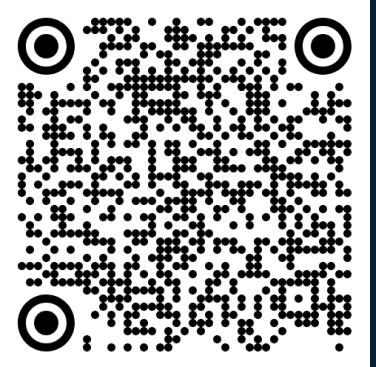




IonoScope

An Educational Android App to
Demonstrate Real-time Ionosphere
Measurements



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- An educational Android app available free on the Play Store which uses **dual-frequency GNSS** (L1/L5) raw measurements on commercial smartphones.
- Measures transit delay of two common GNSS frequencies to estimate Total Electron Content (TEC) in the ionosphere.

- 1. Educational tool**
- 2. Low-cost persistent sensing**



Ionospheric Signal Delay

- The ionosphere behaves as a dispersive plasma where electrons can impact GNSS carrier wave speed [1]
- GNSS signals broadcast on two useful frequencies which have different transit times to a receiver.
 - L1 Band ~1575 MHz (less delay)
 - L5 Band ~1176 MHz (more delay)
 - On order of sub 50 ns delays**
- Estimate Slant range Total Electron Content (STEC) [1]
 - Δt_{L5-L1} transit time difference
 - speed of light c
 - a derived quantity
 - $40.3 \text{ m}^3 \text{s}^{-2} \text{electron}^{-1}$

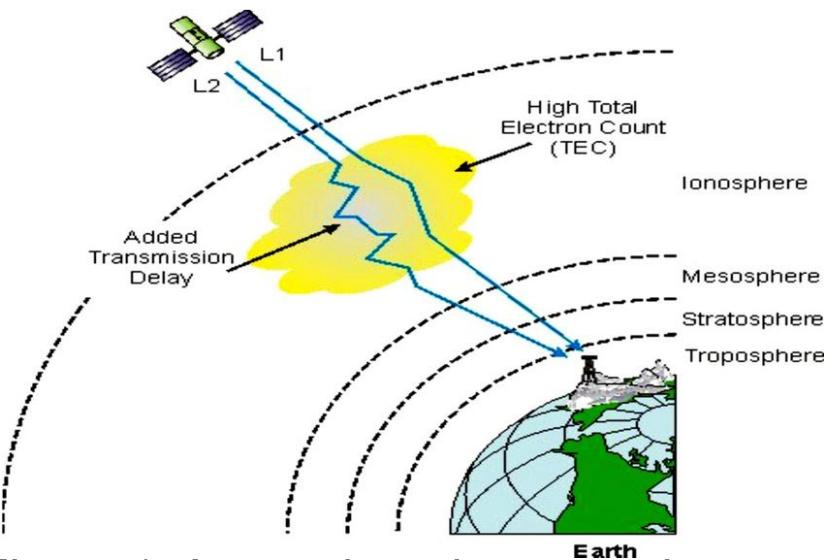


Figure 1. Atmosphere layers and signal delay from TEC (yellow). [2]

$$STEC = \frac{c \Delta t_{L5-L1}}{40.3 \left(\frac{1}{f_{L5}^2} - \frac{1}{f_{L1}^2} \right)}$$



- Newer smartphone hardware and Android APIs support **dual-frequency (L1,L5) GNSS** measurements.
 - 277/742 (~37%) models from 2019-2022 support L1/L5 [3]
- If we can measure the L1 and L5 GNSS transit times...
- Then we can estimate the Slant TEC of the Ionosphere!
- So, let's make an app...



App Architecture

- **Capacitor runtime**
 - Bundles the app components
- **Java GNSS Plugin for Android API**
 - Accesses the raw GNSS data
- **Sveltekit**
 - Implements the UI for Learning pages, settings, measurements
 - Also contains the backend for data analysis
- **SQLite**
 - Stores data locally
 - Exports as CSV file, email/shareable.





Educational tool

1. Learn about the ionosphere and GNSS
2. Use to support Labs investigating ionospheric density

Low-cost persistent sensing

3. Static phones setup for ionosphere measurements



Use 1 - Learning

- **Learn**

- Ionosphere and GNSS Basics
- Signal Propagation and Delay
- Calculating TEC
- SPACE in mind [4]
 - S: Studying the problem
 - P: Planning investigations
 - A: Analyzing data
 - C: Critical thinking
 - E: Evaluating, and Summarizing

- **Engage**

- Real-time data output from GNSS signals
- Figures built in to modules
- Quiz elements to help connect topics

Lesson Pages

The screenshot shows the IonoScope application interface. At the top, there are four navigation icons: Learn (selected), Collect, Logs, and Settings. Below the header is a toolbar with various icons. The main content area has a title "Investigating the Ionosphere". The text explains that the ionosphere is a layer of Earth's atmosphere filled with charged particles, both electrons and ions. These charged particles affect how radio signals, including GPS, travel. It states that in this walkthrough, you'll learn how GPS and the ionosphere interact and how we can measure it. At the bottom, there is a diagram of Earth's atmosphere layers: UV Airglow, Red Line Airglow, Green Line Airglow, Ionosphere, Thermosphere, Mesosphere, Stratosphere, and Troposphere. A vertical scale on the right indicates altitude from 50 mi to 400 mi.

Check on Learning

2. Which of the following equals 1 TECU (TEC Unit)?

- $10^{12} \text{ electrons/m}^2$
- $10^{14} \text{ electrons/m}^2$
- $10^{16} \text{ electrons/m}^2$
- $10^{18} \text{ electrons/m}^2$

Show Explanation

3. Range delay of a GPS signal is linearly proportional to the frequency.

- True
- False

Show Explanation

Score: 3/3 (100%)

Very well done!

Try Again



Use 2 - Labs and Data Analysis

• Collect data

- Real time signal stats
- Shows user filter impacts

• View data

- Summary data tables
- Simple graphs

• Export data

- csv format
- Via normal phone sharing (email, drive saving etc.)

• Sample Lab Worksheet

- Linked in the app and at end of talk
- Built based on considerations in Freeman [5]

Data Collection

IonoScope

Learn Collect Logs Settings

GNSS Measurements

Use this page to view real-time GNSS satellite measurements and ionospheric delay calculations. Current measurements report as slant TEC, vertical TEC calculations coming soon.

Satellite Data

Stop Recording Recording

Updates Received: 339 Visible Satellites: 38

Signal Statistics

L1 Signals: 17 L5 Signals: 13 L1/L5 Pairs: 13

Signal Summary

Satellites tracked: 38
Signal strength: 35.4 dB-Hz

L1/L5 Ionospheric Delay (per Satellite)

Logs and Export

IonoScope

Learn Collect Logs Settings

Measurement Logs

View, export, and manage your recorded ionospheric measurement sessions.

Refresh Data

Sessions

6 total sessions

Session	Count	Share	Delete
Jan 13, 10:00 PM	255		
Jan 13, 09:48 PM	282		
Jan 13, 09:44 PM	35		
Jan 13, 08:53 PM	1861		
Jan 13, 08:47 PM	2381		
Jan 13, 08:39 PM	463		

TEC Measurements Plot

Select Session to Plot:



- Purchase a relatively inexpensive android phone
- Setup in a weather shielded area with sky views
- Calculate satellite biases
- Then run for extended time and visualize ionosphere density in ARC-GIS

Eventual goal:

- Data pipeline to collect and export data automatically
- Automatically plot and view ARC-GIS density heatmaps
- Compare with research-grade receivers



- Only available on Android
 - Apple doesn't expose raw GNSS data
- No device specific satellite bias corrections
 - Can result in some satellites with 'negative' TEC values
 - Only useful for education right now
- Restricted to newer android phones
 - Must have dual band GNSS capability to fully use the app
- Small research team
 - Updates are slow-going as time and energy are available
 - "Overworked and underpaid"... like most teachers



- **Short-term:**
 - Routine app quality of life improvements
 - Improving data visualization
 - Integrating VTEC calculations into the App
- **Long-term:**
 - Extend to all GNSS constellations (currently GPS and GALILEO)
 - Build in persistent background logging for low-cost sensing
 - Test and incorporate satellite biases for low-cost sensing effort.
 - Compare results to research-grade sensors



References

- [1] "Ionospheric Delay - Navipedia." Accessed January 17, 2026.
https://gssc.esa.int/navipedia/index.php/Ionospheric_Delay.
- [2] Abba, Ibrahim, Wan Azlan Wan Zainal Abidin, Thelaha Masri, Kismet Hong Ping, MS Muhammad, and Bong Voon Pai. "Ionospheric Effects on GPS Signal in Low-Latitude Region: A Case Study Review of South East Asia and Africa." *Nigerian Journal of Technology* 34 (June 2015): 523. <https://doi.org/10.4314/njt.v34i3.14>.
- [3] "Crowd-Sourced List of Android Phones That Support Dual-Frequency GPS: [Https://Do... | Hacker News.](https://news.ycombinator.com/item?id=32791569)" Accessed January 17, 2026. <https://news.ycombinator.com/item?id=32791569>. List available at:
https://docs.google.com/spreadsheets/d/1jXtRCoEnnFNWj6_oFIVWflsf-b0jkfZpyhN-BXsv7uo/edit#gid=0
- [4] Pansong, Chollada, Thanapon Keokhumcheng, Patiphan Sumniang, Wishapol Sittichai, Canjie Huang, and Prasert Kenpankho. "Space STEM Education Guide for Global Positioning System Total Electron Content (GPS TEC)." *2024 9th International STEM Education Conference (iSTEM-Ed)*, July 2024, 1–6.
<https://doi.org/10.1109/iSTEM-Ed62750.2024.10663134>.
- [5] Freeman, Ronald H. *Teaching K-12 Particle Physics as an Advocate: A STEM Personal Journey into Radio Wave Science and Technology Research*. n.d.



Questions?

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Resources



<https://github.com/kfilip10/ionoScope>

Resources Contains:

- Slides
- Sample lab worksheet
- Sample data from the app

IonoScope Download



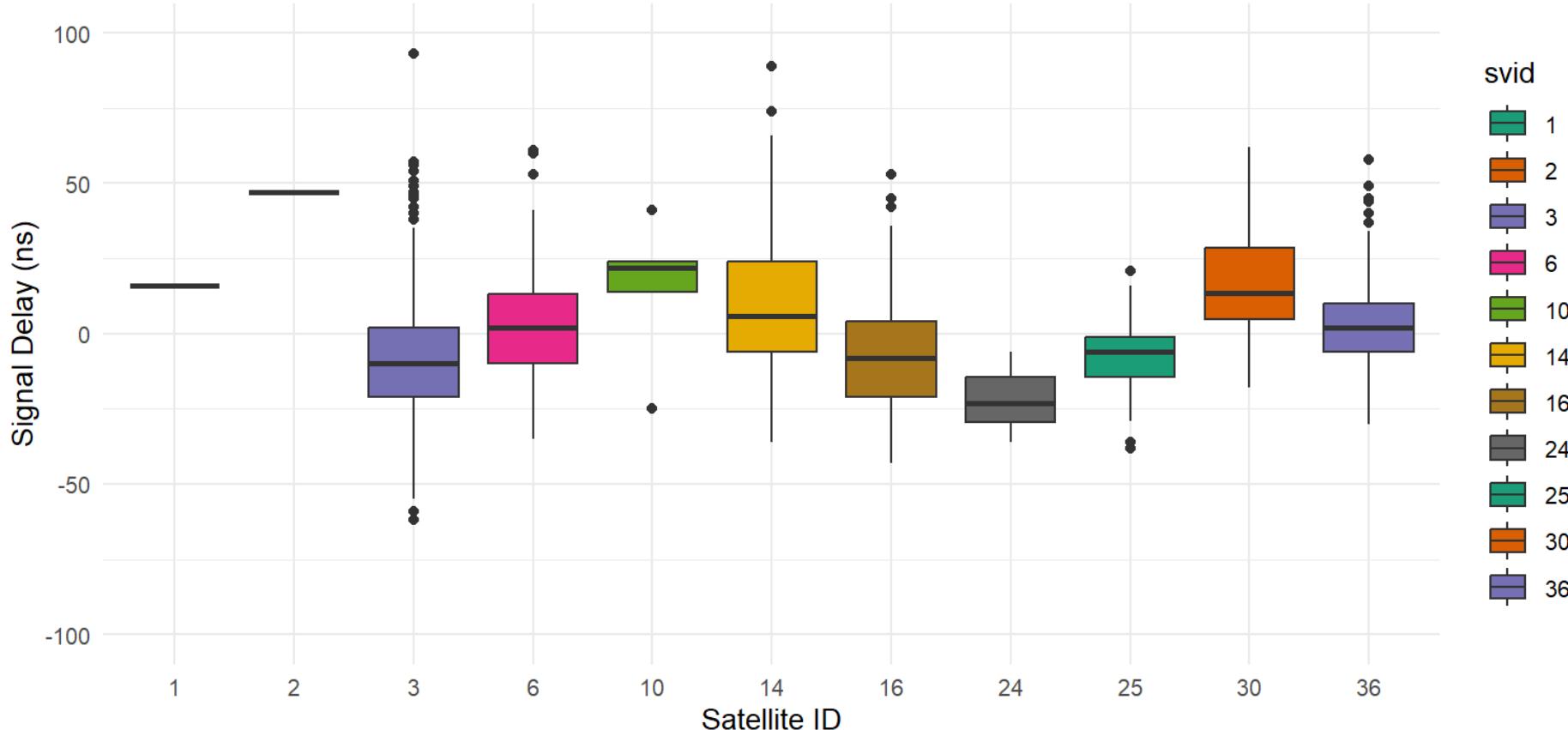
https://play.google.com/store/apps/details?id=com.ktf.ionoscope&hl=en_US



Backup



Boxplot of Signal Delay by Satellite ID



Data variance shows need for device specific correction factors to achieve low-cost sensing goal.



STEC Calc

$$P_i = \frac{c}{\Delta t} \quad \text{Pseudorange (1)}$$

$$I_i = \frac{40.3 \text{ STEC}}{f_i^2} \quad \text{Ionospheric Delay (2)}$$

$$\Delta P = P_{L5} - P_{L1} = I_{L5} - I_{L1} \quad \text{Single Satellite (3)}$$

$$\text{STEC} = \frac{P_1 - P_2}{40.3 \left(\frac{1}{f_1^2} - \frac{1}{f_2^2} \right)} \quad \begin{array}{l} \text{STEC Calc} \\ \text{Sub (3) into (2)} \end{array} \quad (4)$$

$$\text{STEC} = \frac{c \Delta t_{L5-L1}}{40.3 \left(\frac{1}{f_{L5}^2} - \frac{1}{f_{L1}^2} \right)} \quad \begin{array}{l} \text{STEC Calc based on delay (5)} \\ \text{Sub (1) into (4)} \end{array}$$

Pseudorange vs geometric range errors

$$P_i = \rho + c(dT_b + dT_s) + I_i + T + M_i + \varepsilon_i$$

ρ = geometric range

dT_b = receiver clock error

dT_s = satellite clock error

I_i = Ionospheric delay at frequency f_i

T = Tropospheric delay

M_i = Multipath error

ε_i = Measurement noise



STEC to VTEC

$$VTEC = STEC \cdot \cos \chi \quad (18)$$

- Using Figure 2 we can calculate

The latitude (φ), longitude (θ), and zenith (χ) of the IPP are then given by:

$$\varphi = \sin^{-1}(\sin \varphi_{RX} \cos \beta + \cos \varphi_{RX} \sin \beta \cos \gamma) \quad (19)$$

$$\theta = \theta_{RX} + \sin^{-1} \left(\frac{\sin \beta \sin \gamma}{\cos \varphi} \right) \quad (20)$$

$$\beta = \frac{\pi}{2} - \alpha - \chi \quad (21)$$

$$\chi = \sin^{-1} \left(\frac{R_e \cos \alpha}{R_e + h} \right) \quad (22)$$

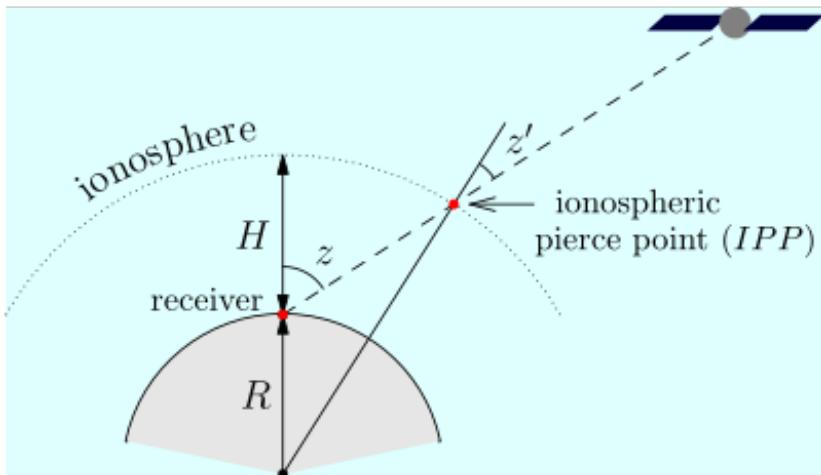


Figure 1: Ionospheric Pierce Point. The angle z' in the figure corresponds to angle χ in Equation 18.

https://en.wikipedia.org/wiki/Ionospheric_pierce_point

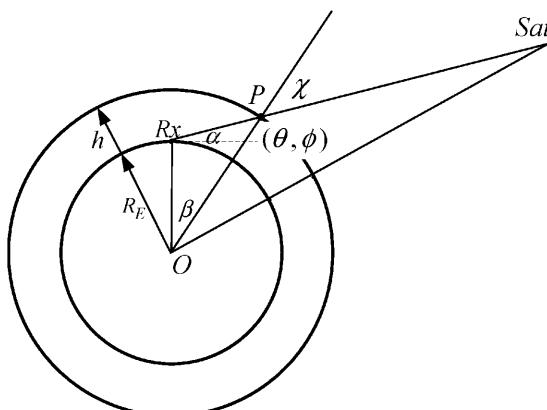


Figure 2: Diagram for calculating the IPP.
<https://www.mdpi.com/2073-4433/13/2/237>