SATELLITE REFLECTION MITIGATIONS

February, 2023

Current Starlink Deployment Status

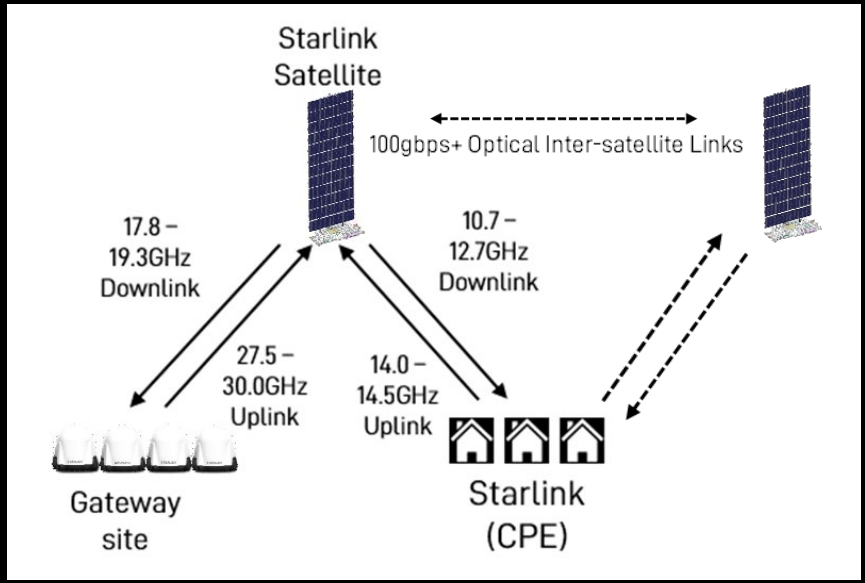
3,700+ satellites launched into low Earth orbit

1,000,000+ customers on all seven continents

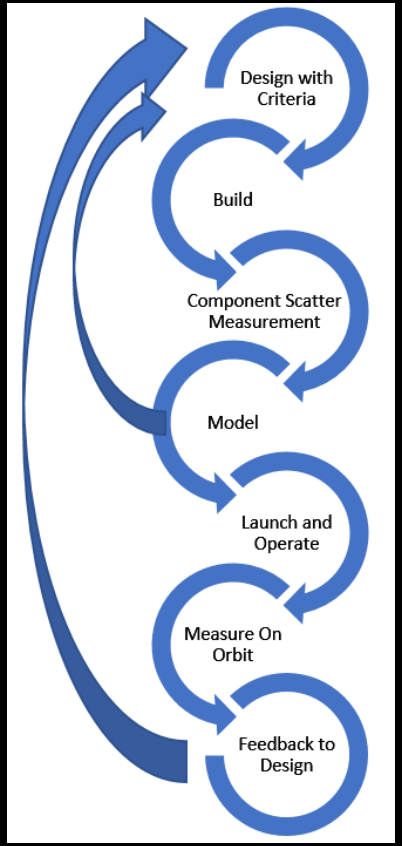
200 Mbps (improving to 1 Gbps) speeds far exceed other satellite systems and are competitive with some terrestrial systems

Gen-2 system critical to fulfilling customer orders and scaling Starlink service approved in 2022, as part of license SpaceX completed a coordination agreement with the US National Science Foundation

https://beta.nsf.gov/news/statement-nsf-astronomy-coordination-agreement



Design Process



Mitigation Impact

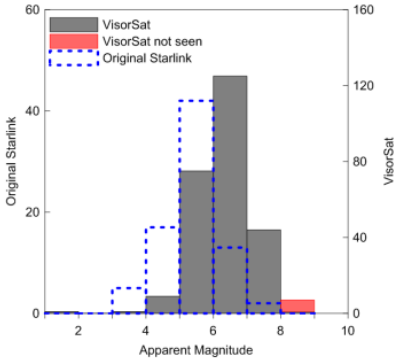
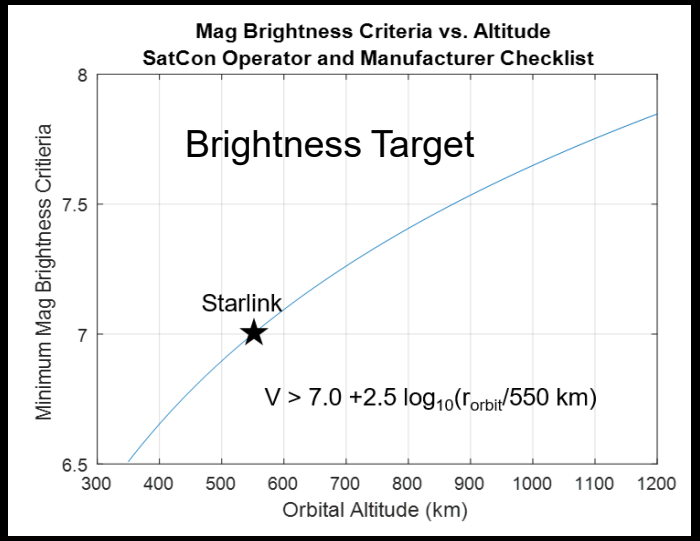
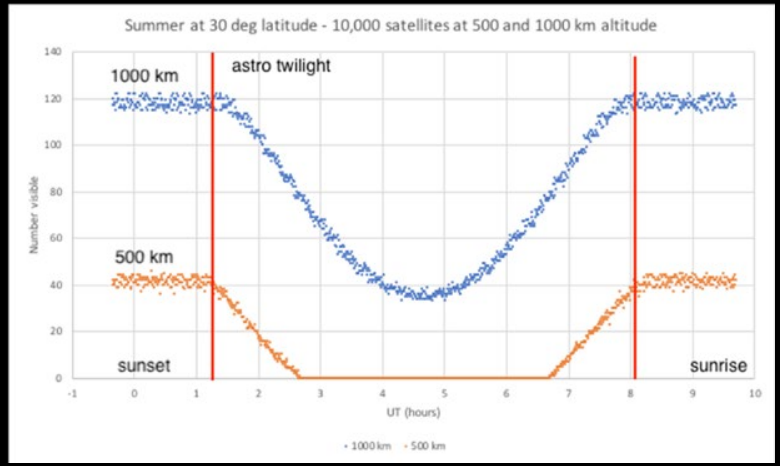


Figure 1. Histogram of apparent VisorSat magnitudes recorded by the visual observers. Also shown are the assigned magnitudes where the satellites were too faint to be seen, along with apparent magnitudes for original-design Starlink satellites.

The Brightness of VisorSat-Design Starlink Satellites by Anthony Mallama, 2021-01-02

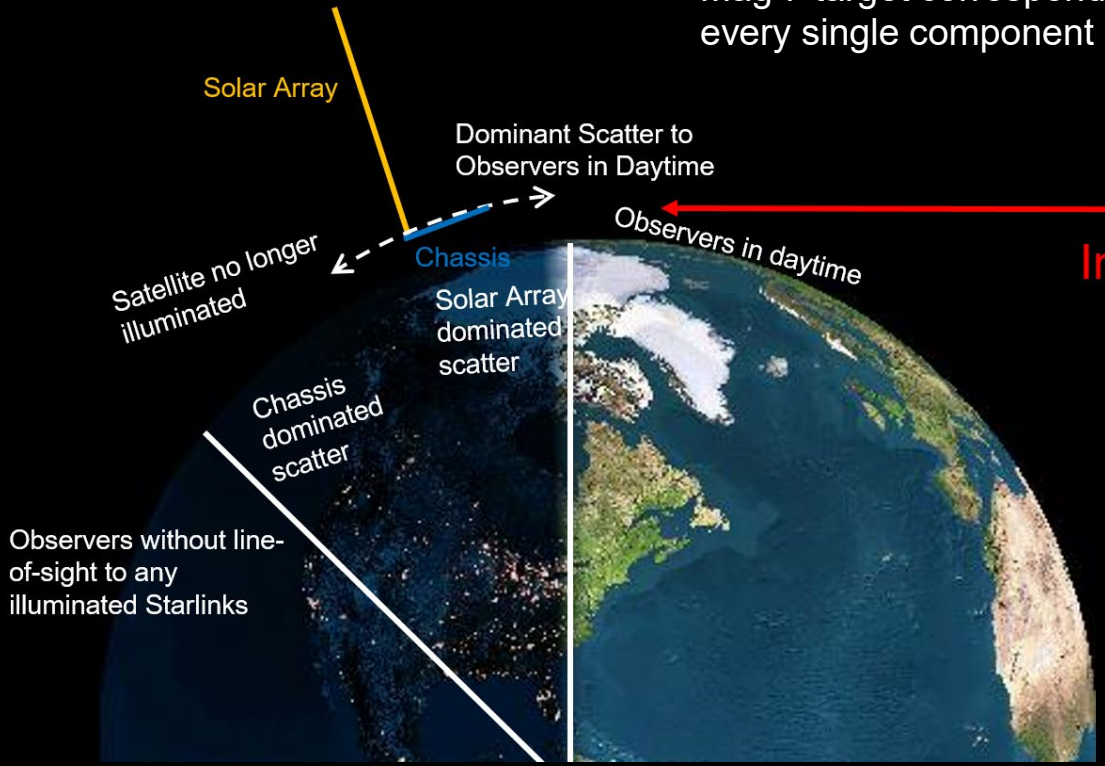


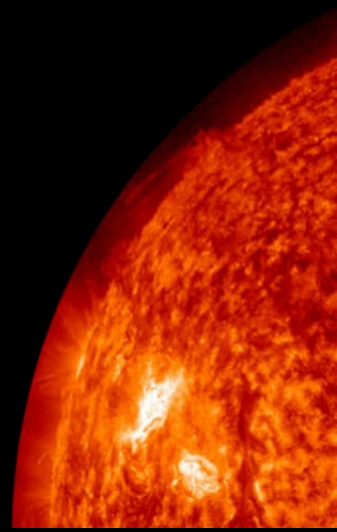


Altitude Impact ->

Mechanism for Satellite Reflections

- Mag 7 target corresponds to ~8U (0.08m^2) white cubesat so every single component must be considered.





Mitigations in Three Areas

Hardware and satellite design

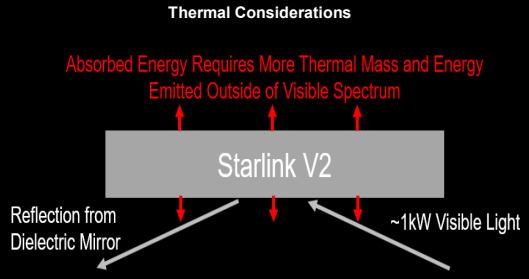
- Shade the reflective surfaces
- Specular materials can scatter light away from Earth
  - Dielectric Bragg mirror film
- Dark materials can be used to absorb light
  - Pigmenting solar arrays and black paint
- Other accommodations
  - Oversize solar arrays so they can off-point to reduce reflections
  - Robust thermal design to accommodate more absorbed heat energy

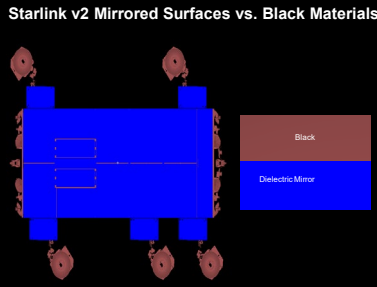
Satellite Operations

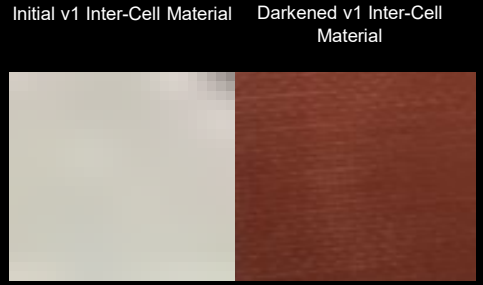
- Off-pointing solar array during orbit raise
- Autonomous attitude adjustments as satellite approaches terminator
  - Off-pointing solar array
  - Biasing bus pointing to reduce likelihood of light reflections toward Earth's surface

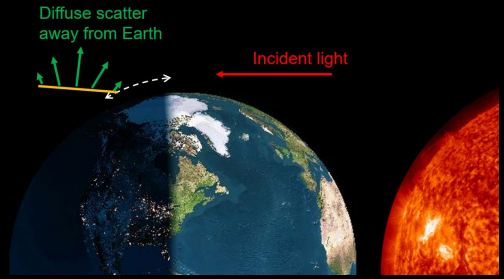
Satellite position predictions

- Publish accurate ephemeris predictions that include planned maneuvers and make them publicly available
- Publish Two Line Elements (TLEs) with planned maneuvers included









Conclusion

- Starlink is making a huge positive impact around the world, while keeping space safe and sustainable

- Through coordination with astronomers and industry-leading standards on space sustainability, SpaceX continues to innovate and implement mitigation solutions

- We welcome collaboration with other operators, and are making in-house products available to other companies

- We agree with NSF that our astronomy coordination agreement and collaboration should be a model moving forward!