of physics undergraduate students with a project that would provide transferable skills while increasing literacy about space sciences.



Components

1) Antenna
2) 75 W Solar panel
3) Aluminum mast
4) Junction box
5) 10 Hz receiver
6) ScintPi 3.0
7) Charge Controller
8) 4G/LTE cellular modem
9) 55 Ah 12V battery
10) ADC w/ voltage divider

Cost without ScintPi: ~$700.00

3. DESIGN

SOLAR POWER + BATTERY

- The system consumes about 3.0 W, or 72 Wh max per day.
- Taking the lowest monthly average for Texas of 4 peak sun hours [2] and 50% efficiency for factors such as positioning and variations in weather conditions, a solar panel would need to provide 36 W as shown in **Eq. 1**:

$$(0.5)\times P_{Solar}(W)\times 4\,\frac{hours}{day} = 72\,\frac{Wh}{day} \;\Rightarrow\; P_{Solar} = 36\,W \qquad (1)$$

- Taking a conservative and cost-conscious approach, we chose to use a 75W panel (US$73.00) instead of a 35W panel (~$50.00).

BATTERY ONLY

- In some situations, observations may only be required for a relatively short period of time (e.g., observation campaigns of a few days). For that scenario, a battery-only design was also investigated.
- For this design, we took into consideration that the operational Depth of Discharge (DoD) of 80% increases the lifespan of our battery by ~50% compared to a DoD approaching 100%. For a nominal voltage of 12V, and an active period of 7 days, we chose a 55 Ah battery as quantified by **Eq. 2**:

$$(0.8)\times C_{Battery}(Ah)\times 12V = 72\,\frac{Wh}{day}\times 7\,days \;\Rightarrow\; C_{Battery}\sim 55\,Ah \qquad (2)$$

- To monitor the battery level, we use an analog-to-digital converter (ADC) to log the battery's terminal voltage on the ScintPi 3.0.

INTERNET CONNECTIVTY

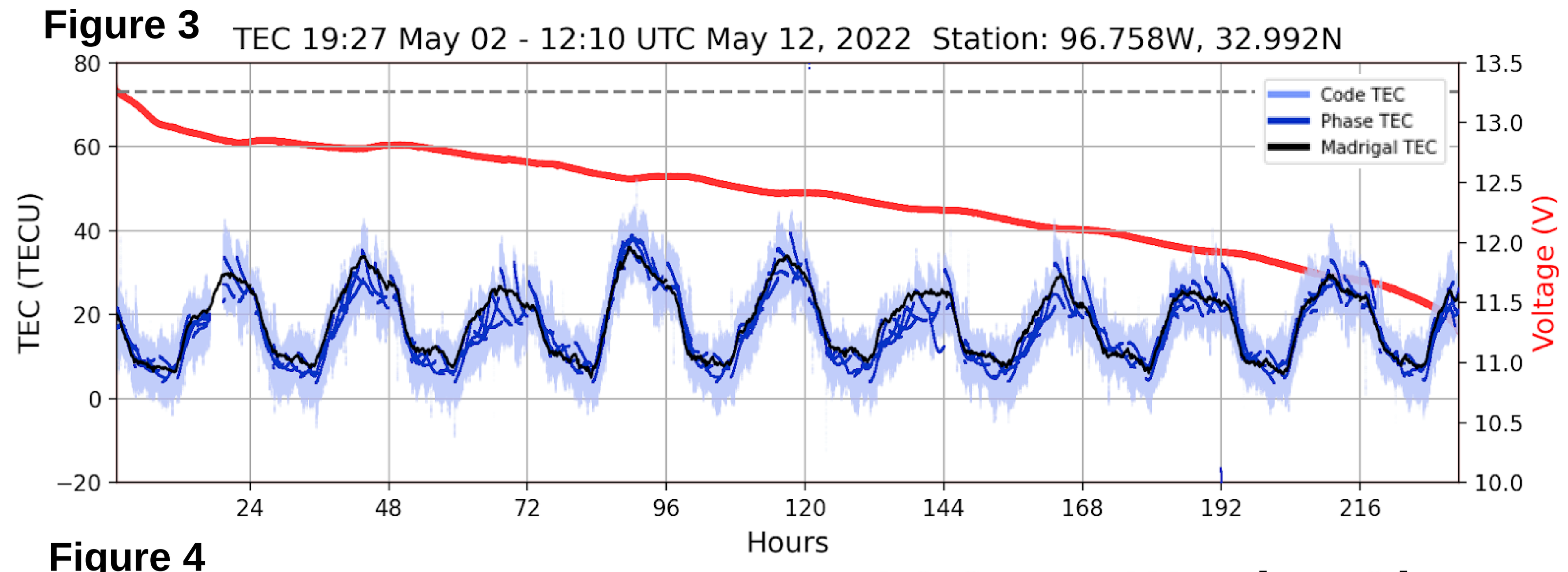
- For remote/internet access, we chose Sixfab's 4G/LTE cellular modem module because of its native Raspberry Pi support and software.
- We developed software that transmit near real-time information comprising satellite positional data sampled every minute and a status file with battery voltage and metadata sent every 30 minutes.
- In applications such as an eclipse, it is critical that the sensor remain running. For that purpose, we also developed a watchdog software to issue an email warning if an update has not been recently uploaded.

4. RESULTS

4.1 TEC Monitoring

- We derive Total Electron Content (TEC) combining pseudoranges and phase measurements of signals from GPS satellites; the resulting estimations referred to as code TEC and phase TEC, respectively. Phase information provides precise, though relative TEC. Code information, on the other hand, provides noisy but absolute TEC estimates.
- Being deployed at mid latitudes (Dallas, TX), we were unable to observe appreciable scintillation during our testing period; therefore, we focus on TEC measurements in our demonstration of the system's monitoring capabilities.
- In **Fig. 3** and **Fig. 4**, we show comparisons of our absolute TEC with TEC provided by MIT Haystack TEC maps for the location of our station (32ºN and 96ºW) [3].
- Note that our TEC was estimated using satellite biases provided by NASA's Crustal Dynamics Data Information System. Receiver bias was estimated using Madrigal TEC.

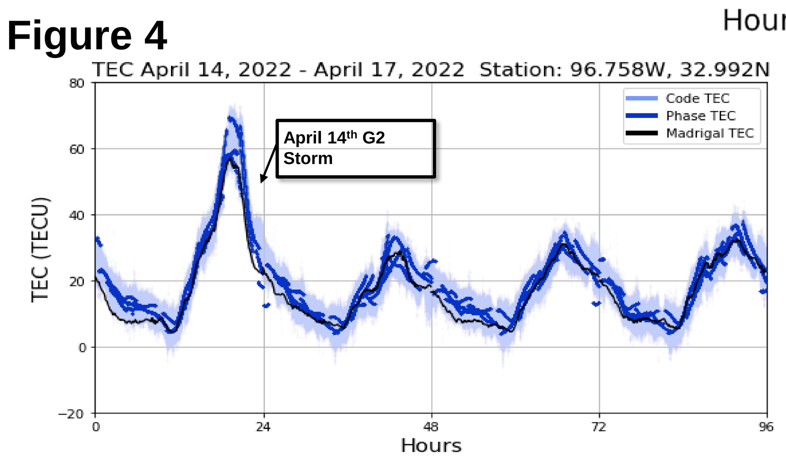
Figure 3



4.2 Battery-Only

- **Fig 3.** demonstrates voltage and TEC measurements when no solar power is provided to the system,
- 236-hour (~10 days) runtime before automatic shut off by charge controller at programmed voltage.

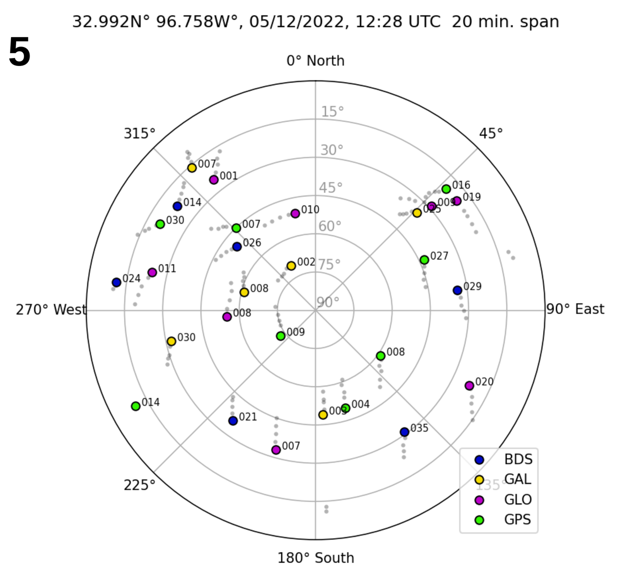
Figure 4



4.3 Space Weather Observations

- On April 14, 2022, 16:00-22:00 UTC, our platform observed TEC rising from an average peak value of ~30 TECU to a peak value of ~50 TECU, **Fig. 4**.
- This rise in TEC may be linked to a G2 (Moderate) geomagnetic storm reported by NOAA that began at 16:45 UTC on April 14, 2022 [4].

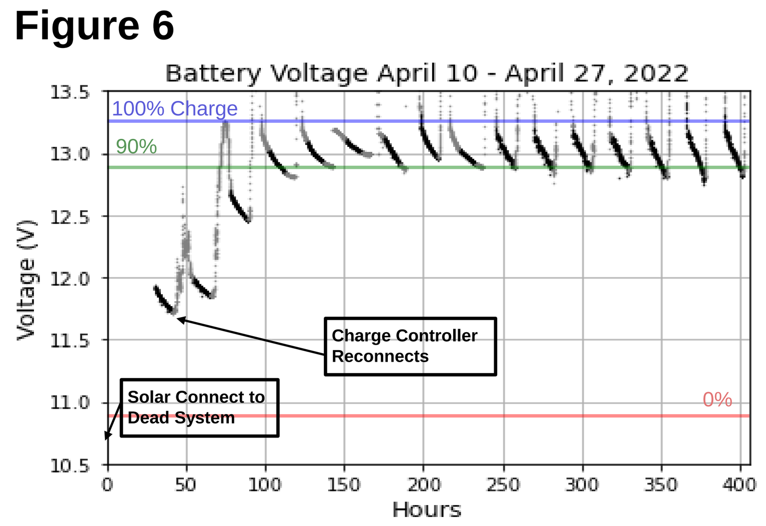
Figure 5



4.4 Communication / Remote Operation

- On average, device transfers 7.4 MB per day (222 MB per month) of data. A 500 MB monthly plan costs ~US$9.00 USD.
- Currently, we are working on near real-time visualization of GNSS information for educational purposes, **Fig 5.**

Figure 6



4.5 Solar Charging Behavior

- **Fig. 6** illustrates the behavior of the system when it is reconnected to solar power from a condition of a discharged battery.
- Battery reaches over 90% charge in ~4 days.
- System maintains nearly full battery after charged.
- Note that voltages recorded during the day (grey) may not accurately reflect battery capacity because they are measured in parallel with the voltage provided by the solar panel.

5. CONCLUSION

Goal 1: For the ScintPi 3.0 to run without host-provided power.

We developed and tested two prototypes:

- A solar powered design capable of holding the system at nearly full charge throughout varying weather conditions.
- A smaller and easier to deploy battery-only design lasting for ~10 days.

Goal 2: To be monitored without host-provided internet.

- This effort resulted in setup and software for the ScintPi 3.0, enabling regular status updates, real-time information, and remote shell access.

Goal 3: To supplement the curriculum of physics undergrad students while increasing literacy about space sciences.

The present effort was led by three undergraduate physics students who, over the course of a semester:

- Drafted timeline, designed, budgeted, and presented results.
- Developed experience with coding, electronics, and hardware.
- Processed and interpreted GNSS observations for space weather applications.

6. FUTURE WORK

- This work will contribute to an NSF GRFP supported project to deploy ScintPi sensors in a distributed array study at Jicamarca Radio Observatory.
- This effort enables the system to be distributed to citizen scientists without using their internet/power.
- We envision deploying several systems throughout Texas to observe the ionospheric response to the 2024 eclipse in Texas, for instance.

References: **[1]** Socola and Rodrigues, under review (2021). **[2]** *PVWatts Calculator*, National Renewable Energy Laboratory **[3]** Anthea Coster, MIT/Haystack Observatory. (2022) Data from the CEDAR Madrigal database. [4] "G1-G2 (MINOR-MODERATE) STORM CONDITIONS MET ON 14 APRIL, 2022", National Oceanic and Atmospheric Administration

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